An Analysis of Functional Differences in Implicit Learning

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Declaration

The following work was carried out at the Department of Experimental Psychology, University of Cambridge, under the supervision of Dr Kate Plaisted Grant. This dissertation has not been submitted, in whole or in part, for any other degree, diploma or qualification at any other University. Chapter II, with amendments, is in preparation for publication (Brown, Kaufman, & Plaisted Grant, 2010), Chapter III, with amendments, has been published (Brown, Aczel, Kaufman, Jiménez, & Plaisted Grant, in press), Chapter IV, with amendments, is under review for publication (Brown, Jiménez, & Plaisted Grant, 2010), and ideas drawn from two other co-authored papers were used generally, but particularly in Chapter II (Kaufman, DeYoung, Gray, Brown, & Mackintosh, 2009; Kaufman, et al., in press). The results from Chapters III and IV have also been presented at the International Meetings for Autism Research (2008 and 2009) and the British Psychological Society: Cognitive Psychology Section's Annual Conference (2009). This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified in the text and Acknowledgements. My work was supported by the Medical Research Council. This dissertation does not exceed the limit of 60,000 words specified by the Degree Committee.

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Summary

This thesis analysed whether functional implicit learning differences existed in two areas that have produced promising, but equivocal, findings: individual differences in typical populations (e.g., Gebauer & Mackintosh, 2010) and group differences between Autism Spectrum Condition (ASC) and Typically Developing (TD) individuals (e.g., L. G. Klinger, Klinger, & Pohlig, 2007). Overall, the results from the four studies presented in this thesis emphasised a lack of functional differences in implicit learning between individuals.

Study I investigated whether there were functional individual differences in implicit learning among a typical population by examining the inter-correlation between the performances of academic psychologists on three implicit learning tasks; the independence of those performances from IQ; the relationships between those performances, intuitive aspects of personality and occupational tacit knowledge; and, finally, whether the performances were related to occupational achievement. There was no evidence of inter-correlation between the implicit learning task performances, nor relationships between any of those performances, and occupational achievement, or personality. The study did replicate a finding that is important to the distinction between implicit and explicit learning: indices of explicit processing, but not performance on implicit learning tasks, were correlated with IQ (e.g., Gebauer & Mackintosh, 2007). Additionally, the study found that Academic Psychology and Business Management Tacit Knowledge Inventories measured knowledge that predicted occupational achievement in academic psychology incrementally to IQ and personality, and was general to both occupations. However, tacit knowledge appeared to be acquired primarily as a function of practice and experience, rather than individual differences in implicit learning. Overall, I asserted that a consideration of the results from Study I with the wider literature currently leads to the conclusion that there are minimal individual differences in implicit learning, which signifies that there is no general implicit learning ability that is critical to *how much* is learnt implicitly.

In the absence of a general ability that determines how much is learnt implicitly, it was argued that there could still be general, prerequisite processes, which are always necessary for implicit learning but without those processes determining the variation in how much was learnt implicitly. Such prerequisite processes would not constitute a psychometric ability but could be conceptualised as general implicit learning processes. This conceptualisation of implicit learning would be supported by the existence of an atypical population who consistently demonstrated profound deficits on all implicit learning tasks and skills associated with an implicit acquisition. There is no convincing evidence of such a patient group, although the ASC population is a plausible candidate (e.g., L. G. Klinger, et al., 2007).

Therefore, Study II compared IQ-matched ASC and TD individuals on a range of implicit learning tasks. The study, taken together with other recent reports (e.g., Barnes, et al., 2008), provided convincing evidence that implicit learning is actually intact in ASC and it was argued that deficits reported in previous studies must have resulted from differences in task procedures (e.g., L. G. Klinger, et al., 2007). In particular, the earlier studies used procedures that encouraged explicit strategies, which disadvantaged the ASC groups who had not been matched for IQ. A further analysis supported that interpretation: TD and ASC groups who were not matched for IQ exhibited differences on an explicit learning task, but not on the implicit learning tasks.

In order to determine whether those previously identified implicit learning deficits in ASC resulted *just* from differences in IQ, or whether there was also a contribution from an ASC difficulty in explicit learning, Study III compared ASC individuals with IQ-matched TD individuals on an implicit learning task, the Serial Reaction Time (SRT) task, with a procedure that encouraged explicit strategies. The SRT procedure was combined with a contextual cueing task that provided an indirect, ongoing index of the extent to which sequence learning was explicit (Jiménez & Vázquez, in press). Study III indicated a difference in initial explicit sequence learning in ASC, which was independent of IQ.

Study IV replicated the difficulty and by using a pre-task manipulation the study was also able to elaborate the nature of that difficulty: ASC individuals were able to learn sequence information explicitly, but they had a specific difficulty with learning to apply that explicit information. Thus, there was good evidence that implicit learning is intact in ASC and that instead ASC individuals have more difficulties with aspects of explicit learning. These findings refute the idea that ASC individuals *successfully* compensate for implicit deficits with explicit compensatory strategies. Instead, together with the ASC propensity for using explicit strategies, an ASC difficulty with explicit processing might explain some ASC deficits in a range of learnt skills, although I acknowledge that there are also plausible alternatives. More generally, these findings and ideas accord with ASC literature concerning impairments in executive functions, which require flexible and intentional processing (e.g., Russell, 1997a) and emphasise that future research is focused on how explicit, executive differences emerge and affect behaviour.

In conclusion, the thesis provided no evidence for the proposal that there are functional differences between individuals in implicit learning. I propose that, taken together with the equivocal evidence discussed in my reviews of the wider literature, it is parsimonious to conclude that there is neither a general implicit learning *ability*, nor general, prerequisite implicit learning *processes*. However, in line with previous literature, the thesis did support functional distinctions between implicit and explicit learning: explicit, but not implicit, learning was related to IQ; and ASC individuals have difficulties with explicit but not implicit learning. Therefore, I assert that a descriptive distinction between explicit and implicit learning remains both useful and valid. This is true even though implicit learning seems to be defined by the absence, or minimal influence, of explicit processing rather than the general presence of an implicit learning ability or processes. Beyond the issue of functional differences, I argue that these findings and conclusions make modest, but not decisive, contributions to some of the other fierce debates in the wider implicit learning literature. Finally, I propose some recommendations, and directions, for future research.

Contents

To Tom, Lily, Charles, and Jessie

““What are you talking about?” “I can’t remember. The Ukrainians. My birth. Candles. I know there was a point. Where did I begin?” And so it was when anyone tried to speak: their minds would become tangled in remembrance. Words became floods of thought with no beginning or end, and would drown the speaker before he could reach the life raft of the point he was trying to make. It was impossible to remember what one meant, what, after all of the words, was intended”” (Safran Foer, 2002, p. 261).

I. General Introduction

"The subject is intrinsically of great interest. Man's power to change himself, that is, to learn, is perhaps the most impressive thing about him" (Thorndike, 1931, p. 3).

Learning is a critical part of our everyday lives. It affords us the flexibility to change our behaviour over time, and to use past experience to improve our responses to old and new environmental challenges. Consequently, philosophers and scientists have been motivated for centuries to understand and characterise the basic nature of learning (e.g., Aristotle, 2007; James, 2009; Plato, 1997). Yet many fundamental issues remain unresolved. One important, unresolved issue is whether there are differences between individuals in implicit learning that are related to meaningful differences between them in their everyday behaviour. In fact, the importance of individual differences in implicit learning has rarely been subject to empirical study. This lack of research is almost certainly a consequence of the fierce debate within the field on other issues, one of which could be interpreted as being about whether implicit learning even exists.

In this introduction, evidence is reviewed that leads to the conclusion that implicit learning certainly exists, *providing it is conservatively defined*. Specifically, implicit learning exists insofar that people can learn when they are not primarily engaged in trying to learn, and that consequently they are unable to report verbally on how or what they learnt. Implicit learning, defined as such, is not substantially contested, nor is the fact that implicit learning tasks provide operational, if impure, measures of this capacity (e.g., D. C. Berry & Dienes, 1993; Cleeremans & Dienes, 2008; Shanks, 2005). Instead, the fierce debate has been focused around surrounding questions including: How does evidence of implicit learning elucidate the role of awareness, attention and automaticity in learning, and in particular, does this evidence definitively demonstrate learning without consciousness? What can such results reveal about the nature of consciousness and mental representation? Does the existence of implicit learning entail the existence of two distinct learning systems, and if so, what are the natures of and differences between the two systems? Or, if it does not, is there other evidence of implicit learning with further characteristics that would demonstrate the existence of two learning systems (e.g., Shanks, 2005)? Such issues remain of utmost importance to the fundamental nature of learning and cognition. However, it is also important to realise that such debate is separate to the undisputed existence of conservative conceptions of implicit learning. This realisation is important because it legitimises the investigation of whether there are important consequences that relate to the capacity of people to learn without express intention, and without being able to report verbally on the process or the resultant knowledge, as measured by implicit learning tasks.

Indeed, the question is not just legitimate but it is extremely important when considering how critical learning is to people, and that individual differences in the capacity for explicit, intentional learning are well understood and demonstrably important to a number of life outcomes (e.g., Carroll, 1993; Kaufman, et al., 2009; Mackintosh, 1998). Consequently, differences in implicit learning have recently received investigation. For example, differences in implicit learning have been explored in terms of the differences between individuals in a typical population (e.g., Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press), and the differences between groups, such as typically developing (TD) and Autism Spectrum Condition (ASC) individuals (e.g., L. G. Klinger, et al., 2007; Mostofsky, Goldberg, Landa, & Denckla, 2000; Romero-Mungu a, 2008). Without providing conclusive evidence, initial results have supported functional differences in both these areas. Specifically, there is evidence that individual differences in implicit learning can be measured and are related to second-language acquisition; there is also evidence of an ASC deficit in implicit learning, which contributes to diagnostic social, communicative and motor impairment. These particular avenues of investigations are clearly of intrinsic interest and importance. Additionally, it is hoped that such functional investigation of implicit learning will contribute, albeit indirectly, to the fierce and important debates surrounding the implicit and explicit learning literature, and will thereby complement the more direct approaches to resolving those debates. Thus, this thesis aimed to provide further empirical examination of both the validity of individual differences in implicit learning, in the new context of occupational achievement, and of the group difference between ASC and typically developing individuals.

1. Implicit Learning

Everyone knows that you can learn implicitly or explicitly. Most people might not call it that, but with a little explanation, they would readily concur that sometimes they have learnt about something intentionally, with effort and ongoing awareness, and yet at other times they seemed to have learnt about something regardless of intention, and with little awareness of both the learning process and what exactly has been learnt. Everyday examples are easy to identify: compare an infant learning language for the first time with an older child studying for a second-language exam. Or remember learning to catch a ball, and then call to mind a physics class explaining trajectories, air resistance, and angles. Any sports people (golfers and cricketers in particular) find the experience of changing their technique using a few explicit instructions from their coach highly dissimilar to when they first picked up the sport during childhood summers in their back garden.

These innocuous and apparently obvious observations belie the questions they raise and the extraordinary amount of corresponding debate and research they have inspired (for some illustrative reviews see: D. C. Berry, 1997; D. C. Berry & Dienes, 1993; Cleeremans, Destrebecqz, & Boyer, 1998; Cleeremans & Dienes, 2008; Dienes & Berry, 1997; French & Cleeremans, 2002; Jiménez, 2003; Perruchet, 2008; A. S. Reber, 1993; Seger, 1994; Shanks, 2005; Stadler & Frensch, 1998; G. Underwood, 1996). Debate has raged on definitions, semantics, methodologies, implications for cognitive architecture, and even on the central issue of veracity: can learning actually occur without awareness and intention, or is it a matter of degree and a trick of everyday experience? There is now substantial evidence and consensus to support the existence of implicit learning, to the extent that people are able to learn when they are not primarily engaged in trying to learn explicitly and deliberately, and are consequently unable to report verbally on how or what they learnt. This evidence has been provided primarily by performance patterns on various ‘implicit learning’ tasks.

2. Implicit Learning Tasks

Arthur S. Reber was the first to utilise a learning task for the study of implicit learning, and is credited with igniting interest in the field. There had been earlier interest in a distinction between automatic and cognitive learning; a major catalyst was Thorndike’s law of effect (Shanks, 2009; Thorndike, 1931). However, prior to A. S. Reber, research and ideas appeared to have been rooted upon explicit hypothesis-testing in learning (e.g., Bruner, Goodnow, & Austin, 1956; Shanks, 2005). In his thesis, A. S. Reber coined the term ‘implicit learning’ and adapted an Artificial Grammar Learning (AGL) task (Chomsky & Miller, 1958; Miller, 1958), which he claimed demonstrated implicit learning (A. S. Reber, 1965, 1967). A. S. Reber has later reported that his thesis *"was not well received"* and that *"a long editorial battle ensued before the work was published"* (A. S. Reber, 2002, p. xi); difficulties that were somewhat prescient of the definitional disagreement and debate that would subsequently characterise the field. Nonetheless, AGL tasks became one of the most common and important procedures for studying implicit learning. During AGL tasks, participants are typically exposed to a series of letter strings that have been created according to an artificial grammar. However, participants are only told about the rules once the initial exposure is finished. Further, they are then instructed that they will see some new strings and will have to decide whether or not strings conform to the rules. Usually, participants are able to make these decisions with better-than-chance accuracy but have little ability to describe the rules. This dissociation has led many researchers to cite performance on the AGL task as a demonstration of implicit learning (for a recent review, see Pothos, 2007).

It was another two decades before there was an explosion in the volume of empirical implicit learning research. Shanks (2005) reported that in the 1980s there were only 15 articles with the term 'implicit learning' in their title, while in the 1990s there were 253. When the equivalent search of the combined Science and Social Sciences Citation Indexes is conducted on the 2000s, it is clear that the upsurge in research has continued: 430 articles have been published in the past ten years. The development of the Serial Reaction Time (SRT) procedure in the late 1980s (Lewicki, Hill, & Bizot, 1988; Nissen & Bullemer, 1987) played no small part in this increase. Together with the AGL, the SRT is the paradigmatic method for studying implicit learning (Shanks, 2005). In a typical SRT procedure, participants are instructed to respond as quickly and accurately as possible to the location of a stimulus that is presented at one of several different possible locations from one trial to the next. Unknown to the participants, the locations in which the stimuli appear follow a regular sequence, and participants typically become faster to respond to locations predicted by the sequence. Learning is described as implicit because participants are generally unable to verbalize the details of the sequence, with only fragmentary knowledge present which is unable to account for performance (Jiménez, Mendez, & Cleeremans, 1996; Jiménez, Vaquero, & Lupiáñez, 2006).

While the SRT and the AGL have been the most frequently used tasks for studying implicit learning, there are several other implicit learning tasks that demonstrate conceptually similar results. For example, there are probability learning tasks (e.g., Millward & Reber, 1968), which have been commonly studied as Probabilistic Classification Learning (PCL) tasks (Gluck

& Bower, 1988). In a typical PCL task, participants have to classify, or make decisions, about stimuli. Following each decision, the participant receives feedback. However, the feedback is probabilistic: thus, for a given stimulus there is no definitively correct answer; instead each stimulus-outcome is associated with a probability greater than zero but less than one. Nonetheless, participants are able to classify stimuli with greater accuracy than chance would predict. Yet, because participants have very little, if any, insight into the relationship between the stimuli and outcomes, the learning is described as implicit (e.g., Gluck, Shohamy, & Myers, 2002).

The Contextual Cueing (CC) task (Chun & Jiang, 1998) is a visual search task in which participants are shown displays of stimuli and are required to detect a target stimulus (e.g., a rotated *T*) within a subset of distractor stimuli (e.g., rotated *L*s). On half of all the displays, the arrangement of the distractors is highly predictive of the location of the target. Participants are typically faster to respond on these trials in comparison to trials in which displays do not reliably predict the location of the target. Learning is implicit because participants rarely notice that contexts are repeated. Moreover, when they are given a test of their explicit knowledge – for example, having to recognise the predictive contexts (Chun & Jiang, 1998), or to generate the location of the missing target when presented with predictive displays in which the target has been replaced by another distractor (Chun & Jiang, 2003; Jiménez & Vázquez, in press) – then participants usually perform no better than chance.

Another variety of procedures are Invariant Feature Learning (IFL) tasks (McGeorge & Burton, 1990). The critical feature of IFL tasks is that participants are incidentally exposed to a set of stimuli, which have an attribute that is common to them all; they have an invariant feature. In a subsequent phase, participants are presented with pairs of novel stimuli, and only one of each pair has the invariant feature, and participants are asked to select which of the two they have already seen. Even though both stimuli are novel, participants select the stimulus with the invariant feature more often than the stimulus without. Learning is implicit because participants are also usually unable to report that there was an invariant feature (e.g., McGeorge & Burton, 1990).

In order to address the question of whether differences in implicit learning have functional implications for everyday life, this thesis has used particular versions of all these five categories of task (AGL, CC, IFL, PCL and SRT; more details are provided in the Methods for each experiment). These tasks are often introduced as principal categories of implicit learning tasks (e.g., Cleeremans & Dienes, 2008). However, there are several other implicit learning tasks. Probably the best known is the Process, or Dynamic Systems, Control task (e.g., D. C. Berry & Broadbent, 1988; Broadbent, 1977). On these tasks, participants have to learn how to control a simulated system (e.g., a ‘factory’) in order to achieve a certain goal (‘output’ for a set period). The equations determining the complex relationships between input and output are withheld. Yet, typically, performance is satisfactory and independent of verbalizable knowledge about the principles of the input-output relationships. Instead, performance is only dependent on practice. Explicit instructions of the input-output principles selectively improve verbal explanations and not performance. Further examples of implicit learning tasks include Covariation Learning (e.g., Lewicki, 1986); the Number Reduction Task (e.g., Haider & Frensch, 2009; Woltz, Bell, Kyllonen, & Gardner, 1996); and Word Segmentation (e.g., Saffran, Johnson, Aslin, & Newport, 1999); while Shanks (2005) has reviewed some other, infrequently cited, demonstrations of implicit learning.

3. Consensus on Implicit Learning

Altogether the above descriptions of implicit learning tasks make it clear that implicit learning tasks share common conceptual features and reliably produce similar conceptual results. Moreover, those results demonstrate that a conservative conception of implicit learning exists: people learn when they are not primarily engaged in trying to learn explicitly and deliberately, and are consequently unable to report verbally on how or what they learnt, as operationally measured by implicit learning tasks. Additionally, given the intensity of debate that is associated with the literature, it is important to emphasise that this interpretation of evidence would achieve a large consensus. For example, Shanks, typically depicted as the fiercest critic in the field, has concluded:

“it cannot be disputed that the examples described at the beginning of the chapter all possess a common „essence’ that marks them out from the more traditional varieties of (explicit) learning studied by psychologists” (Shanks, 2005, p. 216).

The examples of implicit learning tasks provided by Shanks (2005) did not include all the tasks described in this chapter. However, there was no claim that the examples were exhaustive, and no tasks were actively excluded. More important to this demonstration of consensus, the 'common essence' is described in more detail and is patently true of other implicit learning tasks, such as those described in this thesis:

"First, they all involve situations in which the primary task the person engages in is something other than deliberately, explicitly, trying to learn about the contingencies programmed by the experimenter. For instance, in Reber's artificial grammar learning (AGL) task, all that participants are told in the learning phase is that they should try to memorize a series of letter strings. They are not told to try to work out the rules governing the structure of these strings. Hence any evidence that they have indeed learned these rules would suggest that learning was incidental or unintentional....Secondly, the examples have in common the implication that learning can be dissociated from awareness. Participants were shown in these situations to have learned something – to have their behaviour controlled by a variable – of which they were apparently unaware. In most of the cases awareness is assumed to be synonymous with „verbally reportable'" (Shanks, 2005, p. 204).

4. Disagreements on Implicit Learning

To reaffirm, researchers tacitly agree that implicit learning exists, *if* defined conservatively as the capability of people to learn when they are not primarily engaged in trying to learn, and that consequently they are unable to report verbally on how or what they learnt (e.g., D. C. Berry & Dienes, 1993; Cleeremans & Dienes, 2008; Shanks, 2005). However, many do not define implicit learning as such because they are justifiably interested in implicit learning to the extent that it can definitively elucidate the role of awareness, attention and automaticity in learning; the modularity of learning system; and the nature of consciousness and mental representation. Consequently, many researchers instead invoke aspects of A. S. Reber's original claim that implicit learning is learning without awareness, or unconscious learning. In order to provide empirical support of such a definition, researchers insist upon exhaustive, objective attempts that fail to evidence awareness. There is undoubtedly weaker evidence and consensus that implicit learning tasks have documented learning characterised by the objective absence of awareness and consciousness (e.g., Perruchet, 2008; Shanks, 2005), not least because of the resultant difficulties in defining learning without awareness or consciousness. Notoriously, consciousness itself is a 'mongrel concept' (Block, 1995). Indicative of such difficulty, Frensch (1998) listed eleven different definitions provided by contributors to a book he edited with

Stadler (Stadler & Frensch, 1998). More recently, Perruchet asserted that this is still a problem: *"what defines implicitness in IL is far from being agreed upon"* (Perruchet, 2008, p. 609).

Moreover, even once a more global definition of implicit is accepted, there is a considerable methodological challenge of demonstrating the objective absence of consciousness and awareness. In order to demonstrate implicit learning with the 'objective absence of awareness', tests of awareness must satisfy at least three criteria: (i) the information criterion, which states that the assessments must concern the information that is actually governing behaviour; (ii) the sensitivity (exhaustiveness) criterion, which states tests must be sensitive to the extent participants are conscious of the relevant information; (iii) the forgetting criteria, which dictates that attempts should rule out the possibility of awareness that is subsequently forgotten (e.g., Perruchet, 2008; Reingold & Merikle, 1988; Shanks & St. John, 1994). Indeed, in almost all implicit learning tasks, when tests of awareness have met these criteria, participants have been shown to be conscious of the relevant regularities, in the sense that they were able to identify or generate examples of relevant information (Perruchet, 2008; Shanks, 2005). For example, in the AGL, awareness tests adjusted according to the information criterion demonstrated that AGL knowledge can be fragmentary: in addition to whole strings, participants discriminated between letter pairs (bigrams) that were legal and illegal according to the grammar (e.g., Perruchet & Pacteau, 1990). In the CC, a generation task enhanced according to the sensitivity criterion demonstrated that participants could generate contexts above chance if a sufficient number of trials were used (Smyth & Shanks, 2008). In the SRT, a recognition test enhanced by concurrent sampling demonstrated that participants could recognise sequence fragments from probabilistic sequences presented in rapid succession (Shanks, Wilkinson, & Channon, 2003).

However, direct measures of awareness, like generation and recognition tasks, rely on the logic that they exclusively index conscious processes (Reingold & Merikle, 1988). This dubious logic brings the definitional problem back into contrast. Generation and recognition performance, and similar examples, establish that participants are in some sense 'conscious' of the relevant regularities, but it *does not necessarily* establish that the participants are any more conscious than a blindsight patient who is able to discriminate between an object moving up and down (e.g., Cleeremans & Dienes, 2008; Dienes, 2008; Weiskrantz, 1986). That is, they do not evidence another, or for some 'the', critical dimension of consciousness: whether participants are conscious that they are 'conscious' of the regularities; or, whether participants are in possession of a conscious mental state that they are sensitive to the regularities. Yet, such an acknowledgment does not solve the definitional problem. There are then at least three different approaches to what being conscious of a mental state constitutes, all of which demand differing methodological approaches (Cleeremans & Dienes, 2008).

One conception asserts that the significance of a conscious mental state is its accessibility; it is defined by its *"availability for use in reasoning and for rationally guiding speech and action"* (Block, 1995, p. 227). In order to demonstrate implicit learning in this sense, it would be necessary to show that all the knowledge underpinning performance was available for use in another context. Recognition and generation tests are clearly a demonstration of the availability of knowledge on implicit learning tasks. Yet, using detailed correlational analyses, Jiménez, Mendez, and Cleeremans (1996) have demonstrated that in SRT, the knowledge is fragmentary and unable to account for all RT performance. However, it is clearly possible to make the argument that a larger number of generation and recognition tests might reveal more knowledge that is available and able to account for all RT performance.

The second type of approach identified by Cleeremans and Dienes (2008) was made popular by Jacoby (1991), and claims that a critical aspect of consciousness is whether the content of the mental state can be used according to one's intentions. Jacoby also introduced the Process Dissociation Procedure as a means of discriminating whether the learnt knowledge could be used according to intentions. This involves asking participants to behave in a fashion that is consistent or inconsistent with what they had learnt implicitly. Subsequently, the extent to which participants evidence implicit learning when they were asked not to do so is compared with when they were intending to do so. For example, Destrebecqz and Cleeremans (2001) applied this logic to a generation task following an SRT experiment; in an inclusion condition participants had to generate examples of the sequence they had seen, while in the exclusion condition, they had to avoid producing such examples. These authors found that performance was above chance even in the exclusion phase while finding no evidence that performance was worse than in the inclusion phase, and concluded that the knowledge was unconscious insofar that it could not be used in line with intentions. However, subsequent research has been less conclusive. Wilkinson and Shanks (2004) still found no evidence that participants could actively exclude (participants were not able to generate fewer examples than chance), yet they did find generation was significantly reduced in exclusion as compared with inclusion.

A second methodology focuses on determining whether the process of learning, rather than the resultant knowledge, can be manipulated according to intentions. Specifically, the methodology investigates whether learning is possible on implicit learning tasks when attention is diverted from the primary task by the introduction of a concurrent secondary task. For example, Shanks and Johnstone (1999) asked participants to complete a SRT task and concurrently count the number of high tones when high and low tones were being presented randomly after each correct response. Participants still learnt about the sequence, which implies learning without attention. However, Shanks (2005) has argued that it is only evidence of learning with reduced attention because other experiments have shown the manipulation is detrimental to learning even though it does not abolish it (e.g., Shanks & Channon, 2002).

The final approach described by Cleeremans and Dienes (2008) is centred around the idea that *"conscious mental states are states we are conscious of being in"* (Rosenthal, 2002, p. 233). That is, the emphasis is put on subjectively knowing that one knows something (e.g., Dienes, 2008). In order to investigate this idea of consciousness researchers have asked participants to provide concurrent reports about the mental states underpinning their answers. For example, they are asked to provide descriptions (e.g., 'guess', 'intuition', 'knew') and/or confidence ratings. Researchers commonly interpret responses according to two criteria. The 'guessing criterion' argues learning was unconscious if performance remained above chance when considering only the responses on which participants claimed they were guessing. The 'zero correlation criterion' claims learning was unconscious if improvements in performance were not accompanied by increases in confidence (Dienes, Altmann, Kwan, & Goode, 1995). Dienes (2008) recommended a number of studies that provide evidence of participants who were sensitive to regularities from an implicit learning task even though they reported themselves to be guessing (the guessing criterion, e.g., Dienes, et al., 1995; Tunney & Shanks, 2003b; Ziori & Dienes, 2008). Similarly, he advised on several studies that had demonstrated that there was no relationship between confidence and performance; participants were equally confident about correct and incorrect judgments (the confidence criterion, e.g., Dienes, et al., 1995; Channon, et al., 2002; Dienes, 2008). However, in the case of zero correlation some researchers have argued that the failure to find a relationship results from the use of a continuous scale, and that scales asking for binary confidence judgments do reveal a relationship (Tunney, 2005; Tunney & Shanks, 2003b; cf. Dienes, 2010).

In all these approaches to establish learning without consciousness or awareness, it is possible to focus on different aspects of the results to one's own purpose. For example, in process dissociation, it is possible to focus on either the evidence that a participant can generate fewer examples in exclusion than inclusion; or the evidence that those participants are still unable to exclude below chance (Tunney & Shanks, 2003a). In subjective measures, it is possible to focus on either the fact that participants seem to have some subjective idea about their performance insofar that they perform better when describing high as opposed to low confidence judgments (e.g., Tunney & Shanks, 2003a), or that when participants report themselves to be guessing they can still perform at a greater than chance level (e.g, Dienes, et al., 1995). How a researcher interprets the evidence will probably depend upon the kind of research question they are asking. Where absolute answers are required, the problem might be intractable until the field has a better idea and understanding of consciousness; although a great deal of enduring knowledge has been, and will likely continue to be, learnt in the pursuit (e.g., Shanks, 2005). Nonetheless, it seems indisputable that all the counter-evidence for each of the methodologies is indicative of something less than the definition of consciousness that first inspired each of those methodologies. In addition to this, there are reasons for retaining the idea of implicit learning because of functional differences between implicit and explicit learning.

5. Differences between Implicit and Explicit Learning

There are a variety of functional reasons for distinguishing between implicit and explicit learning. For example, there are considerable literatures in many areas of psychology that usefully employ a similar conceptual distinction between the implicit and explicit, including attitude (Greenwald, McGhee, & Schwartz, 1998), creativity (Dijksterhuis & Meurs, 2006), decision-making (Bechara, Damasio, Tranel, & Damasio, 1997; Dijksterhuis, Bos, Nordgren, & van Baaren, 2006), emotion (Damasio, 1996), memory (Schacter, 1987), motivation (King, 1995; McClelland, 1980), orienting and perception (MacLeod, 1998; Risko & Stolz, 2010), personality (Asendorpf, 2007), reasoning (Sloman, 1996), and 'thought' (Dijksterhuis & Nordgren, 2006). However, there is debate about the similarity of the distinctions across these different areas, beyond all being dichotomous, and also about whether the various applications have proved particularly useful (e.g., Keren & Schul, 2009).

The distinction can be fitted into a plausible evolutionary and comparative psychological framework (e.g., A. S. Reber, 1993). The idea is centred on two observations: the relatively recent evolution of consciousness in humans; and the existence of learning as a fundamental process central to all other complex organisms. Parsimony insists that humans and all other organisms would have once shared the same basic learning capacities and that by definition it would have been a learning capacity independent of human awareness. Since consciousness evolved after a basic learning capacity, it is suggested that there must be two mechanisms for human learning: the basic, ancestrally-shared, learning capacity and a second means bestowed by the evolution of consciousness; explicit learning guided by awareness. There are two reasons for arguing that the basic learning capacity must have persisted. First, since consciousness evolved from a psychology incorporating a basic learning capacity, it is likely that they are intimately linked. Second, it is unlikely that an adaptive capacity, such as a reliable mechanism for learning, would be subsequently selected against. However, the evolution of psychology is far more uncertain than morphology, and both arguments are surmised as likelihoods rather than logical consequences. This is pertinent when considering consciousness, which is characterised by a pervasive and mysterious nature. For example, an alternative and plausible argument could be made that the very presence of consciousness fundamentally changed the psychological nature of all other brain processes and rendered all processes as 'one system'.

"Explicit representations are a pervasive and central feature of creative and flexible human cognition" (Clark & Karmiloff-Smith, 1993, p. 504), which are capable of explaining much about human learning (e.g., De Houwer, 2009; Mitchell, De Houwer, & Lovibond, 2009). Yet, incredibly rich explanations of many learning phenomena have also been achieved using 'automatic link machinery' (or connectionist-type) models. For an illustrative review of the successes of these models in explaining associative learning data see Schmajuk and Kutlu (2009), for implicit learning performances see Cleeremans and Dienes (2008), and for reinforcement learning results see Dayan and Abbott (2001). Indeed, authors have argued that the explanatory power of connectionist models provides sufficient reason to abandon a purely propositional account of learning (e.g., Shanks, 2009). Yet, reconciling the propositional and connectionist accounts into one mode of learning is difficult for two reasons. First, without

external intervention, connectionist-type models are unable to analyse, or symbolically represent, their own activity. Yet, people are proficient at this kind of symbolic self-introspection (Clark & Karmiloff-Smith, 1993, p. 504; e.g., Cleeremans & Dienes, 2008). Second, connectionist architectures function to represent how the world actually exists, to track reality, yet people are also clearly capable of representing and entertaining counterfactual possibilities and models (Scott & Dienes, in press). Therefore in order to retain two fairly vast and useful modelling literatures, the indication is that some kind of distinction between two types of learning would be sensible and meaningful.

Potentially, the connectionist and propositional traditions can be somewhat reconciled: perhaps with an explanation that abstract propositions emerge from the basic operations of connectionist networks (e.g., Shanks, 2009), or in a hybrid connectionist model (for a review of possibilities see Cleeremans & Dienes, 2008). Yet, even within such reconciliations there still clearly remains some kind of distinction that is at least worthy of further investigation. This remnant of a distinction might not convince a researcher of the need for absolutely dissociable systems, if they were concerned with cognitive architecture (e.g., Keren & Schul, 2009), but it is worth noting that such researchers disagree about whether the one system should be conceived as predominantly propositional (e.g., De Houwer, 2009; Mitchell, et al., 2009), or connectionist (e.g., Shanks, 2009).

There appear to be different neural substrates for different modes of learning. For example, participants learning either implicitly or explicitly have displayed distinct coding patterns in their recorded event-related brain potentials (e.g., Rüsseler & Rösler, 2000). Neuroimaging suggests that different sites tend to show greater activation depending on whether a learning task was more implicit or explicit (e.g., Dolan & Fletcher, 1999; Lieberman, Chang, Chiao, Bookheimer, & Knowlton, 2004; Skosnik, et al., 2002). Explicit performance tends to be more associated with the medial temporal lobe and hippocampal circuits; implicit performance with the basal ganglia and striatal circuits; with evidence of interaction and competition between the two of them (for illustrative reviews see Poldrack, et al., 2001; Poldrack & Rodriguez, 2004). These interpretations are supported by the classic single dissociation presented in amnesia, a condition in which the limbic region, including the hippocampus and related structures, is characteristically damaged. Amnesic patients can typically learn information implicitly and yet show severely impaired declarative memory for the learning episode (e.g., Knowlton, Mangels,

& Squire, 1996; Schacter, Chiu, & Ochsner, 1993; cf, Speekenbrink, Channon, & Shanks, 2008). Further, double dissociations between different neuropsychological patients suggest that some neural substrates distinct to different types of learning can operate relatively independently of one another (e.g., Bechara, et al., 1995; Knowlton, Mangels, et al., 1996; Knowlton, Squire, Paulsen, Swerdlow, & Swenson, 1996). For example, Bechara and colleagues (1995) reported that a patient with selective damage to the amygdala showed no autonomic conditioning yet declaratively acquired the contingency pairings between the stimuli. By contrast, a patient with selective hippocampal damage showed conditioning but no declarative contingency learning. Additionally, a patient with selective damage to both areas demonstrated no learning of either. In a review by Poldrack and colleagues (2001) the dissociation of neural sites was argued to be supported by neural lesion dissociations in the animal literature (e.g., Packard, Hirsh, & White, 1989; Packard & McGaugh, 1992). While these results again point to functional reasons for distinguishing between modes of learning, some theorists have pointed out that double-crossed, functional dissociations can be produced within single system architectures (e.g., C. J. Berry, Shanks, & Henson, 2008; Dunn & Kirsner, 1988; Plaut, 1995).

It is a widely held view that implicit memory is much more durable than explicit memory. However, while differences in decay patterns are characteristic of implicit and explicit memory measures, it is not always the implicit that is more durable than the explicit (Schacter, 1987). Moreover, the implicit memory and learning fields have quite different methodologies (e.g., Scott & Dienes, 2010), in spite of a good deal of empirical and theoretical overlap (D. C. Berry & Dienes, 1991). Thus, although it is a fairly common assumption that implicit learning and explicit learning result in knowledge with different patterns of decay, there is actually relatively little research. The research that exists suggests implicit learning results in knowledge that is relatively resilient to decay (R. Allen & Reber, 1980; Higham, Vokey, & Pritchard, 2000; Lee & Vakoch, 1996; Tamayo & Frensch, 2007; Tunney, 2003).

There is evidence that the relationship of age with implicit and explicit learning is quite different. Explicit learning has a fairly steep developmental trajectory; for example, older children learn and recall far more words than younger children (e.g., Carroll, 1993; Cole, Frankel, & Sharp, 1971). By contrast, implicit learning seems to be developed from a very early age. For example, Gomez and Gerken found across four separate experiments that children of just twelve months learnt about an artificial grammar (1999; for a follow-up review of infant learning see Gomez & Gerken, 2000). Further, several studies have reported no correlations between performance and age within children of varying ages (López-Ramón, 2007; Vicari, Verucci, & Carlesimo, 2007; Vinter & Perruchet, 2000), while other studies have reported no evidence of group differences between younger and older children (Vinter & Detable, 2003), or children and adults (Meulemans, Van der Linden, & Perruchet, 1998; cf Thomas, et al., 2004). In terms of normal aging, explicit learning appears to decline in old age. For instance, explicit acquisition and subsequent recall is impaired in list learning, paired-associate learning, and prose learning (e.g., Verhaeghen, Marcoen, & Goossens, 1993). Yet, implicit learning has been found to be relatively stable (for a review see Rieckmann & Bäckman, 2009). Rieckmann and Bäckman (2009) suggest that aging differences have only emerged on implicit learning tasks due to either intereference from explicit processing, or the complexity of the learning task exceeding the working memory capacity for chunking of the older participants. Rieckmann and Bäckman (2009) noted that this stability of implicit learning was in spite of the fact that striatal areas typically degrade in old age and suggested that the stability reflected neural reorganisation.

Finally, there is a different relationship between IQ and implicit learning compared with IQ and explicit learning. Explicit learning is closely related to IQ (e.g., Carroll, 1993; Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, Walkenfeld, & Hernstadt, 1991), and appears to predict IQ above and beyond working memory and processing speed (Kaufman, et al., 2009). In contrast, implicit learning appears to be largely invariant of IQ (Feldman, Kerr, & Streissguth, 1995; López-Ramón, Introzzi, & Richard's, 2009; Maybery, Taylor, & O'Brien-Malone, 1995; Myers & Conner, 1992; A. S. Reber, et al., 1991; Vinter & Detable, 2003; cf Fletcher, Maybery, & Bennett, 2000; McGeorge, Crawford, & Kelly, 1997; Salthouse, McGuthry, & Hambrick, 1999). Gebauer and Mackintosh (2007) have provided the most compelling evidence of IQ dissociating implicit and explicit learning. In their study, one group of participants completed implicit learning tasks according to typical implicit instructions, while another group were given instructions to use explicit strategies to aid their performance. Although this instruction manipulation did not change the overall performance across the learning tasks, a relationship with IQ was consistently observed only under the explicit instructions. Most importantly, the dissociation could not have been caused by a difference in the sensitivity of the implicit and explicit learning tasks: the learning tasks were exactly the same, only the instructions varied.

In summary, there is a consensus that people learn when they are not primarily engaged in trying to learn explicitly and deliberately, and are consequently unable to report verbally on how or what they learnt. In spite of this consensus, researchers do not agree whether learning can occur without awareness or consciousness since it seems possible to focus on different aspects of the results from the methodologies for investigating the absolute involvement of consciousness. Nonetheless, it seems indisputable that all the counter-evidence for each of those methodologies is indicative of something less than the definition of consciousness that first inspired each of those methodologies. Further, there are reasons for retaining the concept of implicit learning because of functional differences between implicit and explicit learning including: the existence of plausible comparative and evolutionary frameworks; the differences in computational models that explain much of the different types of learning; different neural sites associated with the different modes of learning; and contrasting relationships of implicit and explicit learning with durability, age and IQ. Taken altogether, this demonstrates that it is a legitimate, empirical question as to whether there are important differences in implicit learning, as measured operationally by implicit learning tasks. It is hoped this question can exist in parallel and complement research that requires more absolute evidence and methodologies, such as efforts to understand how evidence from learning tasks can elaborate the role of awareness, attention and automaticity in learning, and what that evidence can reveal about consciousness, mental representation and the modularity of learning systems.

6. Differences in Implicit Learning

The issue of differences in implicit learning is not only legitimate but potentially extremely important: learning is central to everyday life, and differences in explicit, IQ based processing are extensively researched and have been usefully related to many life outcomes (e.g., Mackintosh, 1998). To this end, some encouraging recent research has begun investigating the possible impact of differences in implicit learning. For example, there has been some success in measuring individual differences in implicit learning in a typical population (e.g., Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press) in spite of the hypothesis by A. S. Reber that such individual differences would be minimal (1993). However, it has been noted that further research and replication would be necessary to make the modest evidence base more convincing (Gebauer & Mackintosh, 2010; Kaufman, et al., in press).

In a second type of approach, group differences between typical and atypical populations have been investigated. A. S. Reber (1993) had hypothesised that implicit learning would be relatively robust in the face of psychological disorders. There is much evidence to support this view: intact implicit learning on particular tasks has been reported in Alzheimer's disease (e.g., Eldridge, Masterman, & Knowlton, 2002); amnesia (e.g., Chun & Phelps, 1999; Knowlton, Mangels, et al., 1996); OCD (Rauch, et al., 2007); Down Syndrome (e.g., Vicari, et al., 2007); dyslexia (e.g., Folia, et al.); Huntington's disease (Knowlton, Squire, et al., 1996); intellectual disability (Vinter & Detable, 2003); Parkinson's disease (e.g., P. J. Reber & Squire, 1999); psychosis and ADHD (Karatekin, White, & Bingham, 2009); and schizophrenia (e.g., Keri, et al., 2000). However, in some of these disorders, there is evidence that there are deficits on other implicit learning tasks: dyslexia (e.g., Folia, et al.); Huntington's disease (e.g., Knowlton, Squire, et al., 1996); Parkinson's disease (e.g., Knowlton, Mangels, et al., 1996); and schizophrenia (Horan, et al., 2008). In the two disorders where only deficits have been reported, it has never been on more than one task: a deficit on the SRT task in Williams Syndrome (e.g., Vicari, et al., 2007); and a deficit on the PCL task in Tourette Syndrome (Kéri, Szlobodnyik, Benedek, Janka, & Gádoros, 2002). Thus, there is clearly an implication that deficits on particular implicit learning tasks do not necessarily provide evidence of general deficits but are instead related to the particular demands of different aspects of the learning tasks.

In contrast, an argument has been made that the deficit is more general in Autism Spectrum Condition (e.g., L. G. Klinger, et al., 2007; Mostofsky, et al., 2000; Romero-Mungu a, 2008), and initial results supported that view (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). Nonetheless, the issue is not yet fully resolved and would benefit from an investigation of the same individuals on a wider range of implicit learning tasks.

Thus, there is not yet entirely convincing, and certainly not extensive, evidence of functional differences in implicit learning. Instead, the field is at stage where it would benefit from further investigation into the possible functional differences. To this end, a dual-approach was applied in this thesis. The first approach was to seek further evidence as to whether there are meaningful individual differences in implicit learning among the typical population. Specifically, Study I investigated the inter-correlation between three implicit learning tasks; the independence of those tasks from IQ; the relationships between those tasks, intuitive aspects of personality and occupational tacit knowledge; and finally whether performance on implicit learning tasks was related to occupational achievement. The second approach was adopted concurrently and examined whether there were group differences in implicit learning between a typically developing and an Autism Spectrum Condition population. Specifically, Studies II, III and IV examined whether there is an ASC deficit in implicit learning, which contributes to diagnostic social, communicative and motor impairment.

II. Individual Differences in Implicit Learning: Study I

1. Introduction

The possibility of individual differences in implicit learning has received little empirical attention. In Chapter I it was asserted that this lack of research is at least partly a result of the complex debate on the validity and details of a distinction between implicit and explicit learning. Another reason is that A. S. Reber has actively theorised that individual differences in implicit learning are likely to be minimal (e.g., A. S. Reber, 1993; A. S. Reber & Allen, 2000). Specifically, A. S. Reber's theory is primarily based on the evolutionary argument that adaptive learning must have existed prior to the relatively recent evolution of conscious, explicit learning, and that old, adaptive structures are relatively stable and invariant between individuals. Although this argument is plausible, the issue is an empirical one and can be tested within a psychometric framework. In order to establish meaningful individual differences in implicit learning, it would be necessary to demonstrate inter-relationships between implicit learning tests; independence from explicit, IQ-mediated cognition; the nature of the relationships with other existing characteristics; and correlation with real-life behaviours assumed to be implicitly acquired (e.g., Carroll, 1993; Gebauer & Mackintosh, 2010). Although such empirical investigation using an individual differences approach has been relatively scant, the research that exists has provided encouraging results (Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press).

Gebauer and Mackintosh (2007) dissociated implicit, in contrast with explicit, learning from a general factor of intelligence. Kaufman and colleagues (in press) also dissociated implicit learning from a general factor of intelligence, and, further, established its independence from explicit associative learning and working memory while providing evidence of a relationship between implicit learning and both educational achievement in second language acquisition, and intuitive aspects of personality. However, there was no evidence of an inter-relationship between several different measures of implicit learning in either of those studies (Gebauer & Mackintosh, 2007; Kaufman, 2009).[1] A further study by Gebauer and Mackintosh (2010) replicated the finding of a correlation between implicit learning and educational achievement in a second language, and importantly, did find some positive relationships among different measures of implicit learning. However, the modesty of that overlap led the authors to encourage further replication and investigation of the relationship.

Thus, one aim of Study I was to provide such replication of the inter-relationships of implicit learning tasks. Additionally, rather than further investigate the relationship of implicit learning to language acquisition, the study investigated the relationship between implicit learning and another domain of everyday behaviour that is popularly associated with an implicit acquisition, this being occupational achievement.

In order to successfully recruit expert participants and thereby allow an interesting investigation of implicit learning and occupational achievement, it was judged unrealistic to include more than three implicit learning tasks in the study; a probabilistic Serial Reaction Time (SRT) task, an Artificial Grammar Learning (AGL) task, and an Invariant Feature Learning (IFL) task. The SRT and AGL tasks were suitable for inclusion since they have been described as paradigmatic methods for studying implicit learning, and are thoroughly researched (Shanks, 2005). Further, the two tasks contrast substantially in their approach to measuring implicit learning. Therefore, it would be reasonable to assume that any shared variance would not result from some other, superficial factor. Lastly, these two tasks have been utilised successfully in the promising initial investigation of individual differences in implicit learning (Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press). IFL has also been used to study implicit learning. Unusually for the implicit learning literature, IFL has been demonstrated with both abstract (McGeorge & Burton, 1990) and real-world stimuli (Kelly, Burton, Kato, & Akamatsu, 2001). It was the successful demonstration of IFL with real-world stimuli that suggested its relevance to this study.

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[1] It should be noted that Kaufman (2009) and Kaufman and colleagues (in press) are not separate studies. Kaufman and colleagues (in press) published an article that was based on some of the data from Kaufman's (2009) thesis. The details of the additional implicit learning tasks and their inter-correlations are only provided in Kaufman's (2009) thesis, thus I reference Kaufman (2009) when referring to that detail of the study reported in Kaufman and colleagues' (in press).

In addition to investigating the inter-relationships between these implicit learning tasks and occupational achievement, the study also sought to clarify further the relationship between implicit learning and some other characteristics, namely practice, explicit IQ-mediated processing, personality, and occupational tacit knowledge. Explicit IQ-mediated processing was assessed, in an attempt to further establish its independence from implicit learning. This assessment was achieved by including both abstract and verbal reasoning IQ subtests, and deriving two further measures of explicit processing, one from the AGL task and the other from the SRT task. There were two reasons for choosing to investigate further the relationship between implicit learning and personality. The first was to replicate the interesting relationships between intuitive aspects of personality and implicit learning that were identified by Kaufman and colleagues (in press). Second, personality is particularly implicated in occupational achievement, and could plausibly interact or mediate the influence of implicit learning on performance. Thus, in order to make a strong case for implicit learning as an independent ability, it was necessary to clarify any possible relationship. An index of practice was included in order to establish whether implicit learning was able to predict occupational achievement independently of practice. This result would help distinguish between the relative importance of individual differences in implicit learning as compared with time.

1.1. Tacit Knowledge

The desire to understand the relationship of implicit learning to occupational tacit knowledge stems from the suggestion that tacit knowledge may be acquired by an implicit learning system (Mackintosh, 1998, pp. 363-367). One reason that such a relationship is plausible stems simply from the description of tacit knowledge: tacit knowledge is *"generally unspoken knowledge gained from experience, as opposed to explicit instruction"* (R. K. Wagner & Sternberg, 1986, p. 52). R. K. Wagner and Sternberg were not responsible for the concept of tacit knowledge; tacit knowledge had been previously invoked in the philosophy of science (Polanyi, 1958), ecological psychology (Neisser, 1976), and organisational behaviour (Schön, 1983). The unique contribution by R. K. Wagner and Sternberg was the development of a tool to assess such knowledge, the Tacit Knowledge Inventory. Over the course of several studies, the authors achieved modest validation of their inventories (e.g., Hedlund, et al., 2003; Sternberg, et al., 2000; R. K. Wagner, 1985, 1987; R. K. Wagner & Sternberg, 1985). Importantly, from these studies there is good evidence that (i) tacit knowledge predicts occupational achievement, and modest evidence that (ii) tacit knowledge does not correlate with IQ and (iii) tacit knowledge does not wholly depend on practice. Insofar that these findings are true, then this suggests that there is some system for acquiring information, specifically tacit knowledge, that is not simply a function of time and yet predicts important differences in performance, and is seemingly *not* mediated by explicit, IQ-dominated, processing. Since it might plausibly be an individual's implicit learning ability that is primarily responsible for the acquisition of tacit knowledge, then it is critical that any relationship between them is elucidated. Further, if tacit knowledge is the intermediary between an individual's implicit learning ability and its behavioural manifestation in performance differences, then the study is actually far more likely to find evidence to support the role of implicit learning in individual performance differences by also measuring that relevant intermediary.

It is important to note that while Sternberg and colleagues (e.g., Sternberg, et al., 2000) strongly believe in the validity of tacit knowledge, other authors are considerably less convinced (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005). Therefore, Study I also provided an opportunity to resolve some of the outstanding issues concerning tacit knowledge, which shall now be described.

R. K. Wagner (1985, 1987) and R. K. Wagner and Sternberg (1985, 1986) devised measures of tacit knowledge concerning specific occupational fields. This was achieved by asking experienced and highly successful individuals in the fields of academic psychology and business management to describe typical work-related situations and possible responses to them. Their descriptions and a tentative theoretical framework were used to assemble, in questionnaire format, two sets of work-related situations requiring judgments about the quality of response alternatives; one for academic psychology, and one for business management. In untimed conditions, the questionnaires ask individuals to indicate the appropriateness of multiple response strategies for a problem situation using a rating scale of 1 (extremely bad or extremely unimportant) to 7 (extremely good or extremely important). Tacit knowledge is quantified using either an 'item-discrimination method' or 'expert-prototype method' (R. K. Wagner, 1985, 1987; R. K. Wagner & Sternberg, 1985 see Method 2.3.4 of this chapter for more details). Since that initial investigation, tacit knowledge has been examined in several other occupations by Sternberg and colleagues including bank management, sales, primary education, clerical work, policing and military leadership (Grigorenko, Sternberg, & Strauss, 2006; Hedlund, et al., 2003; Hedlund, Wilt, Nebel, Ashford, & Sternberg, 2006; Matthew & Sternberg, 2009; Mueller & Bradley, 2009; Sternberg, et al., 2000; Sternberg & Wagner, 1993; Sternberg, Wagner, & Okagaki, 1993; Sternberg, Wagner, Williams, & Horvath, 1995; R. K. Wagner, Sujan, Sujan, Rashotte, & Sternberg, 1999).

An important issue concerning tacit knowledge is its true relationship with IQ, practice and personality. These relationships are clearly instrumental to the interpretation of the role that tacit knowledge, and thus possibly implicit learning, has in determining performance differences. Sternberg and colleagues certainly believe tacit knowledge has been empirically demonstrated to be largely independent of IQ and personality (e.g., Sternberg, 2003; Sternberg, et al., 2000), and not to be solely a function of practice (e.g., R. K. Wagner & Sternberg, 1986). Further, those authors believe that important individual differences in tacit knowledge acquisition remain independent of IQ, personality and practice, and play a role in differences in practical intelligence between individuals. However, other authors interpret their evidence and theories differently (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005).

Gottfredson (e.g., 2003a) has made many strong criticisms of the research but it appears her primary objection is that the *extent* of Sternberg's theorising is not justified by the data. For example, she states that Sternberg makes *"an implausible claim, namely, that tacit knowledge reflects a general factor of intelligence that equals or exceeds IQ in its generality and everyday utility"* (Gottfredson, 2003a, p. 391). Brody has similar complaints of Sternberg's broader theorising on practical intelligence (e.g., Brody, 2003). However, for current purposes, if tacit knowledge could predict meaningful differences independently of IQ, personality and practice, regardless of how relatively restricted that prediction was, then it would still offer significant theoretical support of an additional, albeit less dominant, system with meaningful individual differences.

McDaniel and colleagues have argued that the general format of Tacit Knowledge Inventories can be described as a Situational Judgment Test, insofar that it features a set of common problem situations, which have long been used in personnel selection (e.g., as long ago as 1947, McDaniel, Morgeson, Finnegan, Campion, & Braverman, 2001; McDaniel & Whetzel, 2005). Taken alone, this fact supports the validity of Tacit Knowledge Inventories, and their ability to improve the prediction of performance. However, McDaniel and colleagues also reported meta-analyses that demonstrated situational judgement tests do tend to relate to IQ, personality and practice. McDaniel and colleagues therefore argued that tacit knowledge was acquired according to differences in explicit-IQ mediated cognition and personality over time, and as such that there was no reason to invoke another system to explain the acquisition of tacit knowledge, such as practical intelligence or implicit learning. Thus, if McDaniel and colleagues are correct in identifying R. K. Wagner and Sternberg's (1985) Tacit Knowledge Inventories as Situational Judgment Tests, then it seems unlikely that R. K. Wagner and Sternberg's findings will be replicable. However, given it is at least possible that there is something particular about the inventories R. K. Wagner and Sternberg (1985) have developed, however similar they might appear to situational judgement tests, an empirical replication and investigation using those particular inventories should provide the most convincing resolution to the debate.

However, Gottfredson (2003) argued that even Sternberg's research concerning his own specific Tacit Knowledge Inventories has not always shown such convincing independence from IQ (e.g., p. 377). In reply, Sternberg (2003) contended that, on balance, there was more evidence towards the conclusion of independence from IQ (p. 407-408). Unconvinced, Gottfredson (2003) maintained such strong assertions were only possible by *"reporting evidence selectively and inaccurately"* (p. 415). Rather than debating the evidence that Sternberg and colleagues have provided, selectively, inaccurately or otherwise, a more useful approach is to conduct independent empirical research in order to resolve the issues.

Therefore, Study I analysed the relationship between the Academic Psychology-Tacit Knowledge Inventory (AP-TKI, R. K. Wagner and Sternberg, 1985), and IQ, practice and personality. There were three reasons for using the Academic Psychology-Tacit Knowledge Inventory. The primary reason was that research into the Academic Psychology Inventory has contributed to the pattern of results I have identified as important to the validity of tacit knowledge. Specifically, performance on the Inventory has shown moderate independence from practice (e.g., faculty outperformed postgraduates, who outperformed undergraduates, but there was no evidence of a correlation between tacit knowledge and the year of Ph.D among faculty, $r = .04$); moderate independence from IQ (e.g., there was evidence of a small correlation between IQ and tacit knowledge in one study, $r = .30$, but in another study there was no evidence of correlation, $r = -.09$); and a relationship with real world performance (e.g., tacit knowledge correlated with the number of publications among the faculty, $r = .28$, R. K. Wagner &

Sternberg, 1986). Second, these results are frequently cited in support of tacit knowledge (e.g., Cianciolo, et al., 2006; Hedlund, et al., 2003; Hedlund, et al., 2006; Sternberg, et al., 2000), and yet these results have not been replicated. Clearly, the Inventory warrants further investigation. The final reason was the practical availability of academic psychologists as participants.

The final important tacit knowledge issue that this study addressed was domain generality. The questions used on Tacit Knowledge Inventories are ostensibly quite specific to the relevant occupation, and suggest that the knowledge would be domain specific. Certainly, Gottfredson (2003) interpreted Tacit Knowledge Inventories as assessments of domain specific job knowledge, and McDaniel and colleagues (2005) argued performance on Situational Judgment Tests, and by extension Tacit Knowledge Inventories, is not underpinned by a general factor. However, Sternberg (2003) and colleagues (1986, 2000) have argued to the contrary, claiming, for example, that tacit knowledge is domain general across all practical, occupational, tasks. R. K. Wagner and Sternberg (1986) justified this claim based on the *"the moderately strong correlation (r = .60) found...between performance on the tacit knowledge measures for Academic Psychology and Business Management"* (Wagner and Sternberg, 1986, p. 77), which remained the only empirical evidence offered in the 'Tacit Knowledge as a General Construct' section of Sternberg and colleagues' (2000) book. However, only their undergraduate group were given both of the two different tests of tacit knowledge. Therefore, the correlation could have resulted from the low range of scores achieved by the inexpert undergraduates on *both* inventories. Thus, perhaps it is the case that only undergraduates use domain general tacit knowledge precisely because they lack requisite expertise in their chosen field. Thus, the correlation of undergraduates' scores on different tests of tacit knowledge was insufficient evidence on which to conclude that scores would correlate with one another across the full range of expertise. In order to address this unsatisfactory assessment of Tacit Knowledge in Sternberg and colleagues' study, Study I assessed the relationship between performance on two types of Tacit Knowledge Inventory, Academic Psychology and Business Management (BM-TKI), across a full range of expertise, from undergraduates to professors.

More recently, researchers, in collaboration with Sternberg, have begun investigating overtly generic forms of tacit knowledge (e.g., the College Life Questionnaire, the Common Sense Questionnaire, and the Everyday Situational Judgment Inventory), which ask questions clearly non-specific to occupation. The existence of a positive relationship between generic Tacit

Knowledge Inventories and IQ (Cianciolo, et al., 2006) contrasts with Sternberg's claims about the independence of IQ and occupational Tacit Knowledge Inventories (e.g., Sternberg, 2003), and therefore also contrast with the argument that tacit knowledge is completely general. Instead, this finding of different relationships with IQ is suggestive that, at the very least, generic and occupational Tacit Knowledge Inventories assess different constructs. In order to examine this possibility, participants in Study I also completed a Common Sense Questionnaire (CSQ), in order that the relationship between occupationally-specific Tacit Knowledge Inventories and generic Tacit Knowledge Inventories could be directly assessed.

Finally, it should be acknowledged that it was interesting for Study I to clarify the generality of tacit knowledge, in order to understand the relationship between tacit knowledge, implicit learning and everyday performance. However, it is clearly not critical to theories of implicit learning as a general ability that all types of tacit knowledge are strongly related to one another. Only one tacit knowledge inventory, which meaningfully predicted differences independently of IQ, personality and practice, would need to be related to implicit learning, in order to offer theoretical support to the existence of an additional system with meaningful individual differences. The resultant implication of the independence of different Tacit Knowledge Inventories would be that such a system does not ubiquitously influence individual differences in performance.

In summary, the central aim of this study was to provide a further test of the theory of meaningful individual differences in implicit learning. In achieving this aim, Study I was first interested in whether the overlap between implicit learning tests identified by Gebauer and Mackintosh (2010) was replicable. Similarly, it was necessary to re-examine the independence of implicit learning from IQ-mediated explicit processing (e.g., Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991), and replicate possible relationships between implicit learning and intuitive aspects of personality (Kaufman, et al., in press). In order to establish whether implicit learning was related to meaningful differences in everyday performance in addition to second language acquisition (Gebauer & Mackintosh, 2010; Kaufman, et al., in press), Study I uniquely investigated whether implicit learning was related to occupational achievement. Lastly, since tacit knowledge has been plausibly postulated as an intermediary construct that might mediate the influence of implicit learning influence on behaviour (Mackintosh, 1998), Study I also uniquely examined the relationship between tacit knowledge and implicit learning.

Furthermore, in order to understand fully the implications of a tacit knowledge and implicit learning relationship, the study also took the opportunity to resolve outstanding issues relating to tacit knowledge. In particular, the interpretation of the relationships between tacit knowledge, IQ and personality, have been subject to fierce debate (e.g., Gottfredson, 2003a, 2003b; McDaniel & Nguyen, 2001; McDaniel & Whetzel, 2005; Sternberg, 2003). It has been claimed this is, in part, a consequence of a failure to acknowledge the similarities of Tacit Knowledge Inventories to Situational Judgment Tests, which are better researched (e.g., McDaniel & Whetzel, 2005), and a selective reporting of the data on Tacit Knowledge Inventories (e.g., Gottfredson, 2003b). While such arguments are sensible and plausible, it is hoped that the debate would be resolved by an independent, empirical investigation of those relationships using precisely the same inventories as those devised by Sternberg and colleagues (e.g., R. K. Wagner & Sternberg, 1986).

Finally, the issue of domain generality in tacit knowledge has not received a thorough test to date. Therefore, Study I analysed the relationship between performance on two different occupational inventories by one occupational group that displayed a broad range of expertise, together with performance on an inventory which assesses overtly generic, non-occupational-specific knowledge.

To achieve these aims, 103 academic psychologists completed three implicit learning tasks (SRT, AGL, IFL task), two IQ sub-tests (DAT verbal and analogical reasoning tests), one personality questionnaire (Big Five Inventory), three Tacit Knowledge Inventories (Academic Psychology, Business Management and CSQ) and one General Questionnaire primarily pertaining to their educational and occupational histories.

2. Method

2.1. Participants

The data obtained from 103 academic psychologists were included in the study (61 females). Participants were aged between 18 to 78 years old (M = 31.97, SD = 12.72). In the investigation of occupational achievement with implicit learning and tacit knowledge, the participants were split into three groups depending upon their level of academic expertise (e.g., R. K. Wagner and Sternberg, 1986). There was an undergraduate group (Undergraduates, N = 34), a 'junior' academics group (Junior-Academics, N =39) and a 'senior' academics group (Senior-Academics, N = 30). Junior and senior academics were arbitrarily distinguished depending upon whether their position required them to lead research projects beyond the doctoral level, and/or lecture. Relevant descriptive statistics of these groups of participants are provided in Table 1. Participants were recruited by emailing UK psychology departments and organisations with a request that they invited their members' participation. In return for participation, £1,000, £500 each, was donated to two charities. Participants were excluded if they were not academic psychologists, not 'native English-speakers', or demonstrated evidence of substantial business management experience (to allow comparison with performance on the Business Management Tacit Knowledge Inventory).

Table 1. *Descriptive Statistics indicating Participants' Expertise in Academic Psychology*

Measure	M	SD	Range
Senior-Academics (*N* = 30)			
# Publications	28.73	39.01	0 – 160
# Conference papers	14.66	15.94	0 – 60
Job Title Rating [a]	3.23	1.22	1 – 5
Dept.'s RAE Outcome [b]	47.17	28.58	0 – 85
% Time spent researching [c]	56.61	30.14	0 – 100
Salary (£1000s; *N* = 29)[d]	41.64	12.11	22.50 – 67.50
Years since Ph. D was acquired	10.80	13.63	0 – 45
Years in academic psychology	17.79	12.28	4.27 – 51.14
Age (years)	41.95	13.80	23.83 - 77.54
Junior-Academics (*N* = 39)			
# Publications	1.18	2.42	0 – 11
# Conference papers	1.00	1.81	0 – 8
Dept.'s RAE outcome	46.79	20.37	10 – 85
Years in academic psychology	5.09	2.45	0.55 – 11.15
Age (years)	31.74	9.20	22.53 – 54.30
Undergraduates (*N* = 34)			
Dept.'s RAE outcome	43.24	24.18	10 – 85
Years in academic psychology	1.83	1.24	0.35 – 4.63
Age (years)	23.44	8.35	18.41 – 55.24

Notes: [a] *Job titles rated between 1 to 5: 1 = Associate Research Fellow; 2 = Research Fellow; 3 = Lecturer; 4 = Senior or Principal Lecturer; 5 = Professor or Reader.* [b] *The Department with which the participant was associated. The variable is the percentage of the Department's RAE submitted research judged to be above 3*. Thus, the quality of that percentage of research is equal or better than "internationally excellent in terms of originality, significance and rigour but which nonetheless falls short of the highest standards of excellence" (Research Assessment Exercise, 2008, p. 8).* [c] *Percentage of time that participants spent researching relative to time spent on administration and teaching.* [d] *Salary means are based on the midpoint of the £5,000 bands that participants selected.*

2.2. General Procedure and Apparatus

All data collection occurred remotely. Participants who replied to the recruitment emails were first directed to the online General Questionnaire, which requested general, demographic details and information pertaining to their academic expertise (see Appendix A for details of the questionnaire, which provides screenshots of the questionnaire as presented in Study I). Participants were screened according to exclusion criteria, and the remaining individuals were invited to participate in the entire study. Those participants were sent a download link, user-name and password. All tasks were programmed within Delosis Psytools software. Participants were unable to complete any of the tasks without first downloading and installing the software. This ensured that when a participant was running a task it was safeguarded from interruption from internet problems and other programmes on the computer, and thus all participants received a uniform experience of each task and questionnaire. Additionally, installing software onto participants' machines allowed the utilisation of a battery of three different clocks on Windows and the system timer on Macs to provide millisecond timing accuracy.

All participants were instructed to complete the tasks in one of two of the following orders with the following names (parenthesis information added here for clarity): 1) Personality Questionnaire (BFI); 2) Task C (DAT Verbal IQ subtest); 3) Task F (DAT Abstract IQ subtest); 4) Common Sense Questionnaire (CSQ); 5) Task I (IFL); 6a) Business Management Questionnaire (BM-TKI) or 6b) Academic Psychology Questionnaire (AP-TKI); 7) Task A (AGL); 8a) Business Management Questionnaire or 8b) Academic Psychology Questionnaire; 9) SRT. Fixed orders allow the most accurate comparison between individuals, and for this reason, trial and item order were also fixed. However, it was necessary to use the two different overall task orders to permit a valid within-subject comparison of performance on AP-TKI and BM-TKI.

The task order was chosen to maximise variety, and thus the interest of the participants, in the hope of minimising participant withdrawal. This consideration was particularly relevant to Study I given that participation was remote and that many participants were experts with busy schedules. Participants were instructed, and the software dictated, that they had to finish each task and questionnaire once it had begun, and that they should do so in a quiet and distraction-free environment. Participants were also instructed that they could complete the nine different tasks using as many as breaks as their schedules required; again, this freedom was necessary in order to minimise participant withdrawal. Participants were routinely reminded by email about both the study and their right to withdraw but were sent an exclusion notification after an extended period of inactivity (approximately three months). The mean time to complete all the tasks was 46.54 days (*SD* = 59.53 days). Once a participant completed a task, results were securely transmitted back to the server when an internet connection was available. Each participant's dataset was identified by their user-name and password, which they had to enter prior to completing any of the tasks. Finally, upon completing all nine tasks, participants were sent a questionnaire about the implicit learning tasks, and were asked to complete and return the questionnaire by email.

2.3. Tasks

2.3.1. General Questionnaire

This General Questionnaire asked participants to provide, where they were happy to do so, demographic information and, more importantly, detailed educational and occupational achievement (see Appendix A for more details). The answers to these questions were used to screen potential participants, assign selected participants to one of three groups (Undergraduates, Junior- or Senior-Academics) and compile quantitative indices of expertise (Publications, Conference Papers, Job Title Rating, Dept.'s RAE Outcome, Relative Percentage of Time Spent Researching, Salary), opportunity for practice (time spent in academic psychology and time since Ph. D was acquired) and educational achievement (at both sixteen and eighteen). Some questions were asked in the General Questionnaire that were not used to create these listed indices (see Appendix A for details of questions not used). Those questions were included with the intention of using them to compute more indices of expertise; however, either too few participants responded or data was too non-normally distributed to analyse.

2.3.2. Implicit Learning

Serial Reaction Time (SRT) task

Participants in Study I were asked to respond as quickly and as accurately as possible to a large blue dot appearing in one of four locations by pressing corresponding keys on their keyboard ('V', 'B', 'N', 'M'). They were instructed that upon pressing the correct corresponding button, the blue dot would move to another location and that they should continue the task in this fashion. The location of the dot location followed a 12-digit second-order conditional sequence (312143241342), such that the subsequent location of the dot was perfectly predicted by the previous two locations (e.g., after the series 3 followed by 1, location 2 is expected). However, the sequence was probabilistic, so that occasionally the dot appeared in locations unpredicted by this sequence. These improbable trials were generated randomly on 15 % of trials, by following the constraints of an alternative second-order sequence (132341243142). Thus, in those trials, the series 3, 1 would not be followed by 2, but rather by 4, as stipulated in this alternative series (Schvaneveldt & Gomez, 1998). The utilisation of this probabilistic second-order sequence, and the fact that the response-to-stimulus interval was programmed at 0 ms, should have minimised the use of explicit strategies during learning (Destrebecqz & Cleeremans, 2003). There were 9 blocks of trials: the first was a baseline block, consisting of 48 trials during which both sequences were equally likely; the remainder consisted of 120 trials each with 15 % of improbable trials, as described above. Between each block, the experimenter provided the participant with feedback about their accuracy. Sequence learning was assessed by comparing participants' RT between trials that were generated according to the frequent sequence (i.e. probable trials) and those that were generated by the alternative sequence (i.e. improbable trials).

Artificial Grammar Learning (AGL) task

During a learning phase, participants in Study I were told that they would be presented with a series of nonsense letter strings, which they should memorise because, after each letter string disappeared, they would need to reproduce it using the keyboard. Each string was presented for four seconds. When reproducing the strings, upon typing an incorrect letter, participants were instructed *"Incorrect. Please try again"*. Participants were then presented with the string for another four seconds before trying again to reproduce it. In total, twenty different strings were presented during this learning phase; each was presented twice, once in each of two blocks, which were separated by a short interval. Crucially, all the learning strings conformed to an artificial, semantic-free, finite-state grammar (see Figure 1). To elaborate, grammatical strings are created by following the direction of an arrow and a letter is added to the string whenever a node is passed (e.g., PTTTVPS or TSXXTTVV). These learning strings were replicated exactly from the stimuli reported in A. S. Reber, Walkenfeld, and Hernstadt (1991) and A. S. Reber (1993). Thus, letter strings were between 3-8 letters long and strings were selected so that all the variations of the grammar, the three loops, and all possible beginnings and endings were displayed (A. S. Reber, et al., 1991 and see Appendix A for the complete list of learning phase letter strings used).

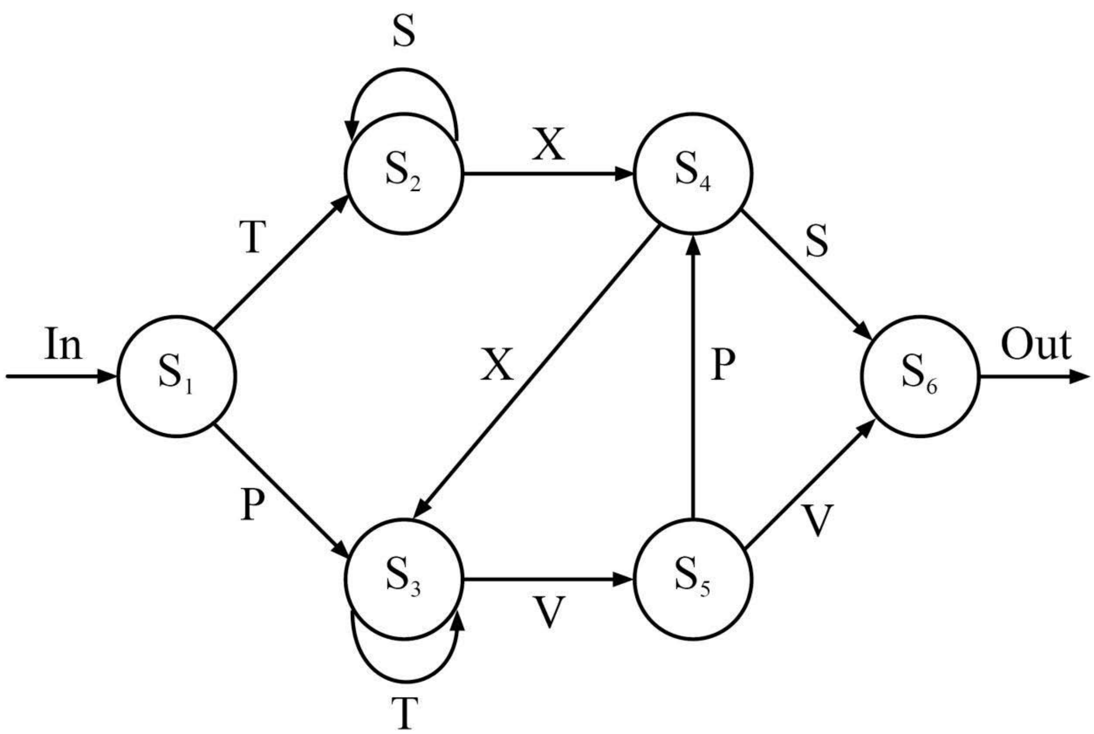


Figure 1. *Schematic diagram of the artificial, finite-state grammar used to produced stimuli for the AGL task (reproduced from A. S. Reber, et al., 1991).*

Instructions up to the end of the learning phase described a memory experiment and the fact that the strings had been produced according to a grammar was unknown to the participants. Upon beginning the test phase, participants were told that the strings had followed rules. Participants were further instructed that they would now see letter strings, some of which followed the rules and some of which did not, and that they would have to judge, according to their first feeling, whether they followed the rules. Test strings were presented one at a time, for a maximum of 6 seconds, with no feedback and a response-stimulus interval of 500 ms. Participants pressed 'Y' to indicate that a string followed the rules and pressed 'N' to indicate that it did not. Test stimuli were also replicated exactly from the stimuli reported in A. S. Reber, Walkenfeld, and Hernstadt (1991) and A. S. Reber (1993). Thus, test stimuli consisted of 25 grammatical letter strings (7 of which were old strings from the learning set and the remaining were novel grammatical strings) and 25 non-grammatical letter strings, which were formed by introducing one or more violations into otherwise grammatical letter strings (A. S. Reber, et al., 1991 and see Appendix A for the complete list of test phase letter strings used). Overall, grammar learning was assessed by comparing classification performance against the chance level of performance.

Invariant Feature Learning (IFL) task

In a learning phase, participants were presented with a series of four digit number strings, and were instructed that they had to press a key to indicate whether the two left-hand digits (by pressing ‘Z’), or two right-hand digits (by pressing ‘M’), summed to give the greater number. Each string was presented until a valid response was provided, after which correct and incorrect feedback were appropriately given. In total, twenty different strings were presented during this learning phase; each was presented twice, once each in two blocks, which were separated by a short interval. Critically, and unknown to participants, all these four-digit number strings included the numeral ‘3’. In the subsequent test phase, participants were shown pairs of four-digit number strings and instructed to indicate which member of the pair had already appeared in the first phase. In fact, all strings presented were new, but only one member of each of the pairs contained the invariant feature, 3. In total, thirty unique pairs of strings were presented during the test phase, during which there was no feedback and no response-stimulus interval. All of the numbers used in the strings, other than the invariant feature 3, were generated randomly with two constraints. First, none of the numbers included a zero to ensure that participants always had to sum both sides of the four-digit number during the learning phase. Second, two adjacent numbers were never the same because this would have made a string more unique and memorable, and may thereby have compromised the cover story for the test phase that one of the pair was repeated from the learning phase (see Appendix A for the complete list of number strings used). Overall, IFL learning was assessed by comparing the selection of test-items containing the invariant feature 3 against the chance level of selection.

2.3.3. Explicit Processing

Two indices of explicit learning were derived, one from the AGL task and one from the SRT task. During the learning phase of the AGL, the mean number of errors that participants made before correctly reproducing each letter string was taken as an index of explicit processing. These errors are indicative of a participant's ability to explicitly remember and reproduce letter strings in the short-term, and have been used previously as a measure of explicit processing that is related to IQ (e.g., A. S. Reber, et al., 1991). During the SRT, mean RTs to improbable trials were used as another index of explicit processing. Such RTs are not the most obvious index of explicit processing. However, 'perceptual speed' (Gs) has been specified within the Horn-Cattell theory of intelligence (Horn & Cattell, 1966) and 'general speediness' has been evoked in Carroll's three-stratum theory of intelligence (Carroll, 1993). Moreover, 'processing speed' has been found to correlate with IQ; for example, higher-IQ participants respond more quickly to simple and four-choice RTs procedures (Deary, Der, & Ford, 2001).[2] Thus, RTs to improbable trials on the SRT provided another index of explicit processing.

2.3.4. Tacit Knowledge

Academic Psychology and Business Management Inventories

The Academic Psychology and Business Management Tacit Knowledge Inventories were reproduced from R. K. Wagner (1985; see Appendix A for screenshots of the inventories as presented in Study I). Both inventories consisted of 12 work-related situations, each of which was associated with 9 to 11 response items for Academic Psychology; and 10 to 11 response items for Business Management. In untimed conditions, participants read a work-related situation and rated the appropriateness of possible response strategies on a 7-point scale by either its quality (1 = extremely bad, 4 = neither good nor bad, and 7 = extremely good) or its importance (1 = extremely unimportant, 4 = somewhat important, and 7 = extremely important). The work-related situations were presented one at a time, and participants had to rate all the responses before irreversibly advancing to the next situation. Prior to advancing from each situation, participants were able to change their ratings freely to all of the response alternatives. Participants rated both the 'actual' and 'ideal' quality, or importance, of each response item. The

[2] It is not clear exactly why RTs provide an index of explicit IQ-mediated processing. Some authors have argued the link between them is individual differences in overall efficiency and speed of the nervous system (Anderson, 1992; Jensen, 1998). However, it is possible that the relationship actually results from the influence of vigilance or ability to avoid distraction on the RT tasks, rather than mere neural efficiency (Mackintosh, 1998).

actual and ideal ratings were originally included to measure relative pragmatic and idealistic orientations. Study I was not interested in this analysis, and only included ideal ratings in case the presence of those alternatives was important to the actual ratings' ability to index expertise.

Tacit knowledge was quantified using the item discrimination method. This method specifies that only a subset of the response alternatives be retained. R. K. Wagner and Sternberg (1985) identified the subset as the items that were differentially rated by experts and novices. It was necessary to retain the remaining items on the scale as the expertise lies in the identification of items as important, or good, *relative* to one another. Items which experts rated *differentially* from novices as unimportant or bad (rather than important or good) were reflected such that all ratings were summed into a single score that reflected the total 'correct' high-scoring of all the discriminatory items.

Later, the authors specified a second scoring method, in order to provide corroboration and validation of their first method (R. K. Wagner, 1985, 1987; R. K. Wagner & Sternberg, 1986). In that instance, each individual's response rating was compared with the mean ratings of a highly expert group. The score was represented by the sum of the squared deviations from the expert profile. High levels of tacit knowledge were indicated by close agreement between an individual's ratings and the prototype. The expert group had been identified by high performance on external criteria. Cut-off points for the criteria to identify experts were relatively arbitrary, but the expert cut-off points were varied slightly, and all such variation yielded similar evaluative results. More importantly, analyses using the item-discrimination method and the expert-group comparison produced the same pattern of results. Since the item-discrimination method identified which items caused differences, and then used those items to establish the magnitude of the differences, without the corroboration from the expert-group method, such item discrimination is suspect. Specifically, although there is no reason to explain why the magnitude of the discriminated items correlated with the external criteria among the experts, group comparisons between experts and non-experts would have been invalid. However, the cost of using an expert group is that those participants cannot be validly included in the main analysis. Therefore, Study I used the item-discrimination method, but critically by using the items that R. K. Wagner (1985) reported as discriminative of the groups in his study. Therefore, group comparisons in Study I were perfectly valid, because the discriminative items were not identified using the current groups, *and* there was no need to exclude any experts. It was preferable to use the discriminative items identified by R. K. Wagner (1985), rather than the exact mean ratings of the expert profile R. K. Wagner reported: *which* items are discriminative are less likely to change over time than the exact mean rating of a particular strategy by a group of experts.

Common Sense Questionnaire

This questionnaire was reproduced from Cianciolo and colleagues (2006; see Appendix A for screenshots of the questionnaire as presented in Study I). The questionnaire consisted of 15 everyday situations for individuals who are employed, or seeking employment, in low- to mid-level entry jobs. Each situation was associated with 8 response items. In untimed conditions, participants read a situation and rated the appropriateness of possible response strategies on a 7-point scale according to its quality (1 = *"extremely bad"*, 4 = *"neither good nor bad"*, and 7 = *"extremely good"*). The situations were presented one at a time, and participants had to rate all the responses before irreversibly advancing to the next situation. Prior to advancing from each situation, participants were able to change their ratings freely to all of the responses alternatives.

Cianciolo and colleagues' (2006) method for deriving a CSQ score was employed. For each of the 15 situations, the deviation of an individual's response profile to all of the solutions from the consensus response profile of the whole sample was taken to index Common Sense Tacit Knowledge. In particular, profiles that adhered closely to the consensus profile represented tacit knowledge about 'Common Sense'. The deviation was quantified by calculating the standardized Euclidean distance (Mahalanobis D^2) of an individual's vector of solution-ratings from the centroid of the sample. The squared Mahalanobis distance provided a useful standardisation by accounting for the different variances and covariances of the different solutions within each situation. In particular, less weight was given to deviation from consensus on a given solution if that solution had a relatively large variance and weak correlation with other solutions in the situation (Rencher, 1995). All the scores were averaged across the 15 situations. This average squared Mahalanobis distance was square-rooted to provide an overall CSQ score. Lastly, the scores were reflected such that a larger CSQ score was indicative of 'better' Common Sense Tacit Knowledge.

2.3.5. IQ: DAT Verbal and Abstract Reasoning

Participants completed both the verbal and abstract reasoning sections of the Differential Aptitudes Test (DAT-V and DAT-A, The Psychological Corporation, 1995). The tests were administered in accordance with the standard guidelines, with the exception that the tasks were completed electronically rather than with pen and pencil. After examples, participants had 25 minutes to complete 40 questions on the DAT-V, and 20 minutes to complete 40 questions on the DAT-A. At the beginning of each question, participants were told how long, and how many questions, remained. In the DAT-V, each participant was presented with an analogy that was missing two words. The participant's task was to select which of the five possible solutions was analogically consistent. In the DAT-A, each participant was presented with a series of four geometric shapes. The series varied according to abstract rules, and participants had to reason which of five possibilities completed the series correctly. Performance was quantified using the raw scores from the two sub-tests. The scores were not transformed into IQ scores; a whole battery of IQ tests was not administered and so no norm tables were available. Moreover, when the sample is so large, and made up of adults, who thus have relatively stable IQs, IQ can be accurately related to other variables in the study by estimating an IQ factor. This was achieved by extracting a general factor from the two sets of raw DAT scores (as standard within the field, e.g., Cianciolo, et al., 2006; Kaufman, et al., 2009).

2.3.6. Personality: BFI

The inventory was reproduced from and administered according to Benet-Martinez and John (1998) and John and Srivastava (1999, see either reference for a full listing of the BFI used in this study). Participants were presented with 44 statements pertaining to characteristics that might apply to them. In untimed conditions, for each statement, participants indicated the extent to which they agreed with the statement using a 5-point scale (disagree strongly to agree strongly). Five scale scores were computed that related to Extraversion (8 items), Agreeableness (9 items), Conscientiousness (9 items), Neuroticism (8 items) and Openness (10 items). These scores were computed as the mean ratings of the items on each scale (after reversing the falsekeyed items) such that the prominence of the traits was reflected in the magnitude of the mean ratings.

3. Results

For all analyses, the alpha level was set at .05, two-tailed and extreme outliers (values either less than three times the interquartile range below the lower quartile, or greater than three times the interquartile range above the upper quartile) were excluded. Where relevant, the appropriate epsilon correction was used when sphericity was violated. Šidák corrections were used to control for familywise error rates during multiple comparisons (Cardinal & Aitken, 2006, pp. 87-90). Where significant interactions were found in mixed analyses of variance, separate ANOVAs on the levels of interest were conducted to establish simple effects. When conducting independent sample *t*-tests, equal sample variances were assumed unless Levene's test for the equality of variances was significant. Cohen's d is reported as a measure of effect size except where relative measures of effect size are more appropriate, and then partial eta-squared (η^2_p) is reported.

3.1. Descriptive Statistics

3.1.1. Implicit Learning

SRT

RTs on error trials were discarded. First trial data were excluded, since meaningful assessment can only occur when the stimuli have been presented sequentially. Figure 2 represents the mean RT (ms) difference between trial-types across blocks. A difference score greater than zero indicates that participants responded faster to the probable trials. Clearly, there was learning: difference scores were above zero and, on average, difference scores after the first block tended to be greater than those on the first block. A within-subject analysis of variance conducted on mean RTs, with two within-subjects factors, Trial Type (Probable vs. Improbable) and Block (1-9), supported this interpretation: there was a main effect of Trial-Type ($F(1, 102) = 134.07$, $p < .001$, $\eta^2_p = .57$), Block ($F(3, 334) = 21.63$, $p < .001$, $\eta^2_p = .18$), and an interaction between Trial-Type x Block ($F(6, 655) = 42.11$, $p < .001$, $\eta^2_p = .29$). A linear contrast confirmed that the differences between trial-type increased across blocks ($F(1, 100) = 146.99$, $p < .001$, η^2_p

= .60). The overall SRT-RT learning score was derived by calculating the difference between mean RT to probable trials and mean RT to improbable trials, excluding the first practice block (*M* = 19.86 ms, Standard Error of Mean (*SEM*) = 1.38 ms).

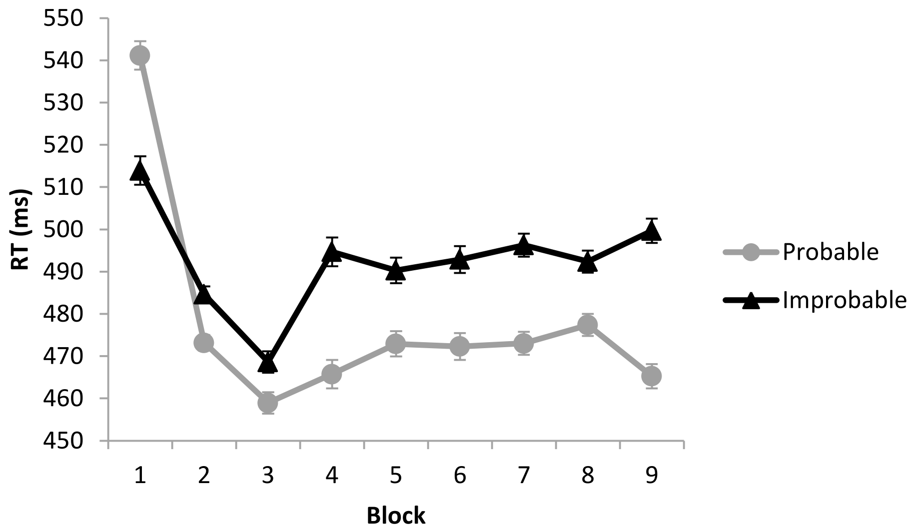


Figure 2. *There was learning on the SRT task; participants were quicker on the probable than improbable trials. Depicted are mean RTs on probable and improbable trials on the SRT across training. The error bars show twice the standard error of differences between trial-type means at different levels of block.*

There were few errors on the task (*M* = 3.12 %, *SD* = 2.16 %). Song, Howard and Howard (2007) argued that accuracy on the SRT index learning in the same way as do RTs: fewer errors on the probable compared to the improbable trials indicate participants must have learnt about the sequence. A within-subjects ANOVA was conducted on the SRT error data, using the same factors as the RT analysis. Consistent with the RT analyses there was evidence of learning (Trial-Type ($F(1, 102) = 84.90$, $p < .001$, $\eta^2_p = .45$; Block, $F(7, 716) = 18.44$, $p < .001$, $\eta^2_p = .15$; Trial-Type x Block ($F(8, 768) = 9.53$, $p < .001$, $\eta^2_p = .09$). A linear contrast confirmed that the interaction was indicative of an increase in the differences between trial-type across blocks ($F(1, 100) = 40.96$, $p < .001$, $\eta^2_p = .29$). The overall SRT-Errors learning score was derived by calculating the difference between mean accuracy to probable trials and mean accuracy to improbable trials, excluding the first practice block (*M* = 3.05 %, *SEM* = 0.33 %).

AGL

The dependent variable was the percentage of test phase letter strings that had been correctly identified above the 50 % chance level. An answer that accurately classified a string ('Yes' to grammatical strings and 'No' to ungrammatical strings) was deemed correct. One-sample *t*-tests demonstrated the basic learning effect (M = 10.60 %, SEM = 0.76 %, $t(102) = 13.87$, $p < .001$, $d = 1.42$).

IFL

Learning was measured using the percentage of test phase number strings that had been correctly selected above the 50 % chance level. A selection was correct if the number string with the invariant feature was selected. One-sample *t*-tests demonstrated the basic learning effect (M = 6.28 %, SEM = 1.01 %, $t(102) = 6.20$, $p < .001$, $d = 0.61$).

3.1.2. IQ

The mean score on the Abstract Reasoning task was 27.97 (SD =7.21, and on the Verbal Reasoning task was 33.33 (SD = 5.86). Using the DAT norm conversion tables as an approximate index, it was estimated that these raw scores suggested a mean IQ in the range of 105 to 117. However, given the sample was made up of adults, and who thus have relatively stable IQs, and was large in size, the variables in the study were more accurately related to one another by estimating an IQ factor through the extraction of a general factor from the raw scores (e.g., Cianciolo, et al., 2006; Kaufman, et al., 2009). Performance on the two subtests correlated ($r = .52$, $p < .001$, $r^2 = .27$), and the general factor was extracted by a principal component analysis. Bartlett's test of sphericity showed that the correlation matrix differed significantly from zero ($\chi^2 = 31.40$, $p < .001$). The general factor accounted for 75.86 % of the variance, as a consequence of correlating strongly with each of the original variables ($r = .87$).

3.1.3. Explicit processing

The mean number of errors that participants made in order to correctly reproduce all forty strings during the learning phase of the AGL task was 14.12 (SD = 9.99). The mean RT to improbable trials on the SRT task was 489.73 ms (SD = 81.74 ms). On both AGL memorisation errors and SRT improbable RTs, better explicit processing was indicated by smaller scores, fewer errors and smaller (quicker) RTs respectively. Therefore, both indices were reflected for ease of interpretation in subsequent sections.

3.1.4. Personality

The scores on the different dimensions of the BFI (Extraversion: M = 3.37, SD = 0.77; Agreeableness: M = 3.81, SD = 0.66; Conscientiousness: M = 3.66, SD = 0.77; Neuroticism: M = 2.84, SD = 0.95; Openness: M = 3.95, SD = 0.59), and the inter-correlations between these dimensions presented in Table 2, were similar to other large-scale studies (e.g., see Table 1 and 2 in Benet-Martinez & John, 1998).

Table 2. *Correlation Matrix of the Dimensions of the Big Five Inventory*

Measure	1.	2.	3.	4.	5.
1. Extraversion	-				
2. Agreeableness	.09	-			
3. Conscientiousness	.01	.34*	-		
4. Neuroticism	-.33*	-.33*	-.19	-	
5. Openness	.23	-.01	.00	-.22	-

* $p < .05$

3.1.5. Tacit Knowledge: Academic Psychology Inventory

Senior-Academics scored higher than Junior-Academics, who in turn scored higher than Undergraduates (Undergraduates: M = 225.21, SEM = 3.92; Junior-Academics: M = 228.28, SEM = 2.72; Senior-Academics: M = 243.20, SEM = 4.46). A one-way ANOVA showed that there was indeed an effect of group ($F(2, 100) = 6.44$, $p < .01$, $\eta^2_p = .13$); further, a planned contrast confirmed that Undergraduates differed from Senior-Academics ($F(1, 100) = 11.35$, $p < .001$, $\eta^2_p = .10$). This replicated R. K. Wagner (1985, 1987) and R. K. Wagner and Sternberg's (1985, 1986) work and added to the evidence that their scale measured expertise in academic psychology. Further validation and replication was provided by correlations within the Senior-Academics group between some external criteria of success in academic psychology and performance on the inventory, see Table 3.

Table 3. *Relationship of Tacit Knowledge Indices with Occupational Achievement in Academic Psychology (Senior-Academics, N = 30)*

	Academic Psychology	General Occupational	Common Sense	IQ
(SqRt) Publications	.46*	.40*	-.02	-.27
(SqRt) Conf. Papers	.53*	.42*	-.03	-.26
Job Title Rating	.38	.31	.19	-.13
Dept.'s RAE Outcome	-.02	-.02	.03	-.02
Time Spent Researching	.00	-.07	.18	.05
(SqRt) Salary (*N* = 29)	.17	.09	-.06	-.29

* $p < .05$

3.2. Outstanding Issues in Tacit Knowledge

3.2.1. Tacit Knowledge and Domain Generality

The assessment of the relationship between performances on Tacit Knowledge Inventories for two different occupations across a whole range of expertise was performed in order to allow conclusions about the generality of tacit knowledge.

Business Management Inventory

Senior-Academics scored higher than Undergraduates and Junior-Academics, while the Undergraduates and Junior-Academics performed similarly (Undergraduates: M = 269.06, SEM = 4.31; Junior-Academics: M = 263.85, SEM = 4.35; Senior-Academics: M = 277.50, SEM = 4.07). A one-way ANOVA showed that there was indeed no evidence for an overall effect of group ($F(2, 100) = 2.39$, $p = .10$, $\eta^2_p = .05$). However, a contrast confirmed that the performance of Senior-Academics was superior to the combined performance of Junior-Academics and Undergraduates ($F(1, 100) = 4.09$, $p = .05$, $\eta^2_p = .04$). Therefore, expert academic psychologists had outperformed non expert-academic psychologists on *both* an Academic Psychology and Business Management Tacit Knowledge Inventory. This supported the claim that the tacit knowledge measured on these inventories is domain general. Moreover, expertise scores on the Academic Psychology-Tacit Knowledge Inventory correlated with the Business Knowledge

Inventory (r = .58, N = 103, p < .001, r^2 = .34), and critically, this correlation remained even within just the expert group (r = .71, N = 30, p < .001, r^2 = .51). This was particularly convincing evidence of domain generality because it replicated and extended the correlation found in undergraduates (R. K. Wagner & Sternberg, 1986) across the *whole range* of expertise.

In order to further test this generality, a principal component analysis was performed on the correlation between AP-TKI and BM-TKI. Bartlett's test of sphericity showed that the correlation matrix differed significantly from zero (χ^2 = 41.75, p < .001). The general factor accounted for 79.15 % of the variance, as a consequence of correlating strongly with each of the original variables (r = .89). Since there were only two variables and one extracted component, obviously the solution could not be rotated. This 'General Occupational Tacit Knowledge' factor, which was general to the AP- and BM-TKIs, also correlated with external criteria of success in academic psychology (see Table 3). Altogether, this suggested that there was a large proportion of variance that was common to both inventories, and moreover, what was common to both was also important in achieving success in academic psychology.

Common Sense Questionnaire

There was no evidence of a correlation between the factor of General Occupational Tacit Knowledge and Common Sense Tacit Knowledge (r = .00, p > .99, r^2 < .01). This was also true when the inventories were correlated with the CSQ separately (AP: r = .03, p = .76, r^2 < .01; BM: r = -.03, p = .76, r^2 < .01). The lack of correlation between the CSQ and occupational tacit knowledge suggested that the domain generality of occupational tacit knowledge was limited. Since the CSQ asks genuinely generic questions unrelated to any specific occupations, the implication was that the generality of occupational tacit knowledge did not extend to knowledge unrelated to occupational performance. Therefore, the remaining issues were examined separately in occupational tacit knowledge and the CSQ.

3.2.2. Occupational Tacit Knowledge and Practice

In Study I, as reported above, there were differences in performance between groups selected for their experience in academic psychology. There were also correlations within the Senior-Academics between performance and (i) (SqRt) Years since Ph. D was acquired (r(30) = .52, p < .01, r^2 = .27), (ii) Years in academic psychology (r (30) = .39, p = .04, r^2 = .15). Further, performance across all participants was correlated with Years in academic psychology (r = .40, p < .001, r^2 = .16). A highly similar relationship emerged between practice and the General Occupational Tacit Knowledge factor. This general factor also correlated with (SqRt) Years since Ph. D was acquired (r = .39, p = .03, r^2 = .16) and Years in academic psychology across all participants (r = .33, p < .01, r^2 = .11).

An important aspect of R. K. Wagner and Sternberg's theorising and evidence on tacit knowledge was that tacit knowledge is at least moderately independent of practice (R. K. Wagner, 1985, 1987; R. K. Wagner & Sternberg, 1985, 1986). That is, although R. K. Wagner and Sternberg identified *between*-group differences in performance related to experience, there was independence *within* the groups (e.g., R. K. Wagner, 1985; R. K. Wagner & Sternberg, 1986). Study I used more sensitive measures to test that claim, and did not replicate that finding. Instead, the results clearly implied that tacit knowledge is strongly related to practice.

3.2.3. Occupational Tacit Knowledge and IQ

The raw scores on the Abstract Reasoning task were similar between the groups (Senior-Academics: M = 26.97, SD = 8.265; Junior-Academics: M = 29.26, SD = 6.315; Undergraduates: M = 27.38, SD =7.161; F(2, 100) = 1.03, p = .36, η^2_p = .02). However, there was a group difference in the raw scores on the Verbal Reasoning task (Senior-Academics: M = 35.43 SD = 3.92; Junior-Academics: M = 34.74 SD = 4.18; Undergraduates: M = 29.85 SD = 7.33; F(2, 100) = 10.79, p < .001, η^2_p = .18). Specifically, a contrast demonstrated that the Senior-Academics and Junior-Academics scored higher than Undergraduates (F(1, 100) = 21.55, p < .001, η^2_p = .18). The groups also differed on the IQ factor (F(2, 100) = 4.16, p = .02, η^2_p = .08) with the IQ factor greater for Senior-Academics and Junior-Academics than Undergraduates (F(2, 100) = 7.83, p = .01, η^2_p = .07). However, it seemed unlikely that the difference between the groups in the IQ factor underpinned the differences in tacit knowledge: as in R. K. Wagner's studies (e.g., 1985, 1987) there was no evidence that the IQ factor was related to Academic Tacit Knowledge (r = -.11, p = .26, r^2 = .01) or the factor of General Occupational Tacit Knowledge (r = -.14, p = .16, r^2 = .02) and this was the case in all three groups separately (rs = -.39 to .06, ps > .05, r^2 < .16). Moreover, the addition of the IQ factor as a covariate did not remove the effect of Group on Academic Tacit Knowledge (F(2, 99) = 7.59, p < .01, η^2_p = .13) or the factor of General Occupational Tacit Knowledge (F(2, 99) = 5.36, p = .01, η^2_p = .10).

Also, the IQ factor did not correlate with indices of expertise in academic psychology (see Table 3). IQ is usually an excellent predictor of success, and the lack of evidence of its relationship with success stood in stark contrast with tacit knowledge. As discussed above, tacit knowledge correlated with some indices of expertise (see Table 3), and thereby demonstrated that the lack of correlation between the IQ factor and expertise was not simply an issue of range restriction. Further, this pattern of results was not simply a consequence of particularly unusual sample of participants with non-predictive IQs: the IQ factor correlated with educational achievement at sixteen (r = .30, N = 91, p < .01, r^2 = .09) and eighteen years of age (r = .26, N = 95, p = .01, r^2 = .07), and thereby corroborated the extensive literature on the external validity of IQ.[3] In contrast, there was no evidence of a correlation between the factor of General Occupational Tacit Knowledge and educational achievements at sixteen (r = -.13, N = 91, p = .21, r^2 = .02) or eighteen years of age (r = .00, N = 95, p = .97, r^2 < .01). This suggested that General Occupational Tacit Knowledge was particularly useful, relative to IQ, at predicting intelligent behaviour specifically in occupational domains.

3.2.4. Occupational Tacit Knowledge and Personality

Personality differences between the groups varied according to the dimension, see Table 4. Scores on Agreeableness, Conscientiousness and Extraversion were very similar between the groups (F < 2). There were, however, group differences on Neuroticism (F(2, 100) = 4.42, p = .02, η^2_p = .08) and Openness (F(2, 100) = 3.63, p = .03, η^2_p = .07). The Undergraduates and Junior-Academics scored more highly than Senior-Academics on Neuroticism (F(1, 100) = 8.83, p < .01, η^2_p = .28), while the Undergraduates scored lowest on Openness, with scores increasing up to Senior-Academics (F(1, 100) = 7.23, p = .01, η^2_p = .21). However, there was no reason to believe that these group differences in personality underpinned the differences in tacit knowledge. First, as in previous studies of tacit knowledge (Sternberg, 2003; Sternberg, et al., 2000), there was no evidence that personality was related to Academic Tacit Knowledge or the factor of General Occupational Tacit Knowledge, see Table 5. Second, even when Neuroticism

[3] Educational achievement was quantified by converting the grades that participants provided in the General Questionnaire; grades at sixteen were converted using the General Certificate of Secondary Education (GCSE) points system; and grades at eighteen were converted using the Universities and Colleges Admissions Service (UCAS) Tariffs.

and Openness were added as covariates, the effect of Group remained on both Academic Tacit Knowledge ($F(2, 98) = 5.07$, $p = .01$, $\eta^2_p = .09$) and the factor of General Occupational Tacit Knowledge ($F(2, 98) = 4.30$, $p = .02$, $\eta^2_p = .08$).Third, there was no evidence of correlation between personality and indices of expertise in academic psychology, see Table 6.

Table 4. *Scores on Big Five Inventory between Groups*

	Undergraduates		Junior-Academics		Senior-Academics	
	M	SD	M	SD	M	SD
Extraversion	3.27	0.88	3.39	0.67	3.45	0.78
Agreeableness	3.89	0.71	3.71	0.61	3.84	0.66
Conscientiousness	3.61	0.62	3.56	0.81	3.87	0.86
Neuroticism	3.02	0.92	3.01	0.88	2.42	0.97
Openness	3.76	0.62	3.96	0.58	4.15	0.53

Table 5. *Relationships between Tacit Knowledge and Personality*

	Academic Psychology	General Occupational
Extraversion	.00	.08
Agreeableness	-.04	-.01
Conscientiousness	.04	.02
Neuroticism	-.17	-.15
Openness	.07	-.01

* $p < .05$

Table 6. *Correlations between Personality and Occupational Achievement in Academic Psychology*

	Extraver.	Agreeable.	Conscien.	Neurotic.	Openness
(SqRt) Publications	-.14	.03	-.25	.02	-.05
(SqRt) Conf. Papers	.15	.18	.15	-.26	.25
Job Title Rating	-.25	-.03	-.17	.10	-.13
Dept.'s RAE Outcome	.00	.19	.04	.02	-.06
Time Spent Researching	.24	.00	-.04	-.13	.24
(SqRt) Salary ($N = 29$)	-.21	.14	-.33	.20	.07

* $p < .05$

3.2.5. Occupational Tacit Knowledge Discussion

The study replicated the finding that Tacit Knowledge Inventories measure occupational achievement. Moreover, the study also suggested a degree of domain generality: performance on Business Management and Academic Psychology Inventories were highly correlated across a range of expertise. This replicated and extended the correlation found in undergraduates by R. K. Wagner and Sternberg (1986), but here across the *whole range* of expertise. By considering only undergraduates, the correlation reported by R. K. Wagner and Sternberg (1986) may have arisen not as a consequence of domain generality but alternatively as a consequence of the inexpert undergraduates using domain general knowledge precisely because they lack expertise. This argument cannot be made about Study I which demonstrated that this correlation remained across both the whole range of expertise, and even in the expert group alone. Further to the evidence of domain generality, the General Occupational Tacit Knowledge factor was correlated with occupational achievement. However, there was a limit to this generality: the occupational Tacit Knowledge Inventories were not related to the Common Sense Questionnaire, which asked genuinely generic questions.

More importantly, tacit knowledge appeared to be critically related to practice. As a consequence of a close relationship between tacit knowledge and practice, the Tacit Knowledge Inventories do not provide compelling evidence of individual differences in an ability, such as implicit learning or practical intelligence. This fact remained, even though the study did not find evidence of a relationship between tacit knowledge and IQ, or tacit knowledge and personality.

Instead, this latter finding reinforces the idea that Tacit Knowledge Inventories could be useful measures for predicting occupational achievement (e.g., McDaniel & Whetzel, 2005; Sternberg, et al., 2000). Even though relationships between tacit knowledge and both IQ and personality might emerge in larger studies (as in SJTs, e.g., McDaniel & Whetzel, 2005), the fact that Study I found relationships between tacit knowledge and occupational achievement, when IQ and personality did not, suggests that some of the prediction of occupational achievement by tacit knowledge would remain incremental to the prediction by IQ and personality. This also replicates research about Situational Judgment Tests, which has demonstrated Situational Judgment Tests provide incremental prediction over IQ and personality (McDaniel & Whetzel, 2005).

Finding measurement tools, such as occupational Tacit Knowledge Inventories and Situational Judgment Tests that predict occupational achievement incremental to IQ clearly does not devalue IQ as a measurement tool or construct. First, as established, it is likely that IQ would still be related to achievement in larger samples. Second, it is possible that when considering achievement within occupations the IQ-occupational achievement relationship is relatively modest and that other factors are relatively more important because IQ has already performed its role: it was a necessary cog in achieving the requisite educational qualifications (e.g, Mackintosh, 1998).

3.2.6. Common Sense Questionnaire: Occupational Achievement, Practice, IQ and Personality

Consistent with having found no evidence of a correlation between the CSQ and occupational tacit knowledge, there was no evidence of a correlation between performance on the CSQ and occupational achievement (see Table 2). In the case of Common Sense, the appropriate index of practice is ‘life experience’, or age. There was support of the questionnaire as a measurement of ability independent of practice: there was no evidence that performance on the CSQ was correlated with age (r = .11, p = .27, r^2 = .01). Performance on the CSQ correlated with the IQ factor (r = .26, p = .01, r^2 = .07). This was a similar magnitude of correlation as found by Cianciolo and colleagues (r = .17 to .19; 2006), and therefore provided further evidence that ‘practical intelligence’ as measured by the CSQ was not wholly independent of IQ. Finding a correlation between CSQ and the IQ factor, but not CSQ and indices of expertise were consistent with one another, given that the study also failed to find a relationship between the IQ factor and indices of expertise. Finally, there was no evidence to suggest CSQ was a surrogate measure of personality (rs -.09 to .13, *ps* > .05, $r^2 < .02$).

3.2.7. Common Sense Questionnaire Discussion

In addition to finding no evidence of a correlation between performance on the CSQ and Tacit Knowledge Inventories, there was no evidence of correlation with indices of expertise. This contrasted with one of the original studies that endorsed the CSQ (Cianciolo, et al., 2006). There are several possible reasons for the discrepancy between that study and the current one. First, the effect, when it is apparent, may not be very strong, and in line with this possibility, the original authors only found evidence of a correlation in one of their two studies. Thus, it may be that opportunity to observe such a weak effect was limited in Study I by the relatively smaller sample size. However, it should be noted, that in addition to the lack of correlations here, they were also not even all in the right direction (see Table 3).

Second, the failure to replicate a correlation may be a consequence of the considerable expertise of the current sample. The relatively extensive expertise of the current sample stood in contrast with the fact that the participants in Cianciolo and colleagues' (2006) study had spent just 1.3 years on average in their current position. It seemed plausible that the type of common sense measured in the questionnaire was more important in determining occupational achievement when expertise was low. Consistent with this, in the study in which Cianciolo and colleagues (2006) failed to find a correlation between the CSQ and occupational achievement, the sample had been in their positions for additional 2.7 years than in the sample in which that CSQ-occupational achievement correlation was found.

Thirdly, although in Cianciolo and colleagues' (2006) studies the participant IQs were not measured for the relevant sample, it was assumed that IQs for such a large sample ($N = 228$) of such a diverse population (the sample was recruited through newspaper flyers and included participants with a wide range of occupations see Cianciolo and colleagues, 2006) was close to 100. This stood in contrast with the estimate of the current sample's mean IQ, which was above average. This discrepancy in sample IQs may also explain the different findings; namely, such common sense would add more value for individuals with lower IQs.

While there was no evidence of a relationship between CSQ and personality, performance on the CSQ correlated with the IQ factor. That CSQ-IQ correlation (r = .26) was of a similar magnitude to that found by Cianciolo and colleagues (r = .17 to .19; 2006). In this study, the Common Sense Questionnaire was the only index of ‘practical intelligence’ as measured by these Common Sense/Everyday type inventories. However, when the general factor underpinning the inventories was extracted, the correlation with the IQ factor was found to be much stronger (r = 0.48, Cianciolo, et al., 2006). Given that the first-order correlations were of equivalent magnitude, it seemed likely that Study I would also have replicated this stronger correlation with a general factor. Regardless of this further assumption, the correlation between CSQ and IQ was replicated, and therefore provided further evidence that ‘practical intelligence’ as measured by ‘Common Sense’ and ‘Everyday’ inventories was not wholly independent of IQ.

In Study I, there was support of the questionnaire as a measurement of ability independent of practice, insofar that there was no correlation of CSQ performance with age. This was not identified as important and thus not reported in the original study by Cianciolo and colleagues (2006), yet it is essential to the validity of the CSQ to have established whether or not CSQ performance was related to age. Without investigating the relationship, it was possible that the inventories were measuring a fund of ‘life’ knowledge acquired simply as a function of time. Yet, given the close relationship of the CSQ with IQ, this evidence of individual differences independent of time could plausibly be a consequence of IQ.

In summary, as with the occupational Tacit Knowledge Inventories, the CSQ does not provide compelling evidence of individual differences in an ability, such as implicit learning or practical intelligence. Specifically, there is little evidence of its external validity, and little reason to suppose that differences in CSQ performance do not result from differences in IQ. However, the CSQ and occupational Tacit Knowledge Inventories measure different constructs. The CSQ appears to be related to IQ, and unable to predict occupational achievement once sufficient expertise and knowledge has been acquired. This stands in contrast with occupational Tacit Knowledge Inventories that appear to measure knowledge, acquired as a function of time, and predict occupational achievement incrementally to IQ and personality.

3.3. Individual Differences in Implicit Learning

3.3.1. Inter-Relationships between Implicit Learning, IQ and Explicit Processes

Table 7 showed that there was no evidence of significant correlations between implicit learning (SRT-RT; SRT-Errors; SRT factor; IFL; AGL) and the IQ factor. This finding stood in contrast with the evidence of correlations between the IQ factor and the indices of explicit processing (RT to improbable trials on SRT and Memorisation errors on AGL, see Table 7).

Table 7. *Correlation Matrix of Learning on Implicit Learning Tasks, IQ and Explicit Processes*

Measure	1	2	3	4	5	6	7	8
1. IQ factor	–							
2. Implicit SRT-RT	.18	–						
3. Implicit SRT-Errors	.11	.36*	–					
4. Implicit SRT factor	.18	.83*	.83*	–				
5. Implicit IFL	.04	-.02	.00	-.01	–			
6. Implicit AGL	.22	-.07	-.10	-.11	.04	–		
7. Explicit Improbable RTs	.32*	.05	.31*	.22	-.09	.06	–	
8. Explicit Memorisation Errors	.41*	.17	.11	.17	.03	.23	.32*	–

* $p < .05$

There were two indices of SRT learning, which correlated (r = .36, p < .001, r^2 = .13). Therefore, in order to ensure that all the different implicit learning tasks were fairly represented, prior to analysing the inter-relationships between IQ, implicit and explicit processes, a general SRT factor was extracted by a principal component analysis. Bartlett's test of sphericity showed that the correlation matrix differed significantly from zero (χ^2 = 14.07, p < .001). The general factor accounted for 68.06 % of the variance, as a consequence of correlating strongly with each of the original variables (r = .83).

Principal component analysis was performed on the correlation matrix for the measures of the IQ factor, implicit (SRT factor; IFL and AGL) and explicit processes (AGL memorisation errors and SRT RTs to improbable trials). Bartlett's test of sphericity and the Kaiser-Meyer-Olkin Measure of Sampling Adequacy (KMO) were conducted to ensure that the present data were suited to a principal component analysis. Bartlett's test of sphericity showed that the correlation matrix differed significantly from zero ($\chi^2 = 52.27$, $p < .001$) and the overall KMO value was satisfactory at 0.66 (this should be 0.5 or greater). The Kaiser-Guttman rule (which states that components with eigenvalues greater than one should be retained, Kaiser, 1960) suggested a 2-component solution that accounted for 51.05 % of the variance. Underlying factors were not assumed to be uncorrelated with one another, therefore oblique (direct oblimin) and not orthogonal rotation was performed. Table 8 shows the pattern matrix with the salient loadings displayed in bold. Measures of the IQ factor and explicit processing displayed their salient loading on component I, whereas the measures of implicit learning all displayed their salient loading on component II. This further reinforced the finding that measures of implicit learning were independent of IQ and explicit processes.

Table 8. *Principal Component Analysis of the Measures of IQ, Implicit Learning and Explicit Processes*

Measure	I	II
IQ factor	**.76**	.13
Implicit SRT factor	.41	**-.61**
Implicit IFL	.01	**.41**
Implicit AGL	.37	**.71**
Explicit Improbable RTs	**.66**	-.30
Explicit Memorisation Errors	**.76**	.15

There was one further key finding implied by two results from this correlation matrix and principal components analysis. First, there was no evidence of any significant first-order correlations between three different measures of implicit learning. Second, although all three of the implicit learning tasks exhibited their salient loadings onto the same component, the loadings of the SRT and AGL were in opposite directions. Together, these findings strongly imply that these three implicit learning tasks show little common variance. While this was in contrast with Gebauer and Mackintosh (2010), this did replicate other large scale studies of implicit learning tasks (Gebauer & Mackintosh, 2007; Kaufman, 2009). Therefore, this supported the theory that individual differences in a ‘general’ implicit learning ability would be minimal (A. S. Reber, 1993). However, this was further examined by a consideration of the correlations of the individual implicit learning tasks and the other variables collected in this study.

Finally, in order to examine whether the lack of correlations between the implicit learning tasks and other measures might have been caused by unreliable tasks Spearman-Brown split-half reliability estimates were calculated. The estimates were all either satisfactory or acceptable (SRT-RT = .63, SRT-Errors = .72, AGL = .73, IFL = .41; i.e., similar magnitudes to Gebauer and Mackintosh, 2009).

3.3.2. Implicit Learning and Occupational Achievement

As reported above in Results 3.1.1 of this chapter there was an overall effect of sequence learning. In order to investigate the influence of SRT learning on occupational achievement, the magnitudes of the SRT factor were analysed between three groups divided according to academic expertise (Undergraduates, Junior-Academics and Senior-Academics). The mean magnitude of the SRT factor was similar between the groups (Undergraduates: $M = 0.05$, $SEM = 0.17$; Junior-Academics: $M = 0.04$, $SEM = 0.16$; Senior-Academics: $M = -0.10$, $SEM = 0.18$), and consistent with this, a one-way ANOVA between these three groups provided no evidence of differences ($F(2, 100) = 0.22$, $p = .80$, $\eta^2_p < .01$).

The SRT factor represented the variance that was general to the two different indices of SRT learning; the RTs and accuracy (see Results 3.1.1 of this chapter). However, there was a possibility that one of the two indices was actually a more accurate measure of the influence of the SRT on occupational achievement. If that were true, then the use of the general factor could have masked the relationship between occupational achievement and the more accurate, single index of SRT learning. Thus, further analyses were performed to consider the effect of occupational achievement on each of the two indices of SRT learning: a Group factor (3 levels, Undergraduates, Junior-Academics and Senior-Academics) was added to the ANOVAs on RTs and accuracy reported in Results 3.1.1 of this chapter. Only the additional results are reported here. In the RT analysis, the magnitudes of the difference scores were comparable between the three groups and therefore suggested that the sequence learning was similar between the groups. Consistent with such similarity, there was no evidence of an interaction between Trial-Type and Group ($F(2, 100) = 0.34$, $p = .72$, $\eta^2_p = .01$) nor a three-way interaction ($F(13, 660) = 1.26$, $p = .23$, $\eta^2_p = .03$). There was an interaction between Group x Block ($F(7, 332) = 2.70$, $p = .01$, $\eta^2_p = .05$). However, this overall RT reduction across block reflected improvement in performance due to practice effects, rather than learning about the sequence because the effect is independent of trial type. This interaction appeared to be a consequence of post-graduates having benefitted the least from practice, i.e. the improvement in postgraduate RTs independent of Trial-Type was smaller than the other two groups. There was no evidence of differences between the groups in overall speed (Group: $F(2, 100) = 0.27$, $p = .77$, $\eta^2_p = .01$).

This SRT-RT effect was also similar in the three groups as measured by the overall RT score (Undergraduates: $M = 17.85$ ms, $SEM = 2.22$ ms; Junior-Academics: $M = 20.84$ ms, $SEM = 2.17$ ms; Senior-Academics: $M = 20.87$ ms, $SEM = 15.76$ ms). A one-way ANOVA between these three groups confirmed this interpretation: there was no evidence of a difference between them ($F(2, 100) = 0.52$, $p = .60$, $\eta^2_p = .01$).

In the accuracy, like the RT, analysis, there was no evidence of differences between the groups in the magnitudes of the differences scores in accuracy between trial-types (Trial-Type x Group, $F(2, 100) = 2.15$, $p = .12$, $\eta^2_p = .04$; Trial-Type x Block x Group, $F(15,771) = 1.07$, $p = .38$, $\eta^2_p = .02$). There was no evidence of a Block and Group interaction ($F(15, 730) = 1.66$, $p = .06$, $\eta^2_p = .03$). Finally, there was evidence of group differences in overall accuracy (Group: $F(2, 100) = 3.47$, $p = .04$, $\eta^2_p = .07$). Fisher's LSD *t*-tests provided no evidence of a difference between Junior-Academics and Senior-Academics ($t(67) = 0.53$, $p = .60$, $d = 0.13$) but did reveal that the Undergraduate group made significantly more overall errors than both Junior-Academics ($t(71) = 2.02$, $p = .04$, $d = 0.47$) and Senior-Academics ($t(62) = 2.34$, $p = .04$, $d = 0.59$).

The SRT accuracy effect was also similar in the three groups as measured by the overall SRT-Errors score (Undergraduates: $M = 3.81$ %, $SEM = 0.57$ %; Junior-Academics: $M = 3.02$ %, $SEM = 0.58$ %; Senior-Academics: $M = 2.24$ %, $SEM = 0.51$ %). Consistent with this, a one-way ANOVA between these three groups provided no evidence of a difference between them ($F(2, 100) = 1.76$, $p = .18$, $\eta^2_p = .03$).

There was an overall learning effect on the AGL task (see Results 3.1.2 of this chapter). This AGL effect was similar in the three groups (Undergraduates: $M = 10.41$ %, $SEM = 1.47$ %; Junior-Academics: $M = 9.85$ %, $SEM = 1.16$ %; Senior-Academics: $M = 11.80$ %, $SEM = 1.37$ %). A one-way ANOVA between these three groups confirmed this interpretation: there was no evidence of a difference between the three groups ($F(2, 100) = 0.55$, $p = .58$, $\eta^2_p = .01$).

There was also an overall learning effect on the IFL task (see Results 3.1.3 of this chapter). Numerically, the Junior-Academics displayed the largest IFL effect of the three groups (Undergraduates: $M = 4.31$ %, $SEM = 1.66$ %; Junior-Academics: $M = 9.06$ %, $SEM = 1.80$ %;

Senior-Academics: *M* = 4.89 %, *SEM* = 1.65 %). However, a one-way ANOVA between these three groups provided no evidence of a difference between the three groups ($F(2, 100) = 2.39$, $p = .10$, $\eta^2_p = .05$).

Finally, it was possible that if implicit learning was related to occupational achievement, the relationship would only be revealed by more sensitive measures of achievement. Therefore, implicit learning performance was correlated with the occupational achievement measured in the Senior-Academics in the General Questionnaire (see Table 1). However, Table 9 demonstrated that there was still little evidence to relate implicit learning to occupational achievement, even using these more sensitive indices of achievement. The N for Senior-Academics was not huge; however, the N was not so small that indices of performance could not correlate with Academic Tacit Knowledge and General Occupational Tacit Knowledge. There were some *negative*, albeit non-significant, correlations between the measure of SRT learning and the different indices of expertise. However, these correlations were unlikely to have been a consequence of an inverse relationship between expertise and implicit learning ability. Instead, if there had been evidence of significant negative correlations, such correlations would have more likely reflected the influence of RTs (or 'processing speed', as indices of explicit processing and correlates of IQ) on this measure of implicit learning.

Table 9. *Relationship between Implicit Learning and Occupational Achievement in Academic Psychology (N = 30)*

	Implicit SRT	Implicit IFL	Implicit AGL
(SqRt) Publications	-.42	-.10	-.07
(SqRt) Conf. papers	.18	.03	-.10
Job Title Rating	-.23	-.12	.08
Dept.'s RAE Outcome	.05	.09	.16
Time Spent Researching	.12	.12	.05
(SqRt) Salary (*N* = 29)	-.41	-.13	-.08

* $p < .05$

Altogether, these analyses provided no evidence to relate implicit learning to occupational achievement. This was consistent with having already failed to find evidence of common variance between the implicit learning tasks.

3.3.3. Implicit Learning and Tacit Knowledge

There was no evidence of correlations between tacit knowledge and indices of implicit learning (see Table 10). This failure was consistent with having already failed to find common variance between the implicit learning tasks, and also failing to demonstrate relationships between implicit learning tasks and occupational achievement.

Table 10. *Relationships between Implicit Learning and Tacit Knowledge*

	Academic Psychology	General Occupational	Common Sense
Implicit SRT factor	.08	.10	-.02
Implicit IFL	.04	-.02	-.01
Implicit AGL	-.12	-.05	.01

* $p < .05$

3.3.4. Implicit Learning and Personality

The dimension of Openness has been related to intuitive aspects of personality in other theories of personality (e.g., John & Srivastava, 1999). Presented in Table 11, the correlations between implicit learning tasks and Openness provided no evidence of a relationship between implicit learning and intuitive aspects of personality. Indeed, there was no evidence that implicit learning was related to any aspects of personality (see Table 11). This was consistent with having already failed to find evidence of common variance between the implicit learning tasks, or any relationship between implicit learning tasks and occupational achievement.

Table 11. *Relationships between Personality and Implicit Learning*

	Implicit SRT factor	Implicit IFL	Implicit AGL
Extraversion	-.13	-.04	-.09
Agreeableness	-.02	.01	.03
Conscientiousness	-.15	.15	.04
Neuroticism	.03	.02	-.05
Openness	.00	.03	.01

$* p < .05$

4. Chapter Discussion

The main aim of the study was to provide a further test of the theory that there are meaningful individual differences in implicit learning. Critically, there was no evidence of common variance between the implicit learning tasks. Further, there was no evidence to relate performance on any of the implicit learning tasks to IQ, occupational achievement, personality or tacit knowledge. Altogether, this data supports the conclusion that there are not important individual differences in implicit learning, and instead supports the theory that individual differences in implicit learning are minimal (A. S. Reber, 1993).

Consideration of these current findings along with the other three large-scale studies of individual differences in implicit learning discourages the conclusion that there are substantial individual differences in implicit learning. Three of the four studies, including the current one, have found no evidence for common variance between different implicit learning tasks (Gebauer & Mackintosh, 2007; Kaufman, 2009). Gebauer and Mackintosh (2010) found inter-relationships between several different learning tasks. However, the inter-relationships identified were sufficiently modest to prompt the authors to acknowledge that *"further replications will be necessary in order to empirically establish the existence of above chance correlations between performance on different implicit learning tasks"* (Gebauer & Mackintosh, 2010, p. 30). Perhaps, the critical aspect of Gebauer and Mackintosh's (2010) study was the fact they used the largest number of implicit learning measures; fifteen different indices were inter-correlated. The identification of individual differences of implicit learning only when the number of implicit learning tasks was large would be consistent with relatively minimal, rather than substantial, individual differences.

Additionally, the evidence to relate implicit learning task performance to functional outcomes is limited. This study found no relationship between implicit learning and occupational achievement, personality, or tacit knowledge. Although Gebauer and Mackintosh (2010) and Kaufman and colleagues (in press) have been more successful than this, there are several ways to reconcile their findings with Study I. Kaufman and colleagues (in press) related SRT task performance, and not what was general to several implicit learning tasks, to second language acquisition and personality. Therefore, the relationships might stem from something that was more specifically measured by the SRT task than from general implicit learning. Gebauer and Mackintosh (2010) did relate the general component they identified to second language acquisition. However, as discussed the reliability of this general component is not clear and, more importantly, the relationship between that general component and second language acquisition was small (r = .15). A more general point is that second-language acquisition and personality are different to occupational achievement and tacit knowledge. It is possible that differences in implicit learning are uniquely critical in language acquisition, and related to intuitive aspects of personality that are independent of tacit knowledge. In the latter case, although Study I also measured personality, Kaufman and colleagues (in press) used different personality questionnaires that might have been more sensitive for the purposes of relating implicit learning and personality. Thus, altogether the literature on individual differences implies that individual differences in general implicit learning are minimal, and insofar that they do exist, they only have a *modest* effect on *some* aspects of behaviour.

An additional aspect of the results of Study I was the replication of a feature of implicit learning that is critical to the retention of the implicit-explicit distinction. Specifically, performance on the implicit learning tasks was not correlated with IQ, which stood in contrast with the correlations between IQ and the indices of explicit processing taken from the same implicit learning tasks. This dissociation reinforces the idea that implicit and explicit-IQ mediated cognition are distinct. However, it is possible that this dissociation is a consequence of the explicit indices being more sensitive than the implicit ones. This remains a possibility even though the indices of explicit processing were taken from the same tasks as the implicit learning measures because all the indices are derived differently. However, given Gebauer and

Mackintosh's (2007) previous dissociation, this possibility seems unlikely. Specifically, the identified dissociation was protected from the possibility of asymmetrically sensitive measures because the learning measures for implicit and explicit performance were derived using exactly the same measurement tools. Critically, participants performed exactly the same tasks in one of two conditions: either under typical implicit instructions or under explicit instruction to use explicit strategies to aid their performance. Although this instruction manipulation did not consistently change overall performance across the learning tasks, a relationship with IQ was consistently observed in the explicit condition. The contrasting relationships of IQ with implicit and explicit measures in Study I support, and are consistent with, Gebauer and Mackintosh's (2007) compelling dissociation.

In resolving outstanding issues relating to tacit knowledge, the study established that tacit knowledge was also unable to provide compelling evidence of individual differences in an ability that was independent of IQ, personality and practice (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005; c.f., Sternberg, et al., 2000; R. K. Wagner & Sternberg, 1986). It was possible that if tacit knowledge was the intermediary between an individual's implicit learning ability and its behavioural manifestation in performance differences, then the study would have only been able to find evidence to support the role of implicit learning in individual performance differences by also measuring that relevant intermediary. Instead, Study I demonstrated that occupational Tacit Knowledge Inventories, like Situational Judgment Tests (e.g., McDaniel & Whetzel, 2005), measure knowledge that is acquired primarily as a function of practice and experience, rather than individual differences in an ability (e.g., Gottfredson, 2003a; c.f., Sternberg, et al., 2000). The inventories, again like Situational Judgment Tests, remained practically useful because they appeared to measure knowledge that predicted occupational achievement incrementally to IQ and personality. Further, occupational Tacit Knowledge Inventories demonstrated some domain generality. However, importantly, sceptics of tacit knowledge as a measure of an ability were not necessarily sceptical of the importance and generality of experience-dependent occupational knowledge (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005). The study also established a limit to the generality of tacit knowledge: the CSQ and occupational Tacit Knowledge Inventories measured different constructs. The CSQ appeared to be strongly related to IQ, and unable to predict occupational achievement once sufficient expertise and knowledge has been acquired (c.f., Cianciolo, et al., 2006).

In summary, there was no evidence of variance common to all the implicit learning tasks, nor was there any evidence to relate performance on any of the implicit learning tasks to IQ, occupational achievement, personality or tacit knowledge. I assert that an overall consideration of this study with the other relevant literature currently leads to the conclusion that, consistent with A. S. Reber's prediction, there are minimal individual differences in implicit learning. The study did replicate another finding that is important to the distinction between implicit and explicit learning: indices of explicit processing, but not performance on implicit learning tasks, were correlated with IQ. Additionally, the study provided independent, empirical investigation of issues in tacit knowledge that have been subject to fierce debate (e.g., Gottfredson, 2003a, 2003b; McDaniel & Nguyen, 2001; McDaniel & Whetzel, 2005; Sternberg, 2003). The study established that tacit knowledge was unable to provide compelling evidence of individual differences in an ability that was independent of IQ, personality *and* practice (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005; c.f., Sternberg, et al., 2000; R. K. Wagner & Sternberg, 1986). Academic Psychology and Business Management Tacit Knowledge Inventories measured knowledge that predicted occupational achievement incrementally to IQ and personality, and was general to both occupations. Critically, however, tacit knowledge appeared to be acquired primarily as a function of practice and experience, rather than individual differences in an ability (e.g., Gottfredson, 2003a; c.f., Sternberg, et al., 2000). Notably, sceptics of tacit knowledge as a measure of an ability are not necessarily sceptical of the generality, nor the prediction capabilities, of *primarily experience-dependent* occupational knowledge (e.g., Gottfredson, 2003a; McDaniel & Whetzel, 2005). Indeed, McDaniel and Whetzel (2005) happily acknowledged occupational Tacit Knowledge Inventories as a variety of Situational Judgment Test, which commonly exhibit these properties. Additionally, the study established a limit to the generality of tacit knowledge: the CSQ and occupational Tacit Knowledge Inventories measured different constructs. The CSQ was strongly related to IQ, and unable to predict occupational achievement once sufficient expertise and knowledge had been acquired (c.f., Cianciolo, et al., 2006).

Finally, the results from this study have an important implication for the direction of the functional analysis of differences in implicit learning pursued by this thesis. Specifically these results, in the context of the equivocal findings of previous studies (Gebauer & Mackintosh, 2007, 2010; Kaufman, 2009; Kaufman, et al., in press), suggest that the idea of functional individual differences in implicit learning is misplaced. There appears to be no general implicit learning ability that is critical to *how much* is learnt implicitly within a typical population. Instead, implicit learning might be better conceptualised as a description of the mode in which a variety of processes are marshalled, but how much is learnt is always dependent on differences in those processes rather than a central implicit learning capacity. There *might* be some general ability still, but its influence appears to be, at best, minimal (Gebauer & Mackintosh, 2010), and certainly not ubiquitously important to functional outcomes.

However, an alternative framework to identifying functional differences in implicit learning still exists. Even in the absence of an overarching, general ability that determines how much is learnt implicitly, there might still be prerequisite processes that are always necessary for implicit learning. Insofar that those prerequisite processes are intact, the variance in how much is learnt implicitly is still dependent on a variety of other processes, such as selective attention, working memory, motor dexterity, perceptual processing. There is not yet empirical evidence for this theoretical position but it could be tested by considering relevant atypical populations. Specifically, if an atypical population consistently demonstrated profound deficits on all implicit learning tasks and skills associated with an implicit acquisition, then a case could be made for such prerequisite processes to implicit learning. Although, investigations into several atypical populations have not provided evidence to support this theory (see review at end of Chapter I), researchers have asserted that there is a general deficit in Autism Spectrum Condition, which contributes to diagnostic social, communicative and motor impairment (e.g., L. G. Klinger, et al., 2007; Mostofsky, et al., 2000; Romero-Mungu a, 2008). While initial results appear to have supported that view (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000), there are some reasons to believe that these demonstrations do not provide definitive evidence of a general implicit learning deficit. In order to provide a comprehensive assessment of the possibility of a general implicit learning deficit in ASC, Study II examined whether ASC individuals have a deficit across a range of implicit learning tasks.

III. Implicit Learning in Autism Spectrum Conditions: Study II

1. Introduction

Autism Spectrum Conditions (ASC) are characterized by social, communicative and motor impairments (American Psychiatric Association, 1994). Implicit learning is believed to be one important mechanism for acquiring social, communicative and motor skills (e.g., Kaufman, et al., in press; McLeod & Dienes, 1993; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Perruchet, 2008; A. S. Reber, 1993), raising the possibility that social, communicative and motor impairments in ASC may arise, in part, from a general deficit in implicit learning (L. G. Klinger, et al., 2007; Mostofsky, et al., 2000; Romero-Mungu a, 2008).

Testing the hypothesis that implicit learning is impaired in ASC requires a comparison of the performance of individuals with and without ASC on a range of implicit learning tasks. Several studies have claimed to find impairments in implicit learning in ASC, on some implicit learning tasks. For example, Mostofsky and colleagues (2000) and Gordon and Stark (2007) reported that individuals with ASC performed worse than typically developing (TD) individuals on one implicit learning procedure, the SRT task. However, there is some reason to question whether the procedure used by Gordon and Stark (2007) and Mostofsky and colleagues (2000) adequately assessed implicit learning. Subsequent research has shown that procedures involving slowly repeating, 'deterministic' sequences (i.e. sequences that follow a continually repeating sequence without interruption) are more likely to encourage the development and use of *explicit* strategies to solve the task (e.g., Destrebecqz & Cleeremans, 2001, 2003; Jiménez, et al., 1996; Norman, Price, Duff, & Mentzoni, 2007; Schvaneveldt & Gomez, 1998). Since Gordon and Stark (2007) and Mostofsky and colleagues (2000) used slowly repeating deterministic sequences (the response-to-stimulus interval was 500 ms and 1500 ms respectively), it is therefore hard to disentangle to what extent the reported differences in performance between the two groups are due to differences in *implicit* or *explicit* learning.

Furthermore, neither of these studies completely matched the two participating groups for IQ. The issue of IQ is highly important: while implicit learning performance has been shown to be unrelated to IQ, explicit learning is strongly correlated (e.g., Carroll, 1993; Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991). Therefore if the task procedures encouraged explicit learning, given the ASC-group had lower IQs, the ASC-deficit would be expected and more likely attributable to explicit processes.[4] This interpretation seems particularly feasible given that when researchers (Barnes, et al., 2008) compared an ASC group with a TD group well-matched for IQ and used a more complicated sequence with shorter response-to-stimulus intervals, then the conclusion was that sequence learning is intact in ASC individuals. In this study, Barnes and colleagues (2008) also found no evidence for differences between the groups on a CC task.

There is also discrepancy between the findings of studies assessing the performance of individuals with ASC on another classic implicit learning procedure, the AGL task. While one study claimed to find ASC deficits (L. G. Klinger, et al., 2007), another found that individuals with ASC did no worse than controls on the task (reported in L. G. Klinger et al., 2007; L. G. Klinger, Lee, Bush, Klinger, & Crump, 2001, as cited in L. G. Klinger et al., 2007). It should be noted, however, that the tasks used in these studies were *adapted* versions of the classic AGL test (e.g., the tasks used shape rather than letter stimuli, and for the test phase required a two-alternative forced-choice discrimination rather than a single-stimulus classification decision) raising the possibility that the adaptations allowed the use of explicit strategies to learn the task rather than providing stringent assessments of implicit processes. This interpretation was corroborated by the finding that the performances on those adapted AGL tasks correlated with IQ (L. G. Klinger et al., 2001, as cited in L. G. Klinger et al., 2007; L. G. Klinger et al., 2007). The difference in ASC performance between the two studies may therefore have arisen from differences in how the groups used *explicit* strategies. This possibility is particularly relevant in light of the fact that the study reporting the ASC deficit used an ASC group who had lower IQs than the TD group (L. G. Klinger, et al., 2007), and therefore would have been at a disadvantage on a more explicit task. Thus, if tasks used in studies of implicit learning in ASC lend themselves to explicit, IQ-related strategies, then it will be difficult to dissociate any performance deficit due

[4] Also consistent with this interpretation, Müller, Cauich, Rubio, Mizuno, & Courchesne (2004) found differences between ASC and TD groups who were not matched for IQ on an SRT task that used slowly repeating deterministic sequences. Specifically, the authors found abnormal activity patterns in the premotor cortex in ASC. However, there was no statistical comparison of the ASC and TD performance data. It is probable that the data were not compared because such an analysis would have had very little power to detect any performance differences: there were only 48 learning trials and eight participants in each group.

to differences in a capacity to learn implicitly from differences in the IQ-mediated explicit contribution.

Attempts have also been made to assess implicit learning on category learning tasks and some studies have claimed to show a deficit (e.g., L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007). However, all such studies used a deterministic, as opposed to a probabilistic, category learning task, which would be more likely to encourage the use of explicit strategies (L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Molesworth, Bowler, & Hampton, 2005). This interpretation is corroborated by the correlation of deterministic category learning with IQ in the one study that reported this relationship (L. G. Klinger, et al., 2007). Further, although both the studies demonstrating a deficit matched the ASC and TD groups for verbal mental age, neither study matched the groups for IQ or chronological age (L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007). In another study (Molesworth, et al., 2005) that did match for chronological age, mental age and IQ, the deficit was not replicated: ASC performance was found to be intact. Thus, it is not clear that there are ASC differences in performance on non-probabilistic category learning tasks. Even if differences are established on this version of the task, it seems likely that they could be due to differences in cognitive processes other than implicit learning.

This review suggests that although there may be a deficit in implicit learning in ASC, it is possible that performance deficits observed so far may arise as a consequence of the recruitment of other, particularly explicit, cognitive processes. This is especially important given that the studies reporting an ASC-deficit did not stringently match ASC and control groups for IQ, and explicit, in contrast to implicit, processes correlate strongly with IQ. Furthermore, it is known that the use of explicit strategies usually changes performance on implicit learning procedures (e.g., Gebauer & Mackintosh, 2007) and that differences between diagnostic groups on an ostensibly implicit task can be attributable to differences in the explicit rather than the implicit component of the task (Koenig, et al., 2008). Therefore, in order to identify more clearly whether the reviewed ASC differences relied on implicit or explicit learning processes, implicit learning procedures are needed that have not been specifically adapted for use with ASC children, and thus better avoid the use of explicit strategies. On such procedures, it is well established that the underlying complexity of the information to be learned makes it much more difficult for explicit strategies to emerge. Study II used four such unadapted procedures (AGL, SRT, CC, and PCL).[5]

The reason for using four, rather than just a single test as in many of the studies above, is that implicit learning tasks necessitate psychological processes in addition to learning, such as encoding and selective attention, and furthermore different implicit learning tasks make different demands of such processes (e.g., Seger, 1994; Squire, Knowlton, & Musen, 1993). Therefore, in order to control for variations in task demands and to allow conclusions about implicit learning in general, it is critical to compare the performance of the same individuals on a range of implicit learning procedures. To illustrate the point, there have been several disorders in which impairment has been reported on one implicit learning task, but has not been replicated on another, including dyslexia (e.g., Folia, et al., 2008); Huntington's disease (e.g., Knowlton, Squire, et al., 1996); Parkinson's disease (e.g., Knowlton, Mangels, et al., 1996; cf, P. J. Reber & Squire, 1999); and schizophrenia (Horan, et al., 2008; cf, Keri, et al., 2000).

The two groups were also assessed on an explicit learning task, Paired-Associates Learning (PAL). It has been argued above that explicit learning was unintentionally measured in several previous attempts to assess implicit learning, and as a consequence of using groups that were unmatched for IQ it was the explicit processes that were responsible for an ASC performance deficit. The validity of this explanation can be explored by including an overtly explicit task, and then comparing the relative patterns of implicit and explicit learning performance in both matched and unmatched groups. Further, the inclusion of the PAL allowed the assessment of another feature in the theory of implicit learning deficits in ASC. Specifically, L. G. Klinger and colleagues (2007) have argued that children with ASC actually use explicit processes to compensate for deficits in implicit learning. Clearly this idea is predicated upon the relative preservation of the explicit over implicit learning, and is thereby tested through a comparison of the relative performances on implicit and explicit learning tasks. L. G. Klinger and colleagues (2007) have ostensibly made such a comparison. However, their measures of

[5] A fifth task was also used – the IFL task. The specific procedure of this IFL task was the same as reported in Study I. However, the task appeared to be inappropriate for children - there was no evidence of learning. Consequently, the task was unable to address the question of whether there were implicit learning differences between ASC and TD children. Thus, for the sake of clarity, the task is not discussed further in this chapter (see Appendix B for the analysis of IFL task performance, which produced no evidence of learning).

explicit learning were actually IQ tests, which did not involve any learning during the course of their experiment.

As discussed, the current literature on implicit learning in ASC highlights different findings between studies. Given this conflict, and in the context of preserved and enhanced abilities in ASC (Mottron, Dawson, Soulières, Hubert, & Burack, 2006), it is also necessary that analyses should properly consider the possibility that implicit learning is preserved in ASC. To this end, Study II employed equivalence analysis (Rogers, Howard, & Vessey, 1993; Stegner, Bostrom, & Greenfield, 1996) to consider all learning data, and consequently does not rely on a failure to reject a null hypothesis as a reason to suppose that performance is preserved in ASC.

Finally, in order to conclude that implicit learning deficit plays a direct role in the social, language and motor deficits common to ASC, it would be necessary *but not sufficient* to demonstrate performance deficits on a variety of implicit learning tasks. Additionally, performance on implicit learning tasks would have to be related to an index of such diagnostic deficits (L. G. Klinger, et al., 2007). Therefore, in Study II the parents of participants were asked to complete the Social Communication Questionnaire (SCQ: Rutter, Bailey, Lord, & Berument, 2003). The SCQ provided a reliable index of autistic symptomatology, which was related to implicit learning performance.

The primary aim was to test the hypothesis that individuals with ASC would show performance deficits on a range of implicit learning tasks, which could not be attributed to other factors such as explicit strategies or task demands. In brief, the study found no support for this hypothesis; instead there was evidence of equivalence (Rogers, et al., 1993; Stegner, et al., 1996) between individuals with and without ASC on implicit learning procedures. This was not a consequence of compensation by explicit learning ability or IQ. Furthermore, there was no evidence to relate implicit learning to an index of ASC symptomatology.

2. Method

2.1. Participants

31 children with ASC (referred to as the ASC group) and 31 Typically-Developing children (referred to as the TD group) were included in the study. All children in the ASC group met established criteria for ASC, such as those specified in DSM-IV (American Psychiatric

Association, 1994) and had previously received a diagnosis for ASC by trained clinicians using instruments such as the Autism Diagnostic Interview (Le Couteur, Lord, & Rutter, 2003). Any other psychiatric diagnosis acted as an exclusion criterion for both the ASC and TD group. The two groups of children were matched for sex (3 females) and chronological age ($t(55) = .28$, $p = .78$, $d = 0.07$) but differed on Verbal IQ ($t(50) = 1.83$, $p = .07$, $d = 0.47$), Performance IQ ($t(52) = 1.83$, $p = .07$, $d = 0.47$) and Full Scale IQ ($t(49) = 2.04$, $p = .05$, $d = 0.52$) of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999), see Table 12. A subgroup from each group of children was selected who were matched for IQ. The sub groups comprised 26 children with ASC and 26 children with TD. These children were matched for sex (2 females), chronological age ($t(50) = .88$, $p = .39$, $d = 0.24$), Verbal IQ ($t(50) = .61$, $p = .55$, $d = 0.17$), Performance IQ ($t(45) = .51$, $p = .61$, $d = 0.14$) and Full Scale IQ ($t(44) = .71$, $p = .48$, $d = 0.20$) of the WASI, and all had IQs within the typical range (the lowest score was 83), see Table 12. The main analyses were conducted on the data from these subgroups. However, a final analysis was conducted using the entire sample, in order to examine the role of IQ in explicit and implicit learning. Table 12 presents the participant characteristics for both the entire groups and the subgroups matched for IQ.

Informed parental consent and the assent of the children were obtained, and ethical permission to conduct the study received from the Cambridge Psychology Research Ethics Committee. 18 of the parents of children with ASC (15 of the ASC-subgroup) and 23 of the parents of TD children (19 of the TD-subgroup) completed the SCQ (Rutter, et al., 2003). The SCQ is a screening tool for autism, which comprises 40 items derived from the ADI-R. The raw scores on the SCQ were converted into percentage scores. All the children in the TD group had scores below the cut-off score of 38.46 % specified by Rutter and colleagues ($M = 10.43$ %, $SD = 7.14$ %, range = 2.56 – 33.33 %; for the TD-subgroup $M = 10.87$ %, $SD = 7.71$ %, range = 2.56 – 33.33 %). Further, the highest score for the TD group was 5.49 standard deviations (5.11 standard deviations for the subgroup) below the mean of the ASC group ($M = 72.59$ %, $SD = 15.82$ %, range = 30.77 % – 92.31 %; for the ASC-subgroup $M = 72.75$ %, $SD = 17.24$ %, range = 30.77 % – 92.31 %).

Table 12. *Mean Age (in years) and WASI IQ Scores for the ASC and TD Groups*

Measure	Entire sample					
	TD *(N = 31)*			ASC *(N = 31)*		
	M	*SD*	*R*	*M*	*SD*	*R*
Chronological age	11.7	1.5	8.9 – 14.3	11.6	1.1	8.7 – 14.4
Verbal IQ	106.9	11.6	81 – 127	99.7	18.5	65 – 147
Performance IQ	107.0	12.3	81 – 135	99.5	18.9	62 – 136
Full-scale IQ	107.8	11.5	88 – 135	99.6	19.2	66 – 147
	IQ-matched sub-groups					
	TD *(N = 26)*			ASC *(N =26)*		
	M	*SD*	*R*	*M*	*SD*	*R*
Chronological age	11.8	1.6	8.9 – 14.3	11.5	1.2	8.7 – 14.4
Verbal IQ	104.3	10.5	81 – 122	102.2	13.5	76 – 122
Performance IQ	104.1	10.9	81 – 127	102.2	15.7	74 – 132
Full-scale IQ	104.7	9.4	88 – 122	102.4	14.1	83 – 126

2.2. Apparatus

A fourteen-inch LCD notebook computer was used for all computerised testing. For the SRT and CC tasks, timing accuracy was of the utmost importance, therefore these tasks were presented using DMDX software and participants recorded their responses using a four-button PIO12 response box (Forster & Forster, 2003). Other tasks were presented using: SuperLab Pro for the AGL Task; RealBasic for the PCL; and Inquisit for the PAL. For all these tasks, responses were recorded using the notebook's keyboard.

2.3. Tasks and Procedure

2.3.1. Implicit Learning Tasks

Contextual Cueing (CC) task

A continuous version of the CC task was used, in which successive trials followed each other with minimal delay (50 ms) and were not preceded by a fixation point. Jiménez and

Vázquez (in press) have shown that this procedure results in levels of learning similar to the usual discrete version developed by Chun and Jiang (1998). In addition, Jiménez and Vázquez's (in press) procedure was followed by using four different responses instead of the usual two-alternative task. This procedure was chosen to make the motor requirements of this task more comparable to those required by the SRT task (see below). Therefore, should specific deficits have emerged, those deficits could have been more confidently attributed to differences in learning rather than motor capabilities.

Instead of using rotated *T*s and *L*s for target and distractor stimuli respectively, the participants were required to detect and identify as quickly and accurately as possible an even number presented among distractors, which were odd numbers. The target numbers (2, 4, 6 or 8) were presented among seven distractor stimuli of the same numerical identity (1's, 3's, 5's or 7's). Participants responded by pressing buttons corresponding to the target's numerical identity (2, 4, 6 or 8) on a four-button response box. Jiménez and Vázquez (2009) have also shown that learning is unaffected by replacing letter-stimuli with number-stimuli.

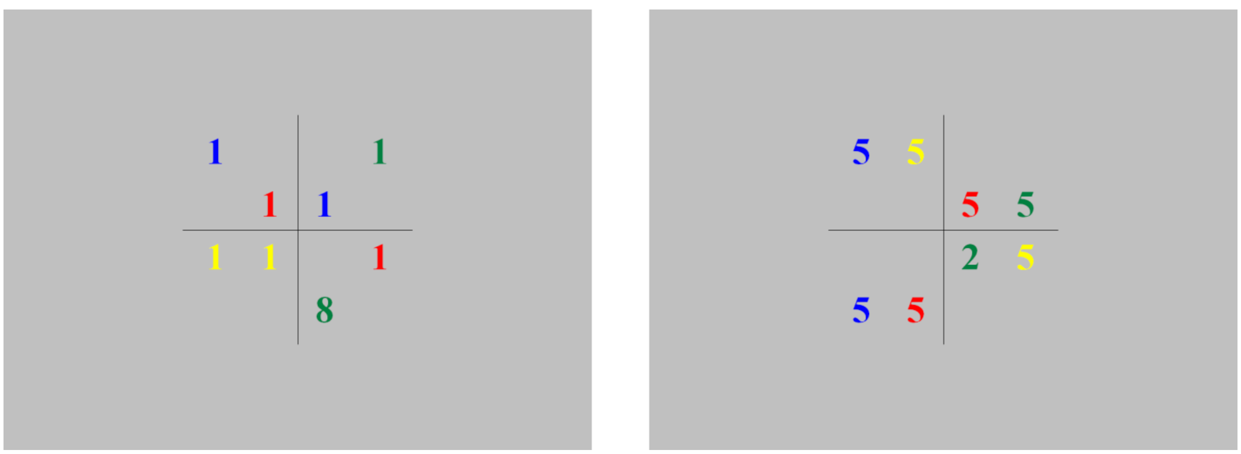


Figure 3. *Examples of the stimuli presented to participants in the CC task. On the left, the target is 8 and the distractors are 1s; on the right, the target is 2 and the distractors are 5s.*

As depicted in Figure 3, on each trial there were two stimuli of each colour, with stimuli evenly distributed over the four quadrants of the display and filling 8 of 16 possible stimuli locations from a 4 x 4 invisible matrix. Within a trial, all the distractors had the same numerical identity, however, the precise combination of location, identity and colour of distractors created a context for the location of a target on each trial. 40 such combinations were generated and each context was always associated with the same target location but a changing target identity. 8

high-frequency contexts were repeated frequently (24 times within each session) and 32 low-frequency contexts were repeated infrequently (on average 6 times per session). Each high-frequency context was associated with a unique target location, while sets of 4 low-frequency contexts were each associated with a different one of the remaining 8 possible target locations. Of the sets of 4 low-frequency contexts associated with a given target location, each context was characterized by a different distractor identity, as well as by a different distribution of locations and colours. Similarly, of the 8 high-frequency contexts, two contexts contained 1's, two contained 3's, two contained 5's and two contained 7's and were each characterised by a different distribution of distractor locations and colours. Thus, all target locations were equally cued, and all distractor identities, colours and locations were equally present. However, the precise combination of distractor location, identity and colour in the high frequency contexts provided greater opportunity than the combinations in the low frequency contexts for participants to be cued to the location of the target in order for the participant to determine its numerical identity.

Each experimental block consisted of 48 trials. Half of all trials within a block contained high-frequency contexts and the remaining half low frequency contexts. These different trial-types (high frequency and low frequency contexts) were randomly intermixed for every experimental block (1-8). The session began with a short practice block, consisting of 8 low-frequency context trials, after which it was ensured that the participant had understood the demands of the task. Between each block, the experimenter provided the participant with feedback about their accuracy and reaction times (RTs). Feedback was provided following any trial on which a participant made an error, by presenting the word *"Error"* at the top of the screen for 150 ms before the next trial was presented. At the start of each session, the solid lines creating the quadrant (see Figure 3) were presented and remained on the screen for the entire block. Each trial begun with the presentation of distractors and target and was terminated following a response. Trials were separated from one another by a 50 ms response-to-stimulus interval, intended to minimise the development of explicit strategies. Learning was measured by comparing each participant's RT in response to the high-frequency trials and the low-frequency trials.

Serial Reaction Time (SRT) task

The same SRT task was used as detailed in Chapter II.2.3.2. The one difference between the two tasks was that in this study participants pressed buttons on a four-button response box rather than a keyboard.

Artificial Grammar Learning (AGL) task

The same AGL task was used as detailed in Chapter II.2.3.2.

Probabilistic Classification Learning (PCL) task

A version of the PCL task developed by Aczél (2006) and Shohamy and colleagues (2004) was used. During a learning phase, participants were told that they would be selling ice cream in an ice cream shop and that 'customers' would come in to buy vanilla or chocolate ice cream cones (see Figure 4). Each time a customer would visit, they would have to try to guess whether the customer would like vanilla or chocolate. After each guess of vanilla or chocolate, participants received feedback on which flavour the customers would have preferred (outcome); the word *"correct"* in white or *"wrong"* in red were displayed at the bottom of the screen for 600 ms, followed by a blank screen for 100 ms. The customers (stimuli) were displayed for 500 ms before participants could respond; participants responded by pressing the 'Z' key to guess chocolate and the '.' key to guess vanilla. Participants were prompted to *"please respond now"* after 1500 ms and the trial timed out with the message *"no response"* after 5000 ms. When participants responded correctly, a coin was added to their 'tip jar' in the ice cream shop.

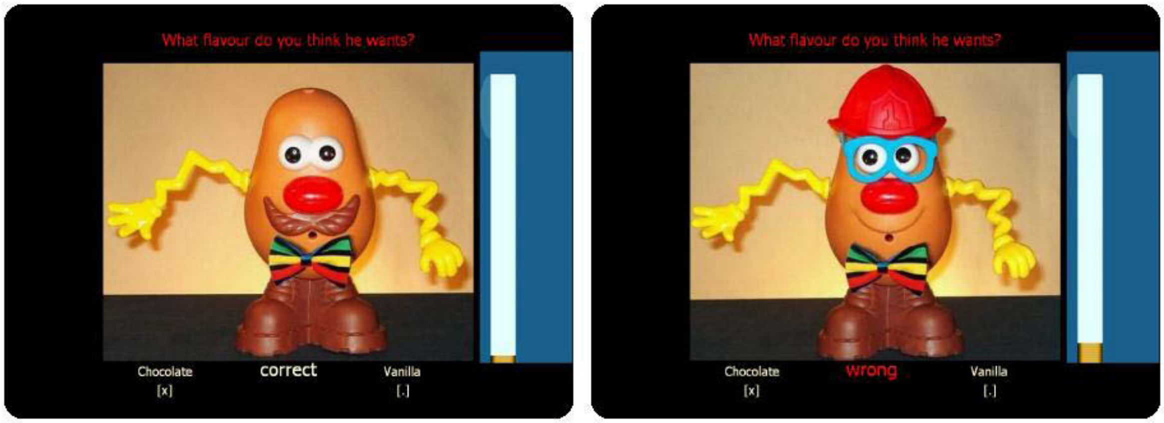


Figure 4. *Illustration of PCL task. Presented above are computer screengrabs from the moment after a participant had made their guess during the learning phase, either correctly (as depicted in the left screengrab) or incorrectly (as depicted in the right screengrab). The screengrabs show two different examples of stimuli (the stimulus on the left has Cue 1 and Cue 4 present, the stimulus on the right has Cue 2, Cue 3 and Cue 4 present – see* Table 13*).*

'MrPotatoHead' toy photographs (see Figure 4) were used as the stimuli that appeared on each trial. 14 different stimuli were created by changing the presence or absence of four discrete cues on the basic MrPotatoHead figure (e.g., moustache or glasses). The combination of cues used was identical to those used by Shohamy and colleagues (2004), and is shown in Table 13.

Table 13. *The Stimuli and Probability Structure of the PCL Task*

Stimulus	Cue 1	Cue 2	Cue 3	Cue 4	*P* (stimulus)	*P* (vanilla|stimulus)
A	0	0	0	1	.136	.143
B	0	0	1	0	.079	.375
C	0	0	1	1	.089	.111
D	0	1	0	0	.079	.625
E	0	1	0	1	.061	.167
F	0	1	1	0	.061	.667
G	0	1	1	1	.042	.250
H	1	0	0	0	.136	.857
I	1	0	0	1	.061	.333
J	1	0	1	0	.061	.833
K	1	0	1	1	.033	.333
L	1	1	0	0	.089	.889
M	1	1	0	1	.033	.667
N	1	1	1	0	.042	.750

Note*: Cue 1 = brown moustache, cue 2 = red hat, cue 3 = blue glasses, cue 4 = bow tie. Each cue could be present (1) or absent (0) for each stimulus. The all-present (1111) and all-absent (0000) stimuli were never used. On any trial during the learning phase, there was a given probability of each of the 14 stimuli appearing (P(stimulus)), and a dynamic stimulus-outcome probability for each of these 14 stimuli. During the test phase, when feedback is removed, the stimulus-outcome probability is static (P(vanilla|stimulus)). All stimuli appeared equally often during the test phase. The overall probability of the vanilla outcome across all stimuli is 50 %.*

Using the 14 stimuli, 214 trials were constructed for the learning phase. As a consequence of the feedback, each stimulus became probabilistically associated with an outcome. Across the entire learning phase the two outcomes (preference for vanilla or chocolate) were equally probable across all stimuli. Once participants completed the learning phase, they undertook the test phase, which was identical to the learning phase with the exception that feedback was no longer provided. With the removal of feedback about the outcome, participants were required to rely on the probabilities between the stimuli and outcomes (stimulus-outcome probabilities) that they had experienced during the learning phase. The stimulus-outcome probabilities between the stimuli varied from near chance (62.5 %) to almost certain (88.9 %), as detailed in Table 13. The test phase consisted of 70 trials with each of the 14 stimuli being shown 5 times. Trials presenting the 14 different stimuli were randomly intermixed during both learning and test phases. Both the percentage of correct guesses, according to which outcome was more likely (above 50 %), and the extent to which this percentage correct matched with the stimulus-outcome probabilities were taken as indices of learning.

2.3.2. *The Explicit Task*

Paired-Associates Learning (PAL) task

Participants were instructed that they should try to learn a series of 3-letter word-pairs (e.g., bun-cab). During this learning phase, they were shown the first word of a pair for 2500 ms and then the second word such that both words were on screen for a further 2500 ms. Participants were shown a total of 15 word pairs in this way, with a response-to-stimulus interval of 200 ms. In the following test phase, participants were sequentially presented with the first word from each of the pairs and were instructed to provide the word with which it was paired, or to skip the trial if they had not learnt the pair. If the response was correct, the message ‘Correct!’ immediately appeared on the screen and remained together with the correct word pair for 2500 ms. An incorrect response yielded the message ‘Wrong!’ with the simultaneous replacement of the incorrect word with the correct answer, and together the message and pair remained for 2500 ms. This whole process was repeated 4 times. Pairs appeared in the same order between equivalent learning and testing blocks, but pair order was randomised across blocks (e.g., pair order was the same for learning 1 and testing 1 but different between learning and testing 1 and learning and testing 2). Learning is indexed by the number of pairs correctly reproduced in each test phase (B. J. Underwood, Boruch, & Malmi, 1978). All words were one-syllable, three-lettered, not infrequent (Thorndike & Lorge, 1944), and regularly spelt, concrete nouns. All words had an age-of-acquisition of less than 7 years according to either Morrison and colleagues’ (1997) norms or acquired teacher-ratings (which correlated well with Morrison and colleagues’ (1997) limited norms, $r = .82$, $p = .01$, $r^2 = .67$).

2.3.3. *General procedure*

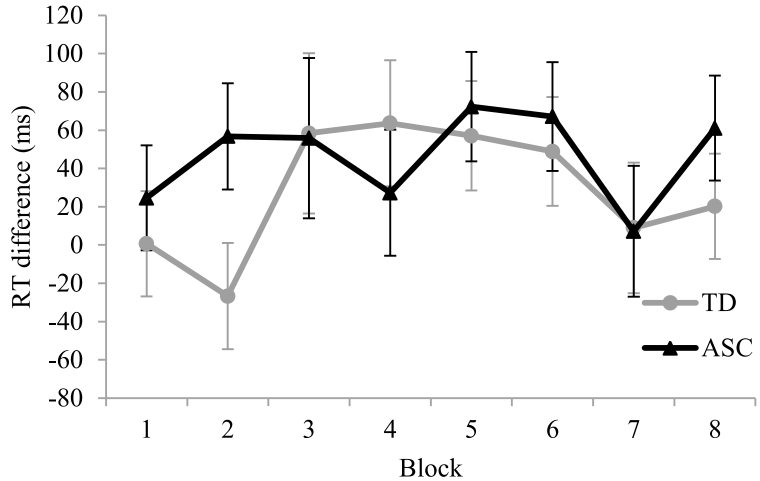
All testing was conducted at the participants’ schools and participants were tested individually in quiet, unused classrooms. Each session lasted approximately 50 minutes with participants taking as many sessions as necessary to complete the tasks, with the constraint that no session would break-up a task. Most participants completed the tests within 3 or 4 sessions, and a minority (2 children) completed testing within 5 sessions. For all the computerised tasks, participants were seated approximately 50 cm away from the laptop. Prior to each task, they were provided with written and oral instructions. The WASI was administered according to the standardised testing procedure. Task and trial order were fixed across participants because the between-group comparison was most important and such fixing minimises the relevant noise and facilitates the most accurate comparison. Further, the order in which the tasks were completed was carefully selected in order to minimise the possibility of priming participants into an explicit mind-set, as it has been demonstrated that explicit instructions increase the contribution of explicit processes on implicit procedures (e.g., Gebauer & Mackintosh, 2007). Therefore, participants completed the tasks in the following order: PCL, CC, AGL, SRT, WASI IQ Test, PAL, and Explicit Interview. The Explicit Interview consisted of a post-task questionnaire about the incidental structures in each of the implicit learning tasks.

3. Results

For all analyses, the alpha level was set at .05, two-tailed and extreme outliers (values either less than three times the interquartile range below the lower quartile, or greater than three times the interquartile range above the upper quartile) were excluded. Where relevant, the appropriate epsilon correction was used when sphericity was violated. Šidák corrections were used to control for familywise error rates during multiple comparisons (Cardinal & Aitken, 2006, pp. 87-90). Where significant interactions were found in mixed analyses of variance, separate ANOVAs on the levels of interest were conducted to establish simple effects. When conducting independent sample *t*-tests, equal sample variances were assumed unless Levene's test for the equality of variances was significant. Cohen's d is reported as a measure of effect size except where relative measures of effect size are more appropriate, and then partial eta-squared (η^2_p) is reported. In all reported equivalence analyses (Rogers, et al., 1993; Stegner, et al., 1996), random within-subject variability in the TD group was used to determine the between-group equivalence threshold.

3.1. CC and SRT Analysis

In the RT analyses for both SRT and CC, RTs on error trials were discarded. First trial data were excluded for the SRT, since meaningful assessment can only occur when the stimuli have been presented sequentially. Figure 5 represents the mean RT (ms) difference between trial-types across blocks on CC (top panel) and SRT (bottom panel). A difference score greater than zero indicates that participants responded faster to the high-frequency contexts in CC and the probable trials in SRT. Clearly, there is evidence of learning: difference scores were above zero and, on average, difference scores after the first block tended to be greater than those on the first block. Mixed analyses of variance conducted on mean RTs supported this interpretation, each had one between-subject factor of Group (ASC vs. TD), and two within-subjects factors, Trial-Type (High-frequency vs. Low-frequency in CC and Probable vs. Improbable in SRT) and Block (1-8 in CC and 1-9 in SRT). In both analyses, there was a main effect of Trial-Type (CC: $F(1, 50) = 27.74$, $p < .001$, $\eta^2_p = .36$; SRT: $F(1, 50) = 57.25$, $p < .001$, $\eta^2_p = .53$), Block (CC: $F(4, 219) = 18.24$, $p < .001$, $\eta^2_p = .27$; SRT: $F(4, 211) = 18.04$, $p < .001$, $\eta^2_p = .27$), and an interaction between Trial-Type x Block (CC: $F(7, 328) = 2.30$, $p = .03$, $\eta^2_p = .04$; SRT: $F(7, 350) = 11.32$, $p < .001$, $\eta^2_p = .19$).



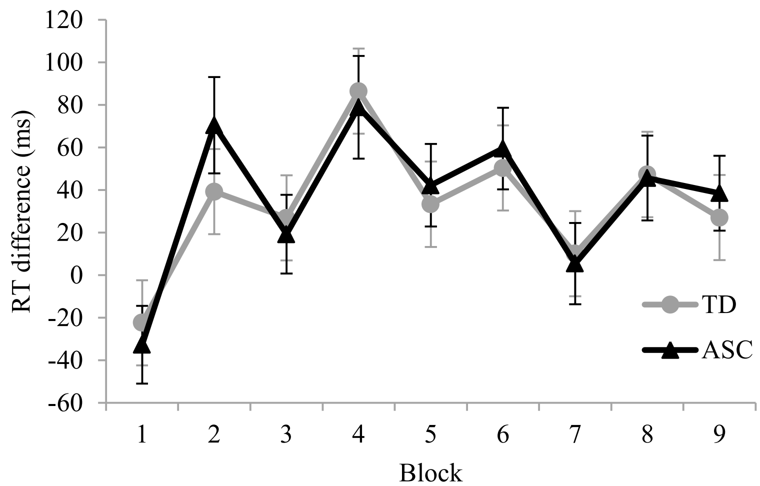


Figure 5. *TD and ASC groups displayed similar learning on the CC and SRT tasks. Depicted are the mean RT differences between high and low-frequency contexts on the CC (top panel) and probable and improbable trials on the SRT (bottom panel) across training for different groups. The error bars show twice the standard error of differences between group means at different levels of block.*

Figure 5 demonstrates that the RT difference scores for both tasks were very closely matched between the groups. Indeed, there was no evidence of group differences in learning in either analysis: on both tasks there was no Group x Trial-Type interaction (CC: $F(1, 50) = 1.52$, $p = .22$, $\eta^2_p = .03$; SRT: $F(1, 50) = 0.12$, $p = .73$, $\eta^2_p < .01$), or between Group x Trial-Type x Block (CC: $F(7, 328) = 1.37$, $p = .25$, $\eta^2_p = .03$; SRT: $F(6, 298) = .50$, $p = .80$, $\eta^2_p = .01$). This was in spite of an actual power always more than .97 to detect even a medium effect (Cohen's F

= .25) on these relevant Group interactions for both SRT and CC (calculated using G*Power, Faul, Erdfelder, Lang, & Buchner, 2007). However, regardless of this sizeable power, in order that the study did not rely on a failure to reject a null hypothesis as a reason to suppose that performance is preserved in ASC, equivalence analyses were employed to determine the equivalence of the learning (e.g., Rogers, et al., 1993). Equivalence analyses were performed on average proportional increase in RT differences across blocks for both tests; this learning index was used because the analysis necessitates an overall score. The analyses rejected the hypotheses of non-equivalence for both tests (CC: $t(50) = 4.47$, $p < .001$; SRT: $t(50) = 4.44$, $p < .001$; see Appendix B for more details of these equivalence analyses) and allowed the conclusion that the groups are statistically equivalent in their overall learning on each task.

On the CC, there was a main effect of Group ($F(1, 50) = 8.03$, $p = .01$, $\eta^2_p = .14$) with mean RTs slower in the ASC group, and no evidence of a Block x Group interaction ($F(4, 219) = 0.97$, $p = .43$, $\eta^2_p = .02$). Given that CC learning was equivalent between the groups, this main effect reflected an ASC difference in baseline speed. On the SRT, the effect of Group was not significant ($F(1, 50) = 3.13$, $p = .08$, $\eta^2_p = .06$) but there was an interaction between Group x Block ($F(4, 211) = 4.15$, $p < .01$, $\eta^2_p = .08$). Given that SRT learning was equivalent between the groups, this interaction reflected a differential effect of general practice on baseline speed. Inspection of the RTs averaged across Trial-Type implied that the ASC group took longer to benefit from practice on the SRT: during the initial blocks the ASC group had slower baseline speeds than the TD group but during the later blocks, once there had been sufficient opportunity for practice, the groups responded equally quickly. Consistent with this interpretation, there was a significant linear contrast for the differences between groups to become smaller as blocks progressed ($F(1, 50) = 6.34$, $p = .02$, $\eta^2_p = .11$).

The slowness in the baseline speed of the ASC group, throughout the CC and early in the SRT, is reflective of typical motor difficulties (e.g., G. Allen, Müller, & Courchesne, 2004; Dowell, Mahone, & Mostofsky, 2009). To examine whether such differences in baseline speed mask differences in learning, two transformations are possible: Barnes and colleagues (2008) have suggested transforming the dependent variable into a measure that expresses learning as a proportion of baseline speed (the difference in speed between trial-types/mean speed on low-frequency or improbable trials); Jiménez and Vázquez (2008) have proposed a Z-score transformation as a means of better analysing group differences in learning on implicit RT tasks.

Analyses of both transformations provided exactly the same pattern of results, thereby reinforcing the conclusion that the groups were equivalent in their amount of overall learning on both the SRT and CC.

There was a small percentage of errors on the SRT, and these errors were similar between the groups (TD: M = 8.42 %; ASC: M = 9.12 %; Standard Error of Difference (*SED*) = 1.03; $t(50) = 0.67$, $p = .50$, $d = 0.17$). Song, Howard and Howard (2007) have shown that errors on the SRT also index learning; fewer errors on the probable compared to the improbable trials indicate participants must have learnt about the sequence. Thus, a mixed ANOVA was conducted on the SRT error data, using the same factors as the RT analysis. These were entirely consistent with the RT analyses presented above: errors were greater on improbable trials and this difference tended to increase across blocks (Trial-Type (F(1, 50 = 27.67, $p < .001$, $\eta^2_p = .36$; Block $F(7, 369) = 3.77$, $p < .001$, $\eta^2_p = .07$; Trial-Type x Block ($F(8, 400) = 4.16$, $p < .001$, $\eta^2_p = .08$), while there was no evidence of any differences between the groups (Group x Trial-Type ($F(1, 50) < 0.01$, $p = .96$, $\eta^2_p < .01$; Group x Block Group x Block: $F(7, 369) = 0.52$, $p = .83$, $\eta^2_p = .01$; Group x Trial-Type x Block ($F(8, 400) = .63$, $p = .75$, $\eta^2_p = .01$.). An inspection of the data, together with a simple effects analysis of the Trial-Type x Block interaction, investigating the effect of block at each of the two levels of Trial-Type, revealed that the learning (i.e., increase in the difference between trial-types across block) was reflected by participants making more mistakes on improbable trials ($F(8, 400) = 4.52$, $p < .001$, $\eta^2_p = .08$) rather than fewer mistakes on probable trials ($F(6, 278) = 1.32$, $p = .25$, $\eta^2_p = .03$). A failure to detect increased accuracy on probable trials, in spite of SRT learning and general practice, is common on SRT tasks (Song, et al., 2007) and can be attributed to a ceiling effect: accuracy is high from the beginning of the task. In the context of this ceiling effect and the resulting insensitivity, it was unsurprising that there was no evidence from this analysis of errors to support the finding from the RT analysis that the ASC group benefitted from general practice more than the TD group.

There was also a small percentage of errors on the CC with the ASC group making significantly fewer errors than the TD group (TD: M = 6.93 %; ASC: M = 2.95 %; *SED* = 0.94 %; $U = 134.00$, $p < .001$, $d = 1.18$). However, the difference in errors between trial-types has been found not to index learning on the CC task (e.g., Chun & Jiang, 1998; Chun & Jiang, 2003). This finding was replicated (Mean difference between trial-type = -0.13 %, SED = 0.28 %, $t(51) = 0.47$, $p = .64$, $d = 0.06$), and there was also no evidence of a group difference in this tendency

(TD: *M* = 0.08 %; ASC: *M* = 0.18 %; *SED* = 0.56 %; *t*(50) = 0.18, *p* = .86, *d* = 0.05). Therefore, the superior overall accuracy of the ASC group provided no evidence of differences in learning, and was instead probably a reflection of the finding that ASC individuals sometimes display Enhanced Perceptual Functioning (Mottron, et al., 2006).

3.2. AGL and PCL Analysis

In both AGL and PCL, the dependent variable was the percentage of correct answers given above the 50 % chance level during their respective test phases. For the AGL, an answer that accurately classified a string ('Yes' to grammatical strings and 'No' to ungrammatical strings) was deemed correct. For the PCL, a guess that corresponded with the more likely outcome for that stimulus was judged correct. One-sample *t*-tests demonstrated the basic learning effect in both the PCL (*M* = 6.84 %, *SEM* = 1.36 %, *t*(51) = 5.05, *p* < .001, *d* = 0.70) and AGL (*M* = 3.28 %, *SEM* = 1.12 %, *t*(51) = 2.93, *p* = .01, *d* = 0.41). Independent sample *t*-tests on the group means provided no evidence of a difference between the groups for both the PCL (TD: *M* = 4.95 %; ASC: *M* = 8.74 %; *SED* = 2.68 %; *t*(41) = 1.41, *p* = .17, *d* = 0.39) and the AGL (TD: *M* = 3.35 %; ASC: *M* = 3.20 %; *SED* = 2.26 %; *t*(50) = 0.07, *p* = .94, *d* = 0.02). Furthermore, subsequent equivalence analyses (e.g., Rogers, et al., 1993) rejected the hypotheses of non-equivalence (PCL: *t*(50) = 3.37, *p* < .01; AGL: *t*(50) = 4.49, *p* < .001; see Appendix B for more details of these equivalence analyses) and allowed the conclusion that the groups were statistically equivalent in their overall learning on each task.

To consider the PCL performance in greater detail, percentage correct above chance was considered at different levels of stimulus-outcome probability. Figure 6 demonstrates that percentage correct increased with the stimulus-outcome probability, and that the two groups' performance was closely matched. A mixed analysis of variance was conducted, with one between-subject factor of Group (ASC and TD) and one within-subject factor of Stimulus-Outcome Probability (probabilities of .63, .67, .75, .83, .86 & .89). A main effect of Stimulus-Outcome Probability (*F*(4, 185) = 3.72, *p* = .01, η^2_p = .07) together with a significant linear contrast for percentage correct to increase with probability (*F*(1, 50) = 10.35, *p* < .01, η^2_p = .17) established that participants learnt more about more likely outcomes, while there was no evidence of group differences (Group: *F*(1, 50) = 1.09, *p* = .30, η^2_p = .02; Group x Stimulus-Outcome Probability: *F*(4, 185) = 0.77, *p* = .54, η^2_p = .02). The performance of participants during the learning phase of the PCL was also considered, in order to investigate the development of the learning. Feedback was still provided during the learning phase, so stimulus-outcome probability was not fixed and is not considered in this part of the analysis. However, for every trial included in this analysis, a stimulus was always more strongly associated with one outcome than the other, and therefore an assessment of performance during the learning phase is still meaningful. For this purpose, the learning phase was split into 4 blocks (excluding the first presentation of stimuli and any trial on which stimulus-outcome probability was 50 %): trials 1-48, 49-96, 97-145, and 146-194. A mixed analysis of variance was conducted on the percentage correct above chance during the PCL learning phase, with one between-subject factor of Group (ASC and TD) and one within-subject factor of Block (Block 1-4). A main effect of Block ($F(3, 150) = 2.76$, $p = .04$, $\eta^2_p = .05$), together with a linear trend for performance to increase, showed that learning emerged across training. Again there was no evidence of any differences between the groups (Group: $F(1, 50) = 0.76$, $p = .39$, $\eta^2_p = .02$; Group x Block: $F(3, 150) = 0.02$, $p > .99$, $\eta^2_p < .01$). Additionally, a strategy analysis (e.g., Gluck, et al., 2002) was performed on this data, and demonstrated that the equivalent overall performance was also underpinned by a similarity in the implicit learning 'strategies' used by the groups (see Appendix B for details of this strategy analysis).

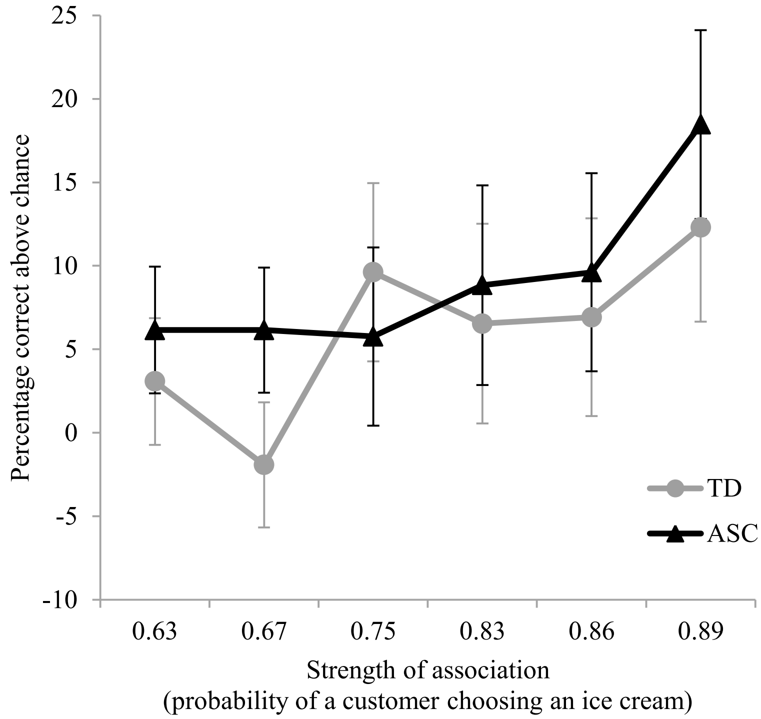


Figure 6. *TD and ASC groups showed similar learning about more likely outcomes on the PCL task. Presented are mean percentage of correct guesses that were provided above chance by participants on the PCL test phase. This score is presented for the two groups at the different levels of stimulus-outcome probability. The error bars show twice the standard error of differences between group means at different levels of stimulus-outcome probability.*

3.3. PAL Analysis

The dependent variable was the percentage of correct responses given during the test blocks. The provision of a word pair that corresponded with its cue constituted a correct response. Each test block was preceded by a learning block. Therefore, the increase in performance across test blocks represented an improvement in performance due to learning, see Figure 7. A mixed analysis of variance, with one between-subject factor of Group (ASC vs. TD) and one within-subject factor of Block (4 levels) supported this interpretation: a main effect of Block ($F(2, 102) = 80.73$, $p < .001$, $\eta^2_p = .62$), together with a significant linear contrast with performance increasing across blocks ($F(1, 50) = 133.90$, $p < .001$, $\eta^2_p = .73$), established that learning had occurred. While the TD group numerically outperformed the ASC group on every test block, see Figure 7, there was no evidence for an effect of Group, ($F(1, 50) = 1.30$, $p = .26$, $\eta^2_p = .03$) nor for an interaction of Group x Block ($F(2, 102) = .62$, $p = .54$, $\eta^2_p = .01$). However, subsequent equivalence analysis on overall test performance revealed there was also no evidence of equivalence ($t(50) = 0.76$, $p = .22$; see Appendix B for more details of this equivalence analysis).

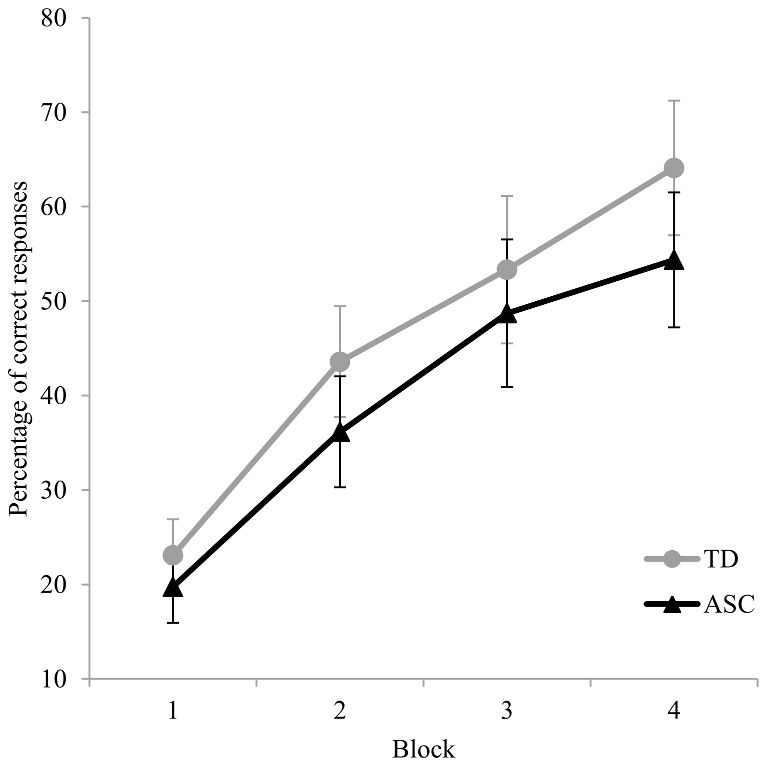


Figure 7. *The TD group displayed a numerically, but not statistically, superior performance to the ASC group on the PAL task. Depicted are mean percentage of correct responses that participants from different groups provided on test blocks in the PAL task. The error bars show twice the standard error of differences between group means at different levels of block.*

To address the ambiguity presented by finding no evidence of either difference or equivalence in the analyses of the PAL, the possible role of IQ in the current implicit and explicit learning tests was considered. Specifically, a series of further analyses were conducted on all the tests but this time including an additional 5 children per group. While the addition of these extra children resulted in the same mean age and sex between groups, the groups were no longer matched on IQ (see 'Entire Sample' in Table 12 for participant characteristics). The analysis of the PAL data revealed that the ASC group performed worse than the TD group (TD: $M = 50.70$ %; ASC: $M = 39.41$ %; $SED = 5.39$ %; main effect of Group, $F(1, 60) = 4.39$, $p = .04$, $\eta^2_p = .07$), with the TD group outperforming the ASC group at every level. However, in contrast, all analyses of all implicit learning tests on the entire groups unmatched for IQ showed an identical pattern of preservation of implicit learning to those conducted on the matched groups.

Finally, there was one further finding that also suggested that explicit processing may be more problematic than implicit processing in ASCs. During the learning phase of the AGL, the mean number of errors that participants made before correctly reproducing each letter string was significantly greater in ASC than TD participants (TD: $M = 1.00$; ASC: $M = 1.48$; $SED = 0.20$; $t(36) = 2.47$, $p = .02$, $d = 0.68$). Unsurprisingly, this result was the same, although the effect was more pronounced, when the groups were unmatched for IQ. These errors are indicative of a participant's ability to explicitly remember and reproduce letter strings in the short-term, and have been used previously as a measure of explicit processing that is related to IQ (e.g., A. S. Reber, et al., 1991). These explicit processes are separate to those processes mediating implicit learning performance on the test phase of the AGL (e.g., A. S. Reber, et al., 1991). Indeed, the errors were not related to implicit learning on the AGL task in either group even when the two groups were considered as the entire sample (see Table 12; TD: $r = -.40$, $N = 31$, $p = .06$, $r^2 = .16$; ASC: $r = .02$, $N = 31$, $p = .99$, $r^2 < .01$).

3.4. Explicit Interviews

Post-task questionnaires indicated that participants of both groups could not freely report what they had learnt on the CC, SRT, AGL and PCL tasks. No further attempts were made to establish quantitatively the extent to which the products of learning were consciously retrievable because it was feared such post-task probing would encourage explicit strategies on subsequent implicit learning tasks (e.g., Gebauer & Mackintosh, 2007). Also, consistent with the interpretation that performance was implicit on these versions of the implicit learning tasks, there was no evidence of a correlation between performance on the implicit learning tasks and IQ in neither the TD nor ASC group. This was true even when each of the two groups were considered as entire samples, who were not matched for IQ, and therefore contained a large range of IQs (see Table 12; TD: range of Pearson's $r = -.08$ to $.32$, $N = 31$, $ps > .05$, $r^2 \leq .10$; ASC: range of Pearson's $r = .08$ to $.40$, $N = 31$, $ps > .05$, $r^2 \leq .16$).

3.5. SCQ Analysis

The relationships were analysed between scores on the SCQ and overall indices of learning from each task (the average proportional increase in RT differences across blocks was used for CC and SRT; mean percentage correct above chance during test phase was used for the AGL and PCL; mean percentage of correct responses given during test was used for the PAL). In the IQ-matched sub-groups (see Table 12) there was no evidence of correlation between SCQ-scores and any of the learning tasks in either group (TD: range of Pearson's r = -.24 to .27, N = 19, ps > .05, $r^2 \leq .07$; ASC: range of Pearson's r = -.23 to .20, N = 15, ps > .05, $r^2 \leq .05$). Similarly, there was no evidence of correlation between SCQ-scores and learning tasks in the entire sample of children, who were not matched for IQ (see Table 12; TD: range of Pearson's r = -.27 to .28, N = 23, ps > .05, $r^2 \leq .08$; ASC: range of Pearson's r = -.17 to .18, N = 18, ps > .05, $r^2 \leq .03$).

4. Chapter Discussion

Performance on the implicit learning tasks reported here is preserved in ASC. Implicit learning was intact across a number of tasks that differed in surface features, each feature being in some way relevant to certain features of ASC: the PCL had a social element to it, involving cartoon faces and characters; the SRT required motor coordination; the CC task involved perceptual processing of context; and it has been argued that the AGL's artificial grammar is related to language (Gebauer & Mackintosh, 2010; Gomez & Gerken, 2000; Kaufman, et al., in press).Thus, in contrast to previous studies, Study II found no deficits in implicit learning in ASC and suggests that a *general* deficit in implicit learning processes is not present in ASC. Furthermore, implicit learning was not related to an index of ASC symptomatology, the SCQ (Rutter, et al., 2003). Together, these findings undermine the argument that such a deficit might play a key role in the social, communicative or motor impairments (L. G. Klinger, et al., 2007; Mostofsky, et al., 2000; Romero-Mungu a, 2008).

These findings converge with other recent reports of intact implicit learning in ASC. For example, Barnes and colleagues, (2008) found preservation on the SRT and CC; Kourkoulou, Findlay, and Leekam (2010) on the CC; Travers, Klinger, Mussey, & Klinger (2010) on the SRT. Further, it is consistent with intact performance on related incidental procedures such as implicit memory and priming (Bowler, Matthews, & Gardiner, 1997; Gardiner, Bowler, & Grice, 2003; Renner, Klinger, & Klinger, 2000).

This raises the question of possible reasons for the discrepancy with other studies that have reported implicit learning deficits (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). One possibility that has been suggested by others is that the observation of intact implicit learning has been obscured in some studies as a consequence of poor matching of IQ between the group with ASC and comparison groups (Soulières, Mottron, Saumier, & Larochelle, 2007). For example, in those studies in which deficits have been reported, the groups of children with ASC had overall lower IQ scores (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000), raising the possibility that the deficit in implicit learning resulted from reduced overall general mental functioning. Interestingly, I did not find support for this possibility in Study II: when I included further individuals in the analysis, such that the ASC group's average IQ score was lower than that of the typically developing group (see Table 12), the evidence of intact implicit learning in the ASC group remained. In direct contrast, comparing these two larger groups unmatched for IQ revealed deficits in ASC in *explicit* learning (PAL task). This observation suggests two important points. First, it reinforces the finding that IQ and explicit learning are intimately related, while implicit learning is relatively independent (e.g., Carroll, 1993; Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991). Second, the intact implicit learning observed in this study cannot be accounted for by IQ or compensations for poor implicit learning by the use of explicit strategies (cf L. G. Klinger, et al., 2007).

Another strong possibility is that the discrepancy between recent studies and the earlier ones reporting a deficit in implicit learning results (at least in part) from differences in the particulars of the tasks and stimuli employed, rather than from genuine differences in implicit learning between children with and without ASC. In particular, studies that have documented impairment in implicit learning have used procedures that seemed to have allowed for the greater use of explicit strategies (e.g., long response-to-stimulus intervals and deterministic sequences on the SRT, Gordon & Stark, 2007; Mostofsky, et al., 2000; non-probabilistic category learning, L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007). When both children with ASC and TD children use explicit, rather than implicit strategies, to solve the tasks, then the impairments in the groups with ASC may well be accounted for by a poorer explicit, rather than implicit, learning performance. This seems a particularly compelling explanation given that 1) explicit, but not implicit, learning is closely related to IQ, 2) these studies reporting deficits included groups of children with ASC with lower IQ than the comparison groups, and 3) the current finding that children with ASC with lower overall IQ than TD children showed deficits in explicit learning in the entire sample analysis of explicit learning. Further, the current results also demonstrate that when implicit learning procedures are used that better prevent explicit strategies from emerging, preservation is found regardless of whether the groups are matched for IQ. Whether or not there is a negative effect of explicit strategies on implicit learning tasks that is independent of IQ and unique to ASC is not clear. For example, particularly dysfunctional strategies or a dysfunctional propensity to use such strategies in ASC would cause such an effect. The worse ASC performance on the explicit processing measure taken from the training phase of the AGL task would be consistent with this possibility. In order to examine this issue directly, Study III compared ASC individuals with IQ-matched TD individuals on an implicit learning task that encouraged explicit strategies.

An issue that is worth emphasising is that on average the current ASC participants were a high-functioning group, as defined by IQ. While all the current results, and other studies (e.g., Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991), emphasise the independence of IQ from implicit learning, it is acknowledged that the interaction of low IQ and autism may be an exceptional case. Furthermore, it is now broadly recognised that high functioning individuals with autism may constitute one of several subgroups of individuals with autistic symptoms, and that the generalizability of research results from this subgroup to another is an issue that can only be assessed empirically and cannot be assumed. Unfortunately, previous studies of implicit learning in autism cannot inform the issue. First, it is not the case that all studies reporting ASC deficits in implicit learning used low-functioning ASC participants (L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). Second and most important, although the only two studies to have included low-functioning ASC groups did both report deficits, they were also among those to be confounded by the use of groups unmatched for IQ and tasks that promoted explicit learning (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001).

Finally, the proposal that implicit learning is intact in ASC seems to contrast with the real world difficulties that ASC individuals have with skills associated with an implicit acquisition, such as language, social and motor skills. However, there are, of course, many other processes that might be different in ASC, which would be sufficient to disrupt the implicit acquisition of those skills, in spite of otherwise intact implicit learning mechanisms. As discussed by Meltzoff and colleagues, (2009) *what* children learn implicitly in the real world is the product of a complex interaction between a variety of influences, and is therefore not simply contingent upon the functioning of learning mechanisms.

For example, one possibility is that the real-world 'implicit' impairments may result from a greater propensity for individuals with ASC to use explicit strategies rather than rely on implicit processing. Indeed, there is evidence that for the implicit acquisition of skills to proceed normally, implicit learning must not be out-competed or obstructed by explicit strategies (e.g., Ashby, Alfonso-Reese, Turken, & Waldron, 1998; Foerde, Knowlton, & Poldrack, 2006; Gebauer & Mackintosh, 2007; Hoyndorf & Haider, 2008; Lieberman, et al., 2004; Lleras & Von Mühlenen, 2004; Poldrack & Rodriguez, 2004). Therefore, an ASC propensity to approach problems using explicit strategies might be sufficient to cause real-world impairment. In line with this possibility, there is evidence that ASC individuals are prone to completing learning tasks more explicitly than TD individuals (Gidley Larson & Mostofsky, 2008; L. G. Klinger, et al., 2007). In addition to this direct evidence, there are many other studies showing that ASC individuals are more prone to solving tasks explicitly (e.g., Theory of Mind performance is mediated explicitly in ASC Happé, 1995; Hill & Frith, 2003). Therefore if, as I have suggested, explicit strategies are overused, then these strategies may interfere with the capacity to learn language, social and motor skills implicitly. This interference would be particularly pronounced if this imbalance was combined with the use of *atypical* explicit strategies during learning. I have argued above that atypical explicit strategies may exist in ASC and I directly examined the possibility in Study III.

In conclusion, the current data together with that from a number of other researchers (Barnes, et al., 2008; Kourkoulou, et al., 2010; Travers, et al., 2010) suggest that individuals with ASC can learn implicitly, and that it is unlikely that such processes are directly responsible for related real-world impairments in language, social and motor skills. It was acknowledged that ASC deficits on implicit learning tasks have also been documented but it was argued that this was due to differences in task procedures, in particular, procedures that promoted the use of explicit strategies and therefore disadvantaged the ASC groups that were not matched for IQ. In order to determine whether those previously identified implicit learning deficits in ASC resulted just from differences IQ, or whether there was also a contribution from an ASC difficulty in explicit learning, Study III compared ASC individuals with IQ-matched TD individuals on an implicit learning task that encouraged explicit strategies.

IV. Explicit Learning on a Simple 'Serial Reaction Time' Task in Autism Spectrum Conditions: Study III & IV

1. Introduction

Implicit learning is thought to be one important mechanism for acquiring social, communicative and motor skills (e.g., Kaufman, et al., in press; McLeod & Dienes, 1993; Meltzoff, et al., 2009; Perruchet, 2008; A. S. Reber, 1993). Since Autism Spectrum Conditions (ASC) are characterized by social, communicative and motor impairments (American Psychiatric Association, 1994) researchers have argued that those impairments in ASC may arise, in part, from a general deficit in implicit learning (L. G. Klinger, et al., 2007; Mostofsky, et al., 2000; Romero-Mungu a, 2008). Indeed, initial empirical studies supported the theory by reporting deficits on a number of implicit learning procedures, including SRT tasks, (Gordon & Stark, 2007; Mostofsky, et al., 2000); Category Learning tasks, (L. G. Klinger & Dawson, 2001); and AGL tasks, (L. G. Klinger, et al., 2007). However subsequently, there have been several studies arguing that implicit learning is actually intact in ASC. Study II reported equivalent performance between TD and ASC groups on the AGL, CC, Probabilistic Classification Learning, SRT tasks, while other researchers have also reported intact ASC performance on the CC and SRT tasks (Barnes, et al., 2008); CC task (Kourkoulou, et al., 2010); and SRT task (Travers, et al., 2010).

In Chapter III it was argued that one possible reason for the discrepancy between studies finding a deficit and those studies that did not was differences in the particulars of the tasks and stimuli employed, rather than from genuine differences in implicit learning between children with and without ASC. In particular, those studies documenting impairments in implicit learning tended to use procedures that allowed for the greater use of explicit strategies. For instance, some arranged deterministic sequences with long response-to-stimulus intervals on the SRT task (Gordon & Stark, 2007; Mostofsky, et al., 2000); asked participants to learn about non-probabilistic categories (Klinger & Dawson, 2001); or used shape- rather than letter- stimuli on the AGL task (Klinger, et al., 2007; see Chapter III.1, for more a detailed discussion as to why these procedures encourage explicit strategies). The argument is that when both children with ASC and TD children use more explicit strategies to solve the tasks, then the impairments in the groups with ASC may well be accounted for by a poorer *explicit*, rather than *implicit*, learning performance. This interpretation is supported by the fact that researchers found no performance differences between TD and ASC children when they used procedures that did not promote such explicit strategies (e.g., Study II , Barnes, et al., 2008; Kourkoulou, et al., 2010; Travers, et al., 2010).

Reviewing these studies establishes that ASC learning deficits have only resulted when explicit strategies were encouraged. The natural conclusion might be that there is an ASC explicit learning deficit. However before coming to that conclusion, it is critical to note that in all those studies reporting deficits the groups of children with ASC also had overall lower IQ scores (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). Therefore, the ASC groups showing poorer performance were unduly disadvantaged by being of lower general mental ability than the comparison group. This is a particularly compelling explanation given that explicit (in contrast with implicit) learning is closely related to IQ (e.g., Carroll, 1993; Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991). Indeed, Study II found that performance on an explicit Paired Associates Learning task was not significantly different between the ASC and TD groups as far as they were matched for IQ, but that an ASC deficit in explicit learning performance emerged when the full (non-IQ-matched) samples were considered. Thus, the available evidence is at least consistent with the interpretation that performance differences simply resulted from differences in the IQs of the groups.

However, there are, in fact, persuasive reasons for supposing there might be atypical explicit processing in ASC individuals that are independent of IQ, and which could impact negatively on certain implicit learning procedures. First, there is evidence of dysfunctional explicit strategies during explicit tasks. For example, in Study II an IQ-matched ASC group were significantly worse than the typical group on the explicit memorisation phase of the AGL task, and there was also a trend for those ASC participants to perform worse on the explicit Paired Associates Learning task.

Second and more generally, there are findings and theories that suggest that the processes supporting explicit learning could be impaired in ASC. Explicit learning requires flexibility and intentional processing (Cleeremans & Jiménez, 2002), and a large body of research in ASC has reported impairments in executive planning (Hill, 2004; O'Hearn, Asato, Ordaz, & Luna, 2008;

Russell, 1997a); action in accordance with goals (Crane & Goddard, 2008; Toichi, et al., 2002); integrating the larger context (Frith, 2003; Happé & Frith, 2006; Loth, Gómez, & Happé, 2008b); using prior knowledge (Loth, Gómez, & Happé, 2008a; Mottron, et al., 2006); deploying intentional/voluntary attention (Leekam & Moore, 2001); and in understanding own and others' minds and intentions, (Baron-Cohen, Tager-Flusberg, & Cohen, 2000; Frith, 2001).

The aim of the present study was therefore to determine whether the differences arising between ASC and TD individuals in an implicit learning task that encourages explicit processes could be observed independently of IQ, and could be attributed to an atypical way of processing explicit knowledge. The study used a simple sequence learning procedure that has been found to result in a considerable amount of explicit knowledge. This SRT procedure was combined with a contextual cueing task that provides an indirect, ongoing index of the extent to which sequence learning is explicit (see below). The idea was that if previous ASC deficits on implicit learning procedures that encouraged explicit processing were due to lower IQ in the ASC groups, then there should be no difference in performance in the current IQ-matched groups. However, if those previous ASC deficits were due to atypical explicit processing while solving the implicit tasks, then the performance of the current ASC group should still show some deficits when compared with the current IQ-matched TD group.

1.1. Sequence Learning and Contextual Cueing

In order to determine whether ASC deficits on implicit learning tasks that encourage explicit processes can be observed independently of IQ, the SRT was an ideal task for three reasons. First, and most importantly, the literature on sequence learning in ASC conforms to the literature review above about implicit learning procedures, ASC deficits and explicit strategies. Specifically, there have been two studies that used SRT procedures that encouraged explicit processes (both used slowly repeating deterministic sequences) that have both identified a deficit (Gordon & Stark, 2007; Mostofsky, et al., 2000), but in those two studies participants were also not matched for IQ. In contrast, there are other studies that used quickly repeating probabilistic sequences, and which matched both groups for IQ, and none of them found significant deficits in ASC performance (Study II, Barnes, et al., 2008; Travers, et al., 2010). Therefore, it is necessary to determine whether the ASC deficits obtained in the first two studies of SRT, which encouraged explicit strategies, would have still arisen *if* the two groups were matched for IQ; in other words, to determine whether there was an independent contribution to ASC deficits on SRT procedures encouraging explicit strategies from atypical explicit processing in ASC.

Second, the conditions that make learning more explicit and less implicit, and vice versa, have been thoroughly researched: several studies have established that procedures involving slowly repeating, so-called ‘deterministic sequences’ (i.e. sequences that follow a continually and slowly repeating sequence without interruption) encourage the development and use of *explicit* strategies to solve the task (e.g., Destrebecqz & Cleeremans, 2001, 2003; Norman, et al., 2007).

The third reason for using the SRT task relies on the recent development of an adaptation to the SRT task. The adaptation can be used to provide an ongoing assessment of the extent to which the sequence learning is explicit. Jiménez and Vázquez (in press) recently demonstrated that the sequence learning effect can be acquired and expressed in the context of a search task. Further, they showed that, if the search contexts contain information about the location of the target, then a contextual cueing effect can be acquired and expressed alongside the sequence learning effect. Jiménez and Vázquez adapted the basic contextual cueing procedure to fit with a SRT task by using four different responses instead of the usual two-alternative task. In a series of experiments to investigate the dual contextual cueing and sequence learning effect, the authors established that when the sequence learning was implicit then both implicit contextual cueing and sequence learning effects emerged. The sequence learning was considered implicit because probabilistic sequences were used and this was verified by participants’ inability to explicitly generate examples of the sequence in a post-test generation task. In contrast, in another condition in which participants were required to learn deterministic sequences, the contextual cueing effect was substantially attenuated. Deterministic sequences were intended to encourage the use of explicit learning strategies. This was confirmed by the ability of the participants to explicitly generate the sequence that had occurred during a post-test generation task. Thus, only when the learning and use of sequence information had been more explicit was the contextual cueing effect suppressed. This interpretation was supported by the fact that the contextual cueing effect was reinstated in a test block when the relevant deterministic sequence was removed. The suppression of the contextual cueing effect therefore reflected the fact that participants were able to respond on the basis of their explicit sequence knowledge, and hence no longer needed to process the context.

Study III used this same modification of the CC task to determine the stage at which the two groups explicitly learnt and applied sequence information, by comparing the stage at which the groups withdrew their processing of the context. Prior to learning the sequence information sufficiently explicitly, learning of the sequence will be implicit and should therefore be accompanied by unattenuated contextual cueing. Important to the validity of the use of this manipulation for Study III, it has previously been demonstrated that there is intact implicit learning performance in ASC individuals on the standard, unmodified CC-task (e.g., Study II, Barnes, et al., 2008; Kourkoulou, et al., 2010). It is predicted that if previous poor performance in tasks involving both implicit and explicit learning is due to a deficit in explicit learning, then the performance of children with ASC would take longer to be dominated by explicit processing, and would instead learn implicitly for an extended period. Therefore, I expected this weaker explicit learning and continued implicit learning to be manifest in ASC by *a reduction* in the typical attenuation of the contextual cueing effect.

As already discussed, learning on certain implicit learning procedures can sometimes be more explicit than is typical and it is therefore important to include measures to assess the nature of the learning displayed. Study III included three means of assessing the extent to which knowledge was explicit: a sequence validity manipulation during the test block; generation tasks (Chun & Jiang, 2003; Jiménez & Vázquez, in press); and subjective measures, such as confidence ratings and judgments (Dienes, 2008; Dienes, et al., 1995).[6]

In summary, Study III compared children with ASC and typical children closely matched for IQ on a hybrid SRT-CC task that assessed the extent to which performance was dominated by explicit processing. To anticipate the result, there was reduced attenuation of the contextual cueing effect at the outset of learning in the ASC group compared to the TD group, suggesting initially reduced explicit processing of the sequence. A second study, Study IV, replicated the difficulty in explicit processing while exploring possible reasons for its existence. Specifically,

[6]An exclusion generation task was designed and programmed, and it was intended that all participants would complete the task at the end of Study III as another assessment of the degree to which SRT knowledge was explicit. However, testing sessions were limited to one hour, and this task was presented last. Consequently, some participants did not reach that part of the experiment. Given the number of alternative explicit learning measures, the partial results were disregarded. A similar time constraint was envisaged for Study IV, and therefore the exclusion generation task was not included in the programme.

the study examined whether the difficulty resulted from slower explicit learning about the sequence or from difficulties in applying explicit knowledge of the SRT sequence.

2. Study III

2.1. Method

2.1.1. Participants

16 children with ASC (referred to as the ASC group) and 16 Typically-Developing children (referred to as the TD group) were included in the study. All children in the ASC group met established criteria for ASC, such as those specified in DSM-IV (American Psychiatric Association, 1994) and had previously received a diagnosis for ASC by trained clinicians using instruments such as the Autism Diagnostic Interview (Le Couteur, et al., 2003). Any other psychiatric diagnosis acted as an exclusion criterion for both the ASC and TD group. Table 14 presents the participant characteristics for each group. The two groups of children were matched for sex (16 males), chronological age ($t(30) = 1.85$, $p = .07$, $d = 0.66$) and IQ ($t(30)$ =0 .05, $p = .96$, $d = 0.02$) of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999), see Table 14. Informed parental consent and the assent of the children were obtained, and ethical permission to conduct the study received from the Cambridge Psychology Research Ethics Committee. 12 of the parents of children with ASC and 14 of the parents of TD children completed the Social Communication Questionnaire (SCQ: Rutter, et al., 2003). The SCQ is a screening tool for autism, which comprises 40 items derived from the ADI-R. The raw scores on the SCQ were converted into percentage scores. All the children in the TD group had scores below the cut-off score of 38.46 % specified by Rutter and colleagues, see Table 14. Further, the highest score for the TD group was 8.35 standard deviations below the mean of the ASC group.

Table 14. *Mean Age (in years), WASI IQ Scores and Social Communication Questionnaire (SCQ) Scores (percentage) for the ASC and TD Groups*

Measure	Study III					
	TD *(N = 16)*			ASC *(N = 16)*		
	M	*SD*	*R*	*M*	*SD*	*R*
Chronological age	12.3	0.9	10.8 – 13.4	12.9	0.9	11.9 – 14.7
Full-scale IQ	105.4	10.1	84 – 119	105.2	11.6	86 – 128
	TD *(N = 14)*			ASC *(N = 12)*		
SCQ Score	7.7	5.6	0 – 18.0	65.0	12.3	38.46 – 82.0

2.1.2. Apparatus and materials

A fourteen-inch LCD Windows notebook computer was used for all the computerised testing. Responses were recorded using the notebook's keyboard. All parts of the computerised task were programmed using INQUISIT 2.0.6, which provides millisecond timing accuracy (De Clercq, Crombez, Buysse, & Roeyers, 2003).

The stimuli consisted of a set of coloured digits printed in Garamond font, 1.3 cm high x 0.8 cm wide, over a grey background, see Figure 8. Target stimuli were even numbers (2, 4, 6, 8) presented in one of four possible colours (red, blue, green, or yellow). The target appeared on each trial at one of the 16 locations defined by an invisible 4 x 4 matrix, 9.2 cm wide x 9.4 cm high, accompanied by seven distractors. Distractors were odd numbers (1, 3, 5, and 7) but within a trial, all had the same numerical identity. Distractor colour and location was chosen so that on each trial there were two stimuli of each colour, with stimuli evenly distributed over the four quadrants of the display and filling 8 out of 16 possible stimuli locations. Vertical and horizontal lines divided the matrix into four quadrants. Between neighboring slots there was a horizontal separation of 2.1 cm and a vertical separation of 1.5 cm.

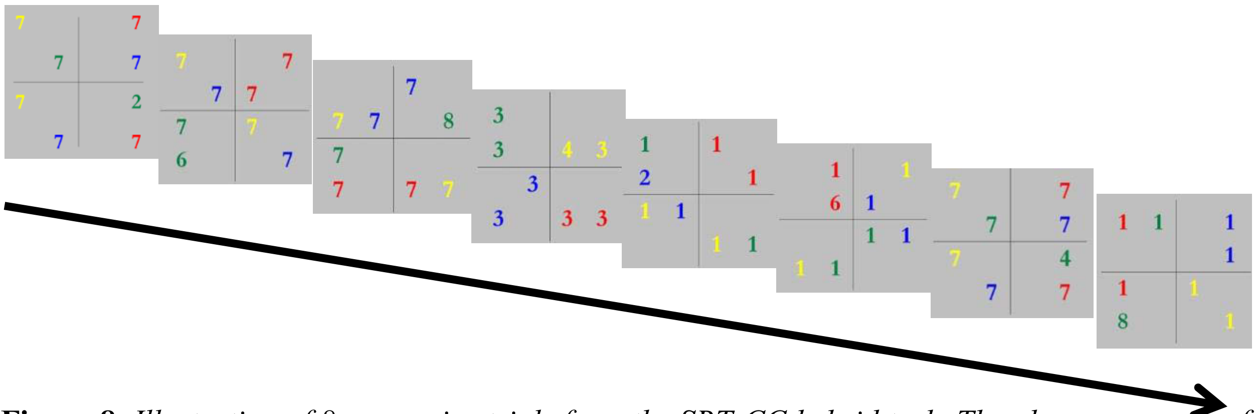


Figure 8. *Illustration of 8 successive trials from the SRT-CC hybrid task. The above sequence of 8 even number targets was one of the training sequences used. 7 possible contexts (combinations of distractor position, colour and identity) are presented above. One context is repeated on the first and seventh trials presented.*

2.1.3. Design and Procedure

General

Participants responded as quickly and as accurately as possible according to the identity of the even number (2, 4, 6, and 8) by pressing the keys V, B, N, M, respectively, with the middle and index fingers of each hand. Training consisted of 1152 trials, divided into 12 blocks of 96 trials. At the start of each block, the solid lines creating the quadrant (see Figure 8) were presented and remained on the screen for the entire block. Each trial then began with the presentation of distractors and target. The stimuli all remained on screen until the participant responded correctly; if a participant responded incorrectly the word *"Error"* appeared in red at the top of the screen and remained with the rest of the stimuli until the correct response was provided. The next trial began after a response-to-stimulus interval of 200 ms. Between blocks, the experimenter provided participants with feedback about their accuracy and reaction times (RTs). Training was preceded by a short practice block, after which it was ensured that the participant had understood the demands of the task.

The location of the target was decided randomly without replacement over successive series of 16 trials. Therefore, effectively each block was comprised of 6 series of 16 trials. After a series of 16 trials, the next trial could appear at any other location except at the location sampled on the previous trial. Distractor identity was pseudo-randomly chosen for each trial from the set so that each distractor-type appeared equally often. The seven distractors plus the target stimulus were coloured and located pseudo-randomly for each trial, so that two of them were drawn in each possible colour (red, blue, green, and yellow), and two items were located in each one of the four matrix quadrants, see Figure 8.

Sequence information

With the exception of the 8-trial practice block, the identity of the target repeatedly followed a deterministic 8-digit sequence (either sequence-a: 2-6-4-8-2-6-8-4 or sequence-b: 2-4-6-8-2-4-8-6) and therefore required a repeated sequence of responses. This was true of all blocks except for block 11. Block 11 was the test block; on half the trials of this block the sequence followed the control sequence. The control sequence was always the sequence to which participants had not previously been exposed during training. Which of the two sequences was the main and which was the control was counterbalanced, in order to prevent the possibility that one of the sequences would produce faster responses just because certain transitions (i.e. the movement between two required responses in a sequence,) were more comfortable than others. Further, both sequences were structurally analogous. Each sequence compromised two presentations of each digit and had only one unique transition, which allowed participants to predict the next event by considering the identity of the previous target (e.g., in sequence-a, the two presentations of target 2 were followed by 6, and in sequence-b, the two presentations of 2 were followed by 4). The two repetitions of these unique transitions were separated by two intervening events, which gave rise to six ambiguous transitions (i.e., transitions in which a single event predicted a different successor on each of its occurrences, as it is the case, for instance, of target 6, which was followed by items 4 or 8 in sequence-a, and by items 2 or 8 in sequence-b). No immediate repetitions (e.g., 6-6) or reversals (e.g., 6-2-6) were allowed within either sequence. Sequences a and b had three transitions in common, but they differed in their unique transitions, and in half of their ambiguous transitions.

During the 11 training blocks (i.e., blocks 1 to 10 and block 12) the training sequence repeated 12 times. Test block 11 contained six repetitions of the training sequence, randomly interspersed with six repetitions of the control sequence. To make sure that the transitions between training and control sequences were made in accordance with the second-order transitions stipulated by the upcoming sequence, the starting (and therefore the end) point of the test block was not selected at random. Instead, the beginning was chosen so that the outgoing sequence ended on a digit (e.g., 4) such that the next digit created a transition that was legal for both sequences (e.g., 4-8). Therefore, the transition from one sequence to the other was legal according to the outgoing sequence and consistent with a second-order transition stipulated by the upcoming sequence. The order participants received the training and control sequence during the test block was fixed to allow a more accurate between-group comparison, but counterbalanced across participants to minimise any order effects.

To assess sequence learning indirectly, RTs in response to control-sequence trials over test block 11 were compared with the average RTs in response to training-sequence trials over the neighboring training blocks 10 and 12. In a test phase design, this represents the fairest and most common assessment of learning because using the average performance from two blocks equally before and after the test block controls for the effects of practice (Jiménez & Vázquez, 2008). Direct comparison with RTs on training-sequence trials within the same test block would not have been fair because the validity of the sequence information on that block has been compromised, and could have negatively impacted upon the application of the sequence knowledge (Jiménez, et al., 2006). However, a number of trials structured according to the training sequence were included within the test block for another reason: to assess the relative flexibility of the acquired knowledge. Jiménez and colleagues (2006) showed that only participants with *explicit* knowledge of a sequence noticed that their knowledge was no longer valid over such a test block. Participants with explicit sequence knowledge stopped using that knowledge to speed responding on trials in which the training sequence was presented in the test block, in order to avoid being misled by irrelevant knowledge when the training sequence was not present in that test block. Thus, the explicitness of knowledge was indirectly assessed by measuring the participants' sensitivity to such a decrease in the validity of sequence information during the test block.

Contextual information

The precise combination of location, identity and colour of distractors created a context for the location of the target on each trial. 40 such combinations were generated and each context was always associated with the same target location but a changing target identity. 8 'high-frequency' contexts were repeated frequently (6 times a block), while the remaining 32 'low-frequency' contexts were repeated infrequently (on average 1.5 times a block). Each high-frequency context was associated with a unique target location, while sets of 4 low-frequency contexts were each associated with a different one of the remaining 8 possible target locations. Of the sets of 4 low-frequency contexts associated with a given target location, each context was characterized by a different distractor identity, as well as by a different distribution of locations and colours. Similarly, of the 8 high-frequency contexts, two contexts contained 1's, two contained 3's, two contained 5's and two contained 7's and were each characterised by a different distribution of distractor locations and colours. Thus, all target locations were equally cued, and all distractor identities, colours and locations were equally present. However, only the precise combination of distractor location, identity and colour of a high frequency context provided a *unique* cue to a target location, which, in addition to the more regular occurrence of high-frequency contexts, helped participants to respond faster to the numerical identity of the targets among high, in contrast with low, frequency contexts. Which 8 of the 16 locations were predicted by the high-frequency contexts and which by the low-frequency contexts was counterbalanced, together with the corresponding exact composition of the 40 contexts (8 high and 32 low). Trials with high frequency and low frequency contexts were randomly intermixed across all trials but this order was then fixed to minimise the noise in the crucial between group comparisons.

Learning was indirectly indexed by comparing reaction times on high vs. low frequency context trials. If participants were cued to the target location by the contextual information, then across the blocks participants would have responded progressively faster to high as compared to low frequency context trials. Also, the effect of contextual cueing over the sequence test block 11 and neighboring blocks 10 and 12 was assessed separately, to ascertain whether the change of sequence over these blocks affected contextual cueing.

Post-task measures

Subsequent to block 12, direct measures of contextual cueing and sequence learning were presented with the order counterbalanced across participants. To assess explicit contextual cueing knowledge, participants were instructed to guess the location of the target in a task in which the high-frequency contexts were presented, but in which the target was replaced by an additional distractor (Chun & Jiang, 2003; Jiménez & Vázquez, in press; c.f., Smyth & Shanks, 2008). If contextual cueing was implicit (or had not occurred), then participants should not be able to guess the correct location above the chance level. Following the suggestions of Smyth and Shanks (2008), two presentations of each repeated context were included, instead of a single one, so as to improve the sensitivity of the location guessing task. Additionally, 8 novel displays were also presented twice each. Rather than guessing the specific location of the removed target, participants were only instructed to guess the quadrant at which it would have appeared in that particular context. Responses were issued by pressing the keys F, V, K, M to indicate the upper left, lower left, upper right, and lower right quadrants respectively. To assess the extent of the explicit knowledge, the proportion of correct responses produced on high-frequency trials was compared with that on novel-context trials.

For sequence learning, a cued generation task comprised of 24 generation blocks was included. Each generation block consisted of 3 trials. The first two trials of each block were exactly the same as those presented over training. On the third, however, the target was removed and replaced by another distractor. Participants were asked to guess the identity of the removed target by relying on the target identity of the previous two trials. The first two trials of each block constituted one of the 12 possible two-trial fragments that could have appeared during the training or test blocks, and participants were instructed to respond to them as they had in the SRT task. Each of the 12 possible two-trial fragments was presented twice, totaling 24 generation tests. The targets were presented in low-frequency contexts, in order to enhance task sensitivity by keeping the generation trials as similar as possible to the main task. To assess the extent of explicit sequence knowledge, the proportion of prediction trials on which participants correctly generated a successor corresponding to the training sequence was compared with that on the control sequence. At the start of this generation task, the importance of accuracy over RTs was emphasized for the third prediction trial, and no feedback was provided on the accuracy of their generation responses. Finally, at the end of all testing, children were asked to report the entire sequence as accurately as possible.

For both SRT and CC generation tasks, the order was generated pseudo-randomly such that each trial had appeared once before any of the trials appeared for the second time, and was then fixed across participants to minimize noise for the between-group comparison.

In accordance with the recommendations of Smyth and Shanks (2008), prior to each of the contextual cueing and sequence learning generation tasks, participants were asked direct awareness questions about the presence of contextual and sequential information respectively. Before the contextual cueing generation task, participants were asked on-screen, *"During the experiment, do you think that any of the displays of odd numbers were repeated?"* Those who answered positively received a follow-up question: *"Approximately, when did you begin to notice this repetition?"* Using a slider labeled from 1 to 12, participants estimated the block in which awareness occurred before finally being asked, *"After you realized particular displays of odd numbers were being repeated, did you try to memorize these displays?"* Following these questions and before beginning the generation task, all participants were informed that *"the displays of odd numbers were repeated"*. Before the sequence learning generation task, participants were asked on-screen *"During the experiment, do you think that there was any sequence or pattern to the order in which you pressed the keys?"* Those who noticed a repetition received a follow-up question: *"Approximately, when did you begin to notice this sequence or pattern?"* Using a slider labeled from 1 to 12, participants estimated the block in which awareness occurred before finally being asked, *"After you realized there was a sequence or pattern to the order in which you pressed the keys, did you try to memorize this sequence or pattern?"* Following these questions and before beginning the generation task, all participants were informed that there was *"a sequence to the order in which you pressed the even numbers"*. There was also one direct question asked after both the generation tasks were completed: participants were told, if possible, to reproduce the sequence from the experiment.

Finally, in accordance with Dienes and colleagues' (Dienes, 2008; Dienes, et al., 1995) research on dissociating implicit and explicit performance, subjective measures of awareness were also included during the generation tasks. Following each generation response, participants classified their answer as either *"A complete guess"*, *"A feeling/intuition"*, *"A memory/knowledge"* and rated how confident they were their answer was correct using a 1 to 7 confidence scale with the anchors 1 = *"Completely uncertain"*, 4 = *"Moderately certain"*, 7 = *"Completely certain"*. According to Dienes' 'zero-correlation criterion' implicit knowledge exists if there is no relationship between confidence and performance, while his 'guessing criterion' states that implicit knowledge exists if a participant's performance is above chance even when they claim to be guessing.

2.2. Results

First trial data were excluded from the main task (blocks 1-12) for all RT analyses of the SRT task because meaningful assessment can only occur when the stimuli have been presented sequentially. RTs on error trials were discarded for all RT analyses. For all analyses, the alpha level was set at .05, two-tailed and extreme outlying RTs (values either less than three times the interquartile range below the lower quartile, or greater than three times the interquartile range above the upper quartile) were excluded. Where relevant, the appropriate epsilon correction was used when sphericity was violated. Šidák corrections were used to control for familywise error rates during multiple comparisons. Where significant interactions were found in the mixed analyses of variance, separate ANOVAs were conducted on the levels of interest to establish simple effects. When conducting independent sample *t*-tests, equal sample variances were assumed unless Levene's test for the equality of variances was significant. Cohen's d is reported as a measure of effect size except where relative measures of effect size are more appropriate, and then partial eta-squared (η^2_p) is reported.

For the SRT task, both RT and accuracy provided indices of learning. RT and accuracy data were subjected to similar analyses. However, the results of the two analyses were entirely consistent with one another, and thus it was deemed unnecessary to report both analyses. Since accuracy is a relatively insensitive index of learning on the SRT (e.g., Study II), no analysis of the accuracy data is reported here beyond the finding that overall accuracy was similar between the groups (TD: M = 93.48 %, SEM = 1.24 %; ASC: M = 94.05 %, SEM = 1.02 %; $t(30) = 0.36$, $p = .72$, $d = 0.13$; see Appendix B for the full accuracy analysis).

2.2.1. Sequence learning

Training: Block 1-10

Figure 9 represents the mean RT at each level of block for each of the two groups. There was a decrease in RTs as participants progressed through the blocks. This improvement in performance could reflect increasing skill with general practice of the task together with acquisition of sequence learning. A mixed analysis of variance, with one between subject factor of Group (ASC vs. TD), and one within subject factor of Block (1-10), confirmed this effect of Block ($F(3, 99) = 79.43$, $p < .001$, $\eta^2_p = .73$). There was no evidence of a Group effect ($F(1, 20)$

= 0.93, $p = .34$, $\eta^2_p = .03$) and the interaction did not reach significance ($F(3, 99) = 2.11$, $p = .10$, $\eta^2_p = .07$). The numerical difference between groups in early blocks of trials is consistent with the finding reported in Study II that ASC participants take longer than TD participants to benefit from the opportunity to generally practice the SRT task. Equally, the performance pattern in the ASC group may also reflect slower acquisition of the sequence learning.

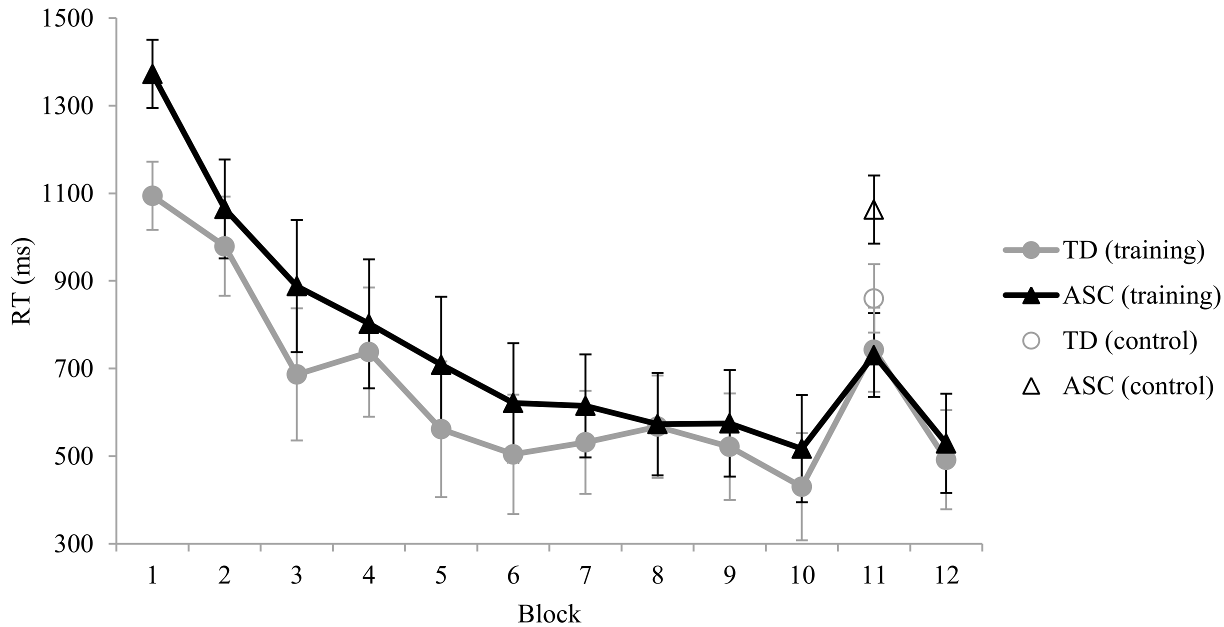


Figure 9. *In Study III, TD and ASC groups displayed similar final sequence learning on the SRT task, as measured by the increase in RTs to the control sequence on the Test block compared with those on blocks 10 and 12. The final learning was also similarly explicit in the two groups, as measured by the increase in RTs to the training sequence presented with low global validity during the test block. There was an indication that the ASC group were initially slower than the TD group. Depicted are mean reaction times across the experiment for different groups. The error bars show twice the standard error of differences between group means at different levels of block.*

Test: Block 10-12

To specifically assess whether participants had learnt the sequence (without the additional effect of general practice that was also present during initial training blocks), performance was compared between training blocks 10 and 12 and in test block 11. Mean RTs to just the novel *control* sequences in test block 11 were compared with mean RTs to the training sequences averaged between the neighbouring blocks 10 and 12, in order to assess whether performance was disrupted on novel control sequences in test block 11. Indicative of sequence learning, responses were slower to control sequences on block 11 than across block 10 and 12.

The magnitude of this difference was comparable between the groups (TD: Mean difference (*M*) = 398.74 ms; ASC: *M* = 539.44 ms; *SED* = 137.45 ms). Consistent with this interpretation, a mixed ANOVA with factors of Group and Block (Control Sequences Block 11 vs. Block 10&12) confirmed the sequence learning effect with an effect of Block $F(1, 30) = 46.59$, $p < .001$). The ASC group were not significantly slower overall than the TD group ($F(1, 30) = 3.79$, $p = .06$, $\eta^2_p = .11$). More importantly, there was a lack of evidence for an interaction between Group and Block ($F(1, 30) = 1.05$, $p = .31$, $\eta^2_p = .03$), which was consistent with a final sequence learning effect that was similar between the groups.

Sequence validity: Block 10-12

To assess whether this sequence learning was explicit, an indirect measure was taken comparing performance on the *training* sequence of Block 11 to that on the same training sequence in Blocks 10 and 12. If participants were explicitly aware of the sequence and thus surprised by the appearance of the novel control sequence in Block 11, then performance would be expected to be slower across all sequences in Block 11 relative to the familiar training sequence exclusively present in Blocks 10 and 12. Responses were indeed slower to the training sequence in Block 11 than in Block 10 and 12. The magnitude with which the RTs were slowed was similar between the groups (TD: Mean difference (*M*) = 281.69 ms; ASC: *M* = 207.26 ms; *SED* = 72.01 ms). A mixed ANOVA with factors of Group and Block (Training Sequences Block 11 vs. Block 10&12) revealed a main effect of Block $F(1, 30) = 46.10$, $p < .001$, $\eta^2_p = .61$) and no significant effect of Group ($F(1, 30) = 0.07$, $p = .80$, $\eta^2_p < .01$) nor interaction between Group and Block $F(1, 30) = 1.07$, $p = .31$, $\eta^2_p = .03$). This analysis suggested that the learning was similarly explicit between the groups according to this indirect measure.

Post-task Tests: SRT Generation

A direct measure of whether explicit sequence knowledge had been acquired was taken in an SRT generation task by comparing the percentage of correctly generated sequence fragments on training versus control sequences. Performance on the training sequence was superior to control sequence performance (Training: *M* = 67.19 %; Control: *M* = 47.10 %; *SED* = 4.55 %). This difference in performance between sequences was comparable between the groups (TD: Mean difference between Training and Control sequences (*M*) = 19.64 %; ASC: *M* = 20.54 %;

SED = 9.09 %). A mixed ANOVA with using factors of Group and Sequence (Training vs. Control) as factors revealed an effect of Sequence ($F(1, 30) = 19.53$, $p < .001$, $\eta^2_p = .39$) but no significant effect of Group ($F(1, 30) = 1.22$, $p = .28$, $\eta^2_p = .04$) nor interaction between Group and Sequence ($F(1, 30) = 0.01$, $p = .92$, $\eta^2_p < .01$). This analysis suggested that the sequence learning of each group was explicit to the same extent.

2.2.2. Contextual cueing

Training: Block 1-10

Mean RTs to high- and low-frequency contexts were compared as a measure of contextual cueing. Figure 10 represents the mean difference between high- and low-frequency context trials in each block for both the groups. A difference score greater than zero indicates contextual cueing. In general, there appeared to be minimal contextual cueing during the training blocks 1-10, see Figure 10. A mixed ANOVA with factors of Group, Context (High vs. Low) and Block (1-10) as factors provided support for this interpretation. There was an effect of Block ($F(3, 99) = 78.73$, $p < .001$, $\eta^2_p = .72$) but no significant effect of Context ($F(1, 30) = 0.56$, $p = .46$, $\eta^2_p = .02$) or interaction between Context and Block ($F(5, 152) = 1.26$, $p = .28$, $\eta^2_p = .04$). There was no significant effect of Group ($F(1, 30) = 0.96$, $p = .34$, $\eta^2_p = .03$) or interaction of Group with any other factor (Group and Context: $F(1, 30) = 0.11$, $p = .75$, $\eta^2_p < .01$; Group and Block: $F(3, 98) = 2.11$, $p = .10$, $\eta^2_p = .07$).

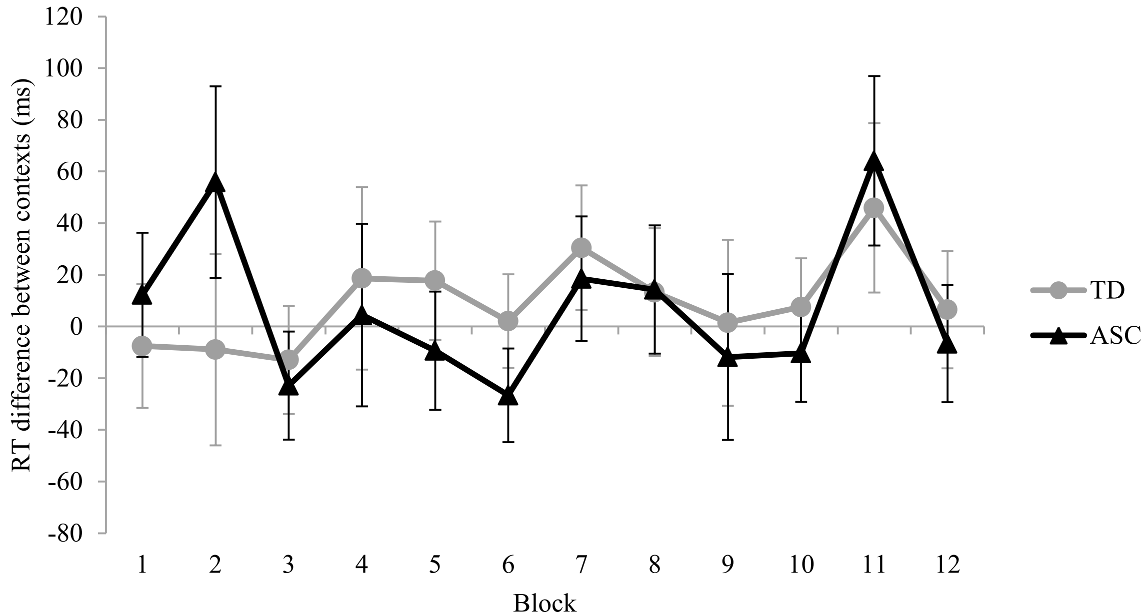


Figure 10. *In Study III, the ASC group showed an atypical attenuation of contextual cueing in the first two blocks of training. After this acquisition phase, both groups showed an extremely similar pattern and magnitude of contextual cueing; contextual cueing was attenuated in both groups until the test block, when training sequence knowledge was removed and invalidated, and consequently contextual cueing emerged. This re-affirmed the role of explicit sequence knowledge in suppressing contextual cueing throughout the rest of task. Presented are the RT differences between contexts across the task. The error bars show twice the standard error of differences between group means at different levels of block.*

Examination of Figure 10 indicated a numerical tendency for a lack of the typical attenuation of contextual cueing in the performance of the group with ASC in the earliest two blocks. Unsurprisingly, this was not supported by the presence of a three-way interaction ($F(5, 152) = 1.21$, $p = .31$, $\eta^2_p = .04$), as this difference was masked by the similarity of performance between the two groups in all later trial blocks. Given the prediction that atypical explicit processing in the ASC group may affect the typical attenuation of contextual cueing, the training data were separated into two groups of trial blocks and analysed further. The first group of trial blocks consisted of blocks 1 and 2; the second comprised trial blocks 3-10.

For the first group of blocks (blocks 1 and 2), the TD group's mean difference score was close to zero but the mean difference score in the ASC group was larger (TD: $M = -8.21$ ms; ASC: $M = 34.12$ ms; $SED = 20.24$ ms). This implied that there was contextual cueing in the ASC group, and that this was larger than the contextual cueing effect in the TD group who did not seem to have learnt about the contexts. This was supported by a mixed ANOVA with factors of

Group, Context and Block (1-2). The analysis yielded main effects of Group ($F(1, 30) = 4.59$, $p = .04$, $\eta^2_p = .13$), Block ($F(1, 30) = 23.96$, $p < .001$, $\eta^2_p = .44$) and an interaction between these two factors ($F(1, 30) = 4.73$, $p = .04$, $\eta^2_p = .14$). There was no evidence of an effect of Context ($F(1, 30) = 1.64$, $p = .21$, $\eta^2_p = .05$), or interaction between Context and Block ($F(1, 30) = 0.79$, $p = .38$, $\eta^2_p = .03$). Of greatest importance was an interaction between Group and Context ($F(1, 30) = 4.37$, $p = .05$, $\eta^2_p = .13$). Simple effects analysis, investigating the difference in responding to high vs. low frequency contexts in each group separately, established contextual cueing in the ASC group ($F(1, 15) = 7.98$, $p = .01$, $\eta^2_p = .35$) in these initial two trial blocks, but provided no evidence for contextual cueing in the TD group ($F(1, 15) = 0.26$, $p = .62$, $\eta^2_p = .02$). This analysis therefore confirmed that there was a contextual cueing effect over the first two blocks in the ASC but not the TD group. There was no evidence of a three-way interaction ($F(1, 30) = 0.90$, $p = .35$, $\eta^2_p = .03$).

The analysis of performance between blocks 3-10 examined contextual cueing during the main section of the task. On average, the differences between high- and low-frequency contexts were close to zero and this seemed true of both the groups (see Figure 10). This suggested that there was no contextual cueing effect in either group in this group of trial blocks. A mixed ANOVA, with factors of Group, Context and Block (3-10), confirmed this impression. There was no significant effect of Context ($F(1, 30) = 0.10$, $p = .76$, $\eta^2_p < .01$), replicating the modulation of contextual cueing by the presence of explicit sequence learning demonstrated by Jiménez and Vázquez (in press), and the lack of evidence of an interaction between Group and Context ($F(1, 30) = 1.24$, $p = .27$, $\eta^2_p = .04$) or Context and Block ($F(5, 139) = 1.55$, $p = .18$, $\eta^2_p = .05$) suggested typical modulation of contextual cueing by explicit sequence knowledge in both groups during trial blocks 3-10. There was a main effect of Block ($F(3, 101) = 27.11$, $p < .001$, $\eta^2_p = .48$), indicating that RTs (irrespective of high- or low-frequency context) decreased across trial blocks 3-10. There was no evidence of a Group effect ($F(1, 30) = 0.56$, $p = .46$, $\eta^2_p = .02$), an interaction between Group and Block ($F(3, 101) = 2.15$, $p = .09$, $\eta^2_p = .07$), or a three-way interaction ($F(5, 139) = 0.18$, $p = .97$, $\eta^2_p = .01$).

Test: Block 10-12

The analysis of performance in trial blocks 10-12 examined the effect of invalidating and removing sequence knowledge during Trial Block 11 on contextual cueing. Mean RTs between contexts on Block 11 were compared with those in the two neighbouring blocks 10 and 12.There was an increase in contextual cueing on Block 11 relative to Block 10 and 12 (see Figure 10). The magnitude of this increase in contextual cueing was similar between the groups (see Figure 10). A mixed ANOVA with factors of Group, Context and Block (10-12) revealed a main effect of Block ($F(2, 57) = 41.41$, $p < .001$, $\eta^2_p = .58$), reflecting the sequence learning effect reported earlier. The overall effect of Context was not significant ($F(1, 30) = 3.93$, $p = .06$, $\eta^2_p = .12$) but, more importantly for the present purposes, there was an interaction between Context and Block ($F(2, 56) = 8.53$, $p < .01$, $\eta^2_p = .22$). Simple effects analysis of this interaction revealed a significant difference between RTs to high- and low-frequency contexts during block 11 ($F(1, 31) = 11.53$, $p < .01$, $\eta^2_p = .27$) but no such evidence of contextual cueing during block 10 and 12 ($F(1, 31) = 0.01$, $p = .93$, $\eta^2_p < .01$). Furthermore, a planned contrast comparing the difference between the contexts in block 11 with the differences in block 10 and 12 demonstrated that the contextual cueing effect was significantly larger in Block 11 ($F(1, 31) = 12.14$, $p < .01$, $\eta^2_p = .28$). There was no main effect of Group ($F(1, 30) = .68$, $p = .42$, $\eta^2_p = .02$) or interaction of Group with any other factor (Group x Context $F(1, 30) = 0.06$, $p = .81$, $\eta^2_p < .01$; Group x Block $F(2, 57) = 0.28$, $p = .75$, $\eta^2_p = .01$; Group x Context x Block $F(2, 56) = 0.79$, $p = .45$, $\eta^2_p = .03$). Overall, these results indicated that contextual cueing emerged in test block 11 and that its emergence occurred comparably in both groups. In turn, the appearance of contextual cueing during block 11, when sequence knowledge was removed and invalidated, reconfirmed the critical role explicit sequence knowledge must have been playing in suppressing contextual cueing earlier in the rest of task.

CC Generation task

Performance was analysed by comparing the percentage of correctly generated target locations on high-frequency contexts with the chance level of 25 %. There was no evidence that performance was above chance ($M = -1.17$ %, $SEM = 2.01$ %, $t(31) = 0.58$, $p = .57$, $d = 0.10$) or that there was a difference between the groups (TD: $M = -1.56$ %; ASC: $M = -0.78$ %; $SED = 4.09$ %; $t(30) = 0.19$, $p = .85$, $d = 0.07$). This analysis implied that neither group had explicit knowledge about contexts and that all learning about context was implicit.

2.2.3. Subjective measures

The above analyses demonstrated that participants had knowledge about the sequence capable of underpinning performance on the SRT generation task. Additionally, such performance implied that the sequence knowledge was explicit, to the extent that it was available for use in more than one context (see Chapter I.4 for more discussion of the theoretical underpinnings of generation tasks). As a further assessment of the degree to which the sequence knowledge was explicit, the subjective measures obtained during the SRT generation task were also analysed. Specifically, the analysis considered whether sequence knowledge was explicit in the sense that participants also had the subjective experience of knowing when they were accurately generating examples (Dienes, 2008; Dienes, et al., 1995). According to the guessing criterion for subjective measures, there was no evidence of implicit sequence knowledge: there was no evidence that training sequences could be generated more often than test sequences when participants claimed to be guessing (Mean difference = 10.48 %, *SED* = 8.55 %, $t(26) = 1.23$, $p = .23$, $d = 0.24$). There was no evidence of a group difference in this regard (TD: $M = 13.15$ %; ASC: $M = 8.00$ %; *SED* = 5.15 %; $t(25) = 0.30$, $p = .77$, $d = 0.11$). Similarly, there was a suggestion that sequence knowledge was not implicit because it did not appear to meet the zero-correlation criterion. Specifically, there was an indication that participants generated more training than control sequences when their confidence was high than when it was low (High Confidence, ratings 5 to 7, = 21.74 %; Low Confidence, ratings 1 to 4, = 4.93 %; *SED* = 13.82 %). However, a mixed ANOVA on generation performance with factors of Group, Sequence (Training vs. Control) and Confidence (High vs. Low) showed that the interaction between Sequence and Confidence was not significant ($F(1, 22) = 1.36$, $p = .26$, $\eta^2_p = .06$). Further, there was no evidence that this interaction was different between the groups, as there was no evidence of three-way interaction with Group ($F(1, 22) < 0.01$, $p = .98$, $\eta^2_p < .01$). However, there was an issue of power in this particular analysis of the zero-correlation criterion: six participants provided no low-confidence answers, and thus provided no data, while the number of generation trials (22) was already small before being split between into high and low confidence.

The analyses of performance on the CC generation task provided no evidence of accurate generation performance, and thereby implied that any CC knowledge was not explicit. Since there was no evidence of accurate CC generation, it was impossible to determine whether accurate and inaccurate performances were accompanied by appropriate subjective experiences.

However, a comparison between the subjective measures taken from the two different generation tasks was appropriate because the comparison provided a more powerful test of the zero-correlation criterion for sequence knowledge. Specifically, the analysis determined whether accurate SRT and inaccurate CC generation performances were accompanied with appropriate subjective experiences. Confidence on the SRT-generation task was greater than the confidence on the unseen contexts from the CC-generation task (SRT: $M = 4.77$; CC: $M = 3.65$; $SED = 0.15$); this implied the knowledge underpinning performance on the SRT generation task was explicit. The two groups were quite similar in overall confidence across both generation-tasks (TD: $M = 4.50$; ASC: $M = 3.92$; $SED = 0.38$). Critically, the difference in confidence between the two tasks was similar between the groups (TD: $M = 1.24$; ASC: $M = 1.01$; $SED = 0.30$). This was confirmed by a mixed ANOVA on the mean confidence ratings using factors of Group and Generation Task (SRT vs. CC - Unseen Contexts). There was a main effect of Generation Task ($F(1, 30) = 57.02$, $p < .001$, $\eta^2_p = .66$), and no evidence of an effect of Group ($F(1, 30) = 2.44$, $p = .13$, $\eta^2_p = .08$) or interaction ($F(1, 30) = 0.60$, $p = .45$, $\eta^2_p = .02$).

Furthermore, both groups classified a greater number of answers as memories during the SRT as compared to the CC generation task (SRT: $M = 45.60$ %; CC: $M = 21.68$ %; $SED = 4.63$ %); this also indicated that performance on the SRT generation task was determined by explicit knowledge. Overall, the groups classified a similar percentage of answers as memories (TD: $M = 35.60$ %; ASC: $M = 31.68$ %; $SED = 8.00$ %) but more importantly, the difference percentage between the tasks was similar between the groups (TD: $M = 28.23$ %; ASC: $M = 19.60$ %; $SED = 9.27$ %). This was confirmed by a mixed ANOVA on the mean percentage of answers classified as memories using Group and Generation-Task as factors. There was a main effect of Generation task ($F(1, 30) = 26.64$, $p < .001$, $\eta^2_p = .47$), but no evidence of an effect of Group ($F(1, 30) = 0.24$, $p = .63$, $\eta^2_p = .01$) or interaction ($F(1, 30) = 0.87$, $p = .36$, $\eta^2_p = .03$). This evidence of accurate subjective knowledge about generation performance reinforced the conclusion that both groups had explicit sequence knowledge.

2.2.4. Direct awareness questions

Subjective measures, RT analyses and generation performance all suggested that sequence knowledge was similarly explicit for both groups by the end of the task. Consistent with this finding, the majority of participants from both groups reported that they had noticed the sequence (all 16 TD participants and 13 of the 16 ASC participants). Further, of those participants who noticed the sequence the majority of participants from both groups tried to memorise it (15 of the 16 TD participants and all 13 ASC participants). A majority of those participants demonstrated that they had memorised the *entire* sequence successfully by correctly producing the 8-digit training sequence at the end of the experiment (9 TD participants and 11 ASC participants). The answers to the direct awareness questions were also consistent with the finding that contextual knowledge was not explicit, and that that absence of explicit knowledge was true for both groups: only a minority of participants from each group claimed to have noticed some regularity in the contexts (5 out of the 16 TD participants and 6 out of the 16 ASC participants), and only 4 participants from each group reported trying to memorise any of the contexts. Finally, there was consistency from these responses with the conclusion that the lack of contextual cueing attenuation in the first two trial blocks reflected slower acquisition of explicit sequence knowledge in the ASC participants: only 1 ASC participant reported noting the sequence in block 1 or 2 compared with 4 TD participants.

2.2.5. Discussion

The main aim of Study III was to assess whether there were differences in explicit sequence learning between ASC and TD individuals that were independent of IQ. The analyses reported here demonstrated both groups successfully achieved sequence learning, and that the magnitude of the effect, as measured by differences between mean RTs to control sequences on test block 11 and compared with mean RTs to training sequences on the neighbouring blocks 10 and 12, was large and equivalent between the groups. Furthermore, there was a variety of evidence that the sequence learning was explicit, and the extent to which it was explicit was equivalent between the groups: there was a similarly detrimental effect of sequence invalidation to both groups, and both groups demonstrated successful generation performance and accurate subjective measures. This leads to the conclusion that the groups achieved a significant and similar final level of explicit sequence learning, and that there were no differences between ASC and TD individuals in final explicit learning when matched for IQ.

However, there is also evidence that ASC individuals were slower to learn and/or apply the sequence explicitly, independently of IQ. This initial acquisition of explicit sequence learning has not been assessed before. First, there was a suggestion that the ASC group were initially slower. This reduced explicit processing was corroborated by the atypical attenuation of implicit contextual cueing in the ASC group during the first two blocks of the task. Learning explicitly about the sequence typically leads to the selective attenuation of learning about the context (Jiménez & Vázquez, in press), as demonstrated by the current TD group. Therefore, the absence of the typical attenuation of contextual cueing in the ASC group is indicative of slowed explicit sequence learning. This interpretation, that the initial ASC contextual cueing effect is a consequence of the ASC group having not yet acquired and/or applied explicit sequence knowledge, is strongly supported by the interaction of contextual cueing and sequence knowledge for the rest of the task. The two groups show an identical use of explicit sequence knowledge to suppress contextual cueing during blocks 3-10, and both show equivalent contextual cueing when the sequence knowledge has been manipulated to be invalid during test block 11. Consistent with this interpretation, fewer ASC individuals reported noticing the sequence as early as the first or second block.

In order to further corroborate this important finding, an additional analysis was conducted to compare the initial contextual cueing of the ASC and TD individuals in either the presence or absence of sequential information. The performance of two groups from this study was compared with the contextual cueing performance of a subset of the two groups from Study II. Subsets of the two groups in Study II were chosen in order that the four groups were matched for sex (all males), chronological age ($F(3, 66) = 2.12$, $p = .11$, $\eta^2_p = .09$) and IQ ($F(3, 66) = 0.82$, $p = .49$, $\eta^2_p = .04$) of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999), see Table 15. The crucial difference between the two studies was that Study II used a non-sequential CC design. Everything else about the design of the tasks in the two different studies was comparable (see III.2.3.1 for a comparison). There was one procedural difference: the length of the blocks in Study II was half the number of trials. While this would have made a complete analysis of RTs from the two studies inappropriate, the consideration of the learning index (difference scores) and the relative comparisons between the groups were valid. In Study II, there was evidence of similar contextual cueing in both the groups, named here as the ASC-Study II (Mean DS = 44.40 ms, *SED* = 6.54 ms) and TD-Study II groups (Mean DS = 25.93 ms, *SED* = 12.13 ms). Consistent with this, a mixed ANOVA on RTs (Group x Context (High vs. Low) x Block (1-2)) yielded an effect of Context ($F(1, 36) = 26.05$, $p < .01$, $\eta^2_p = .42$) but provided no evidence of any other effects or interactions relating to learning (all $Fs \leq 2.21$, $ps \geq .15$ and $\eta^2_p \leq$

.06). There was a Group effect for the ASC-Study II individuals to be slower overall ($F(1, 36) = 4.22$, $p < .05$, $\eta^2_p = .11$; see Chapter III.3.1 for more details). The contextual cueing effect in the ASC group from Study III (ASC-Study III: Mean DS = 34.12 ms, *SED* = 12.08 ms) and the absence of evidence for contextual cueing in the TD group from Study III (TD-Study III: Mean DS = -8.21 ms, *SED* = 16.24 ms), has already been established above. Therefore, separate analyses had provided evidence of contextual cueing in the ASC-Study III, ASC-Study II and TD-Study II groups but had provided no evidence in the TD-Study III group. Consistent with these analyses, a one-way ANOVA between all four Groups from the two studies (Group (ASC-Study II; TD-Study II; ASC-Study III; TD-Study III) on the mean difference scores across the first 192 trials, yielded an effect of Group ($F(3, 66) = 3.52$, $p = .02$ $\eta^2_p = .14$). Furthermore, two planned contrasts comparing (i) the TD-Study III group with the TD-Study II group, and (ii) the TD-Study III group with the three remaining groups (ASC-Study II; TD-Study II; ASC-Study III) demonstrated that the TD-Study III group's contextual cueing effect was significantly smaller than (i) the TD-Study II group ($F(1, 66) = 4.09$, $p = .05$, $\eta^2_p = .06$) and (ii) the average effect for the ASC-Study II; TD-Study II; ASC-Study III groups ($F(1, 66) = 9.22$, $p < .01$, $\eta^2_p = .12$). Finally, a one-way ANOVA comparing just the three groups that had demonstrated a contextual cueing effect (ASC-Study II; TD-Study II; ASC-Study III) provided no evidence of group differences ($F(2, 51) = 0.83$, $p = .44$ $\eta^2_p = .03$). Together, these analyses suggested that the presence of a sequence had inhibited contextual cueing in the first 192 trials in TD individuals. In contrast, there was no evidence that the sequence had any effect on the contextual cueing of ASC individuals during the first 192 trials. Thus altogether there is convincing evidence that there was a difference between the groups in initial explicit sequence learning.

Table 15. *Mean Age (in years), WASI IQ Scores and Social Communication Questionnaire (SCQ) Scores (percentage) for ASC and TD Groups*

Measure	Subset of groups from Study II					
	TD-Study II *(N = 19)*			ASC-Study II *(N = 19)*		
	M	*SD*	*R*	*M*	*SD*	*R*
Chronological age	12.2	1.4	9.2 – 14.3	12.0	1.0	10.8 – 14.4
Full-scale IQ	105.6	11.0	91 – 135	100.3	15.0	79 – 126
	TD *(N = 15)*			ASC *(N = 11)*		
SCQ Score	11.6	8.1	2.5 – 32.5	69.9	16.9	30.0 – 85.0

3. Study IV

The findings of Study III indicate a difference in initial explicit sequence learning in ASC. However, the nature of the difference is not clear. It is possible that the reduced attenuation of contextual cueing in the ASC group may have been a consequence of either a difficulty in the initial stages of acquisition of the actual sequence information or poorer application of that acquired sequence knowledge. A second study attempted to tease apart whether the reduced effect of explicit processing on contextual cueing in the ASC group was due to slower explicit learning about a sequence or reduced ability to apply explicit sequence knowledge.

In order to do so, precisely the same method was used but with a critical manipulation: the inclusion of a pre-task learning phase. In this pre-task phase, all participants memorised the sequence that would be present in their task to the same criterion performance level. As a consequence of such a pre-task manipulation, both groups would have demonstrably equivalent knowledge of the actual sequence information. Therefore, remaining performance differences would imply that ASC individuals are slower at explicitly applying sequence information to sequence learning task success. Additionally, remaining performance differences would provide a replication of the modest ASC difficulty identified in Study III.

3.1. Method

3.1.1. Participants

16 children with ASC (referred to as the ASC group) and 16 Typically-Developing children (referred to as the TD group) were included in the study. None of the children had participated in the previous study. All children in the ASC group met established criteria for ASC, such as those specified in DSM-IV (American Psychiatric Association, 1994) and had previously received a diagnosis for ASC by trained clinicians using instruments such as the Autism Diagnostic Interview (Le Couteur, et al., 2003). Any other psychiatric diagnosis acted as an exclusion criterion for both the ASC and TD group. Table 16 presents the participant characteristics for both the groups. The two groups of children were matched for sex (16 males), chronological age ($t(21) = 1.13$, $p = .27$, $d = 0.40$) and IQ ($t(30) =0\ .75$, $p = .46$, $d = 0.26$) of the Wechsler Abbreviated Scale of Intelligence (WASI: Wechsler, 1999), see Table 16. Informed parental consent and the assent of the children were obtained, and ethical permission to conduct the study received from the Cambridge Psychology Research Ethics Committee. 13 of the parents of children with ASC and 9 of the parents of TD children completed the Social Communication Questionnaire (SCQ: Rutter, et al., 2003). The raw scores on the SCQ were converted into percentage scores. All the children in the TD group had scores below the cut-off score of 38.46 % specified by Rutter and colleagues, see Table 16. Further, the highest score for the TD group was 8.94 standard deviations below the mean of the ASC group. See Table 16 for a summary of the groups' characteristics.

Table 16. *Mean Age (in years), WASI IQ Scores and Social Communication Questionnaire (SCQ) Scores (percentage) for the ASC and TD Groups*

Measure	Study IV					
	TD *(N =16)*			ASC *(N =16)*		
	M	*SD*	*R*	*M*	*SD*	*R*
Chronological age	12.0	0.5	11.3 – 13.1	12.3	1.2	10.4 – 14.8
Full-scale IQ	107.0	11.2	92 – 126	104.1	10.6	83 – 122
	TD *(N =11)*			ASC *(N =15)*		
SCQ Score	6.5	5.1	0 – 12.8	59.1	21.0	28.2 – 89.7

3.1.2. Apparatus, materials, design and procedure

Precisely the same apparatus and materials were used as in Study III. The same design and procedure were used with two modifications. First, following initial instructions and the 8 practice trials but prior to start of the main task, participants were told that they would be presented with an 8-digit sequence. Further, they were instructed to memorise the sequence because it would present in the subsequent task, which they had just practised, and so memorising it would help them to press the buttons more quickly. Finally, they were told that once the sequence had disappeared after 3 seconds, they would be required to reproduce the sequence without making a mistake five times. When reproducing the sequence, upon typing an incorrect number, participants were instructed *“That is not the right number - please start again”*. Participants were then presented with the sequence for another 3 seconds before trying again to reproduce it. Second, blocks 3-10 were removed from the main task, since Study III had demonstrated that the differences of interest in explicit processing had occurred during the first two blocks, and by removing blocks 3-10, the other indices of explicit processing (the test block, the sequence validity manipulation, the generation task and subjective measures) would all be more appropriately placed and thus sensitive to detect such differences.

3.2. Results

Exactly the same analysis techniques and procedures were applied as described for Study III. For the SRT task, the results of the two analyses of accuracy and RT were entirely consistent with one another. Thus as in Study III, the analysis of accuracy is not reported here beyond the finding that overall accuracy was similar between the groups (TD: M = 93.39 %; ASC: M = 91.13 %; SED = 1.85 %; $t(25) = 1.23$, $p = .23$, $d = 0.43$; see Appendix B for the full accuracy analysis).

3.2.1. Pre-task phase

All participants memorised the sequence, which would be present in their task, to the same criterion performance level. Specifically, all participants correctly reproduced the sequence without errors 5 times. Further, there was no evidence of a difference between the groups in the number of mistakes made in achieving this (TD: M = 3.94; ASC: M = 4.25; SED = 1.41; $t(30) = 0.22$, $p = .83$, $d = 0.08$)

3.2.2. Sequence application learning

Training: Block 1-2

Figure 11 represents the mean RT at each level of block for each of the two groups. There was a decrease in RTs as participants progressed from blocks 1 to 2. A mixed ANOVA with factors of Group, and Block (1-2), confirmed this effect of Block ($F(1, 30) = 83.21$, $p < .001$, $\eta^2_p = .74$). There was no evidence of an effect of Group ($F(1, 30) = 1.39$, $p = .25$, $\eta^2_p = .04$), however, importantly, there was an interaction between Group and Block ($F(1, 30) = 4.95$, $p = .03$, $\eta^2_p = .14$). Inspection of Figure 11 and simple effects analysis revealed the source of this interaction: the performance of the groups was very similar in Block 1 ($F(1, 30) = 0.32$, $p = .58$, $\eta^2_p = .01$), and although both groups' performance improved significantly between blocks 1 and 2, (TD: main effect of block, $F(1, 15) = 58.69$, $p < .001$, $\eta^2_p = .80$; ASC: main effect of block, $F(1, 15) = 26.34$, $p < .001$, $\eta^2_p = .64$), the performance of the TD group was numerically, though not quite significantly, better than that of the ASC group in Block 2 ($F(1, 30) = 3.22$, $p = .08$, $\eta^2_p = .10$). Thus, the performance of the TD group improved to a greater extent compared to the ASC group. As discussed above, the improvement in performance over the first few blocks of

SRT tasks reflects both general practice effects and sequence learning (both learning sequence information and applying it). In Study II, which used a task that allowed sequence learning to be dissociated from general practice effects, ASC participants were shown to benefit from general practice. Critically, ASC participants took longer to benefit from that practice effect, i.e. over time the practice effect *decreased* TD and ASC differences in RTs. In contrast, the interaction in the present study demonstrated that the difference between the ASC and TD performance *increased* over time – i.e. after the first block. Therefore, the interaction was highly suggestive that the difference emerged as a result of slower learning to apply the sequence in the ASC group.

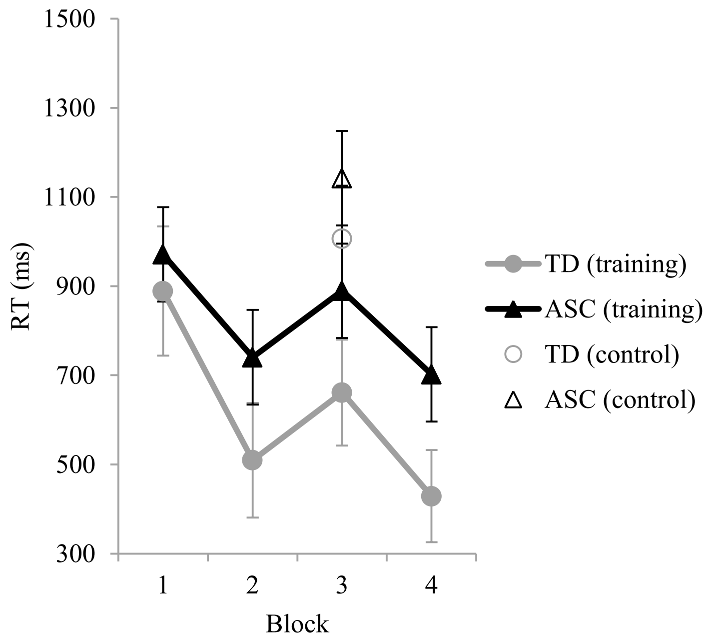


Figure 11. *In Study IV, TD and ASC groups both displayed disruption on the test block, as measured by the increase in RTs to the control sequence on the Test block compared with those on blocks 10 and 12 and the increase in RTs to the training sequence presented with low global validity. To the extent that the two groups did not differ in this disruption, it might be assumed that the ASC group learnt to apply sequence knowledge typically. However, this conclusion was mitigated by several other pieces of evidence that demonstrated worse sequence application learning in the ASC group. Depicted are mean reaction times across training for different groups. The error bars show twice the standard error of differences between group means at different levels of block.*

Test: Block 2-4

Whether or not the participants had learnt to apply the sequence was assessed by comparing the mean RTs to control sequences in Test Block 3 to mean RTs to training sequences on the neighbouring Blocks 2 and 4. For both groups, there were faster RTs on blocks 2 and 4 relative to test block 3, indicating that both groups had learnt to apply the sequence. The magnitude of these difference scores were comparable between the groups and therefore suggested that application of sequence knowledge was similar in both groups (TD: Mean difference (*M*) = 536.06 ms; ASC: *M* = 423.29 ms; *SED* = 93.79 ms). Consistent with these interpretations, a mixed ANOVA with factors of Group and Block (Control Sequences Block 3 vs. Block 2&4) confirmed the effect of sequence application learning with a main effect of Block ($F(1, 30) = 104.64$, $p < .001$, $\eta^2_p = .78$). The ASC group were numerically, but not significantly, slower overall than the TD group (Group $F(1, 30) = 3.92$, $p = .06$, $\eta^2_p = .12$), but, the lack of an interaction provided no evidence of group differences in learning to apply the sequence ($F(1, 30) = 1.45$, $p = .24$, $\eta^2_p = .05$).

Sequence validity: Block 2-4

As an indirect measure of whether the application of the sequence was explicit, mean RTs to training sequences on test block 3 (during which the sequence validity was disrupted) were compared with mean RTs to training sequences on neighbouring blocks 2 & 4. Both groups had increased RTs on the test block 3 compared with neighbouring blocks 2 & 4, and the magnitude with which the RTs were increased was similar between the groups (TD: Mean difference (*M*) = 190.94 ms; ASC: *M* = 170.74 ms; *SED* = 53.36 ms). A mixed ANOVA using factors of Group and Block (Training Sequences Block 3 vs. Block 2&4) supported this interpretation: although, the group with ASC was overall slower than the TD group ($F(1, 30) = 4.60$, $p = .04$, $\eta^2_p = .13$), there was a main effect of Block ($F(1, 30) = 45.94$, $p < .001$, $\eta^2_p = .61$) but no evidence of an interaction between Group and Block ($F(1, 30) = 0.14$, $p = .71$, $\eta^2_p = .01$). The similarly detrimental effect of sequence invalidation to both groups suggested that the application of sequence knowledge was similarly explicit between the groups.

SRT Generation task

Performance was analysed by comparing the percentage of correctly generated sequence fragments on training and control sequences. Performance on the training sequence was superior to control sequence performance, and thereby implied the groups had learnt to apply the sequence (Training: M = 77.90 %; Control: M = 41.74 %; *SED* = 4.80 %). However, this superiority was smaller in the ASC group, as a consequence of the ASC group generating fewer correct sequence fragments of training sequences (TD: Mean difference between Training and Control sequences (M) = 45.98 %; ASC: M = 26.34 %; *SED* = 9.60 %). This interpretation was supported by a mixed ANOVA with factors of Group and Sequence (Training vs. Control) as factors. There was a main effect of Group ($F(1, 30) = 5.21$, $p = .03$, $\eta^2_p = .15$) and Sequence ($F(1, 30) = 56.77$, $p < .001$, $\eta^2_p = .65$), and an interaction between Group and Sequence $F(1, 30) = 4.19$, $p = .05$, $\eta^2_p = .12$). Closer inspection of the data revealed the source of this interaction: while the groups were similar on control sequence generation (TD: M = 40.63 %; ASC: M = 42.86 %; *SED* = 5.48 %), they were very different on training sequence generation (TD: M = 86.61 %; ASC: M = 69.20 %; *SED* = 6.17 %). Simple effects, investigating the effect of Group for each of the training and control sequence generation separately provided statistical evidence of a difference between the groups on training ($F(1, 30) = 7.96$, $p = .01$, $\eta^2_p = .21$) but not control sequences ($F(1, 30) = .17$, $p = .69$, $\eta^2_p < .01$). Further simple effects, which considered the effect of Sequence in each group separately, established that an effect remained in each group (TD: $F(1, 15) = 92.15$, $p < .001$, $\eta^2_p = .86$; ASC: $F(1, 15) = 10.03$, $p = .01$, $\eta^2_p = .40$), and therefore implied that the interaction between Group and Sequence in the original analysis was the result of the sequence effect being *greater* in the TD than the ASC group, and *not* an absence of the ASC sequence effect altogether. In summary, this led to the conclusion that both groups were able to apply sequence knowledge explicitly, but the TD group were better able to do so, evidenced by their superior generation of training sequence fragments.

3.2.3. Contextual cueing

Training: Block 1-2

Mean RTs to high- and low-frequency contexts were compared as a measure of contextual cueing. Figure 12 represents the mean difference between high and low frequency context trials in each trial block for both groups; a difference score greater than zero is evidence of contextual cueing. There appeared to be minimal contextual cueing during the training blocks. A mixed ANOVA with Group, Context and Block (1-2) as factors provided some support for this interpretation. There was a main effect of Block ($F(1, 30) = 84.67$, $p < .001$, $\eta^2_p = .74$) and an interaction of Group and Block ($F(1,30) = 4.42$, $p = .04$, $\eta^2_p = .13$), but no evidence of an overall effect of Context ($F(1, 30) = 3.96$, $p = .06$, $\eta^2_p = .12$), Group ($F(1, 30) = 1.40$, $p = .25$, $\eta^2_p = .04$) or interaction of Group and Context ($F(1, 30) = 0.76$, $p = .39$, $\eta^2_p = .03$). However, there was an interaction of Context and Block ($F(1, 30) = 4.50$, $p = .04$, $\eta^2_p = .13$). Inspection of Figure 12 suggests that this interaction arose as a consequence of some contextual cueing in Block 2. Indeed, simple effects showed there was evidence of contextual cueing in Block 2($F(1, 31) = 6.54$, $p = .02$, $\eta^2_p = .17$) but not in Block 1 ($F(1, 31) < 0.01$, $p = .96$, $\eta^2_p < .01$). This appeared to arise chiefly as a consequence of the contextual cueing in the ASC group. The three-way interaction that would have supported this interpretation was not significant ($F(1, 30) = 0.74$, $p = .40$, $\eta^2_p = .02$) but given the Study III finding of atypical attenuation in the ASC group, the evidence of contextual cueing in Block 2 was considered separately for each group. Indeed, there was evidence of contextual cueing in the ASC group ($F(1, 15) = 6.89$, $p = .02$, $\eta^2_p = .32$) but not the TD group ($F(1, 15) = 1.06$, $p = .32$, $\eta^2_p = .07$).

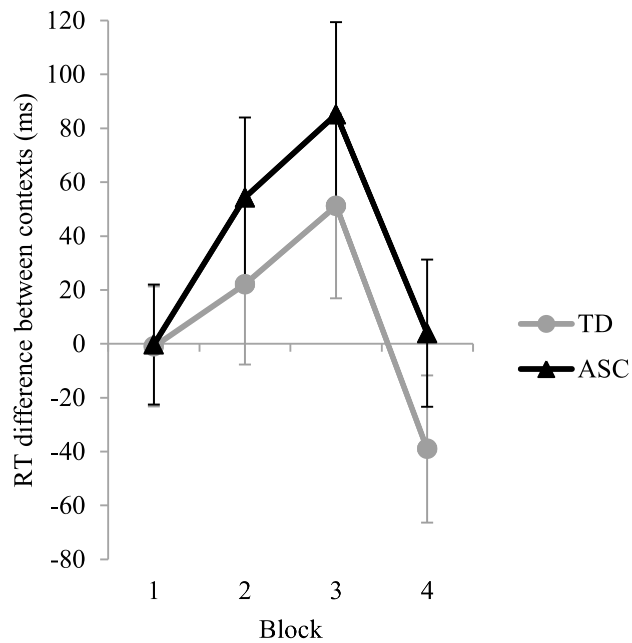


Figure 12. *In Study IV, the ASC group showed an atypical attenuation of contextual cueing across blocks 2-4, as demonstrated by a greater contextual cueing effect. Overall, the effect of removing and invalidating sequence information in block 3 caused contextual cueing to increase in both groups. Crucially this increase was part of an overall effect of contextual cueing across the blocks 2-4 in the ASC, but not the TD, group. Presented are the RT differences between contexts across the task. The error bars show twice the standard error of differences between group means at different levels of block.*

Test: Block 2-4

The analysis of performance in trial blocks 2-4 examined the effect of invalidating and removing sequence knowledge during Trial Block 3 on contextual cueing. Mean RTs between contexts on Block 3 were compared with those in the two neighbouring blocks 2 and 4.There was an increase in contextual cueing on Block 3 relative to Block 2 and 4 (see Figure 12). While this pattern was common to both groups, the overall effect of Context appeared greater in the ASC group (see Figure 12). A mixed ANOVA with factors of Group, Context and Block (2-4) fully corroborated this interpretation. There were overall effects of Group ($F(1, 30) = 4.72$, $p = .04$, $\eta^2_p = .14$), Context ($F(1, 30) = 11.20$, $p < .01$, $\eta^2_p = .27$) and Block ($F(2, 60) = 56.29$, $p < .001$, $\eta^2_p = .65$). There was no evidence of a Group and Block interaction ($F(2, 60) = 0.79$, $p = .46$, $\eta^2_p = .03$), but critically, there was an interaction between Group and Context ($F(1, 30) = 4.22$, $p = .05$, $\eta^2_p = .12$). This Context by Group interaction reflected an overall greater contextual cueing effect in the ASC group and, consistent with this, simple effects showed an overall context effect in the ASC ($F(1, 15) = 12.04$, $p < .01$, $\eta^2_p = .45$) but not the TD group ($F(1, 15) = 1.06$, $p = .32$, $\eta^2_p = .07$). There was also a Context by Block interaction ($F(2, 60) = 8.10$, $p < .01$, $\eta^2_p = .21$), reflecting the prominence of the contextual cueing effect in the test block when sequence information was removed and invalidated (see Figure 12). A linear contrast, comparing the difference between the contexts in Block 3 with the differences in Blocks 2 and 4, confirmed that the contextual cueing effect was significantly larger in Block 3 ($F(1, 31) = 8.52$, $p = .01$, $\eta^2_p = .22$). The increase in contextual cueing appeared equally true for both groups (see Figure 12). However, in order to confirm there was a contextual cueing effect in the TD group in Block 3, and remove any doubt that might have been raised by the interaction between Group and Context, further simple effects demonstrated a significant contextual cueing effect in the TD group in Block 3 ($F(1, 15) = 5.79$, $p = .03$, $\eta^2_p = .28$). There was no three-way interaction ($F(2, 60) = 0.04$, $p = .97$, $\eta^2_p < .01$).

Overall, this CC analysis of the test blocks demonstrated that the effect of removing and invalidating sequence information in block 3 caused contextual cueing to increase in both groups. Crucially, this increase was part of an *overall* effect of contextual cueing across the blocks 2-4 in the ASC group. This overall contextual cueing effect was significantly larger than in the TD group, for whom there was no evidence of an *overall* contextual cueing effect across blocks 2-4.

CC Generation task

Performance was analysed by comparing the percentage of correctly generated target locations on high-frequency contexts against the chance level of 25 %. There was no evidence that overall performance was above chance ($M = 5.08$ %, $SEM = 2.77$, $t(31) = 1.83$, $p = .08$, $d = 0.32$) but there was a difference between the groups (TD: $M = -0.78$ %; ASC: $M = 10.94$ %; $SED = 5.21$ %; $t(23) = 2.24$, $p = .03$, $d = 0.80$). However, there was still no convincing evidence of above chance performance when each group was considered separately (TD: $M = -0.78$ %, $SEM = 2.48$, $t(15) = 0.32$, $p = .94$, $d = 0.08$; ASC: $M = 10.94$ %, $SEM = 4.58$, $t(15) = 2.39$, $p = .06$, $d = 0.60$). While, this represented a hint of generation performance in the ASC group, critically, only 41.37 % of the correct generations provided were answered correctly on both presentations of the context. Only these answers that were provided on *both* presentations of the context represented reliable evidence of explicit performance. Yet, there was no evidence that this proportion of repeated responses was greater for correct than incorrect answers (Mean difference between percentage of repeated answers for correct and incorrect generations = 11.70 %, *SED* = 9.96 %, *p* = .26, *d* = 0.29). Therefore, it appeared that the ASC trend was not indicative of explicit generation performance. Correspondingly, participants were less confident about their answers, and classified fewer answers as memories, on high-frequency repeated contexts than to *previously unseen* contexts (Mean difference in confidence ratings = 0.19, *SED* = 0.08, *t*(15) = 2.51, *p* = .02, *d* = 0.63; Mean difference in percentage of memories = 6.64 %, *SED* = 3.15 %, *t*(15) = 2.11, *p* = .05, *d* = 0.53). Overall, this analysis implied that neither group had strong explicit knowledge about contexts and that learning about context was largely implicit.

3.2.4. Subjective measures

The analyses of the SRT generation task demonstrated that participants had knowledge about the sequence that was explicit, to the extent that it was available for use in more than one context. There was further evidence that sequence knowledge was explicit from the subjective measures. Specifically, according to the guessing criterion there was no evidence of implicit knowledge: when the participants reported themselves to be guessing, there was no evidence that training sequences were generated more often than the test sequences (Mean difference = 0.40 %, *SED* = 13.08 %, *t*(14) = 0.03, *p* = .98, *d* < 0.01). There was no evidence of a group difference in this regard (TD: *M* = -25.85 %; ASC: *M* = 23.36 %; *SED* = 23.52 %; *t*(13) = 2.09, *p* = .06, *d* = 1.08). Additionally, there was evidence that the knowledge was not implicit because it failed the zero-correlation criterion: participants generated more training than control sequences if their confidence was high than when it was low (High Confidence, ratings 5 to 7, = 49.61 %; Low Confidence, ratings 1 to 4, = 10.66 %; *SED* = 10.40 %). This difference in generation performance depending on confidence was similar between the groups (TD: *M* = 56.08 %; ASC: *M* = 24.46 %; *SED* = 20.25 %). A mixed ANOVA on generation performance with factors of Group, Sequence (Training vs. Control) and Confidence (High vs. Low) confirmed the interaction between Sequence and Confidence ($F(1, 22) = 15.81$, $p < .01$, $\eta^2_p = .42$), and was consistent with the lack of a three-way interaction with group ($F(1, 22) = 2.44$, $p = .13$, $\eta^2_p = .10$).

The analyses of performance in the CC generation task provided no evidence of accurate generation performance, and thereby implied that any contextual cueing knowledge was not explicit. Since there was no evidence of accurate CC generation, it was impossible to determine whether accurate and inaccurate performances were accompanied by appropriate subjective experiences. However, a comparison of subjective measures between the two generation tasks allowed a further assessment of sequence knowledge in relation to the zero-correlation criterion. Specifically, there was an assessment of whether accurate SRT generation and inaccurate CC generation were accompanied with appropriate subjective experiences. Confidence on the SRT-generation task was greater than the confidence on the unseen contexts from the CC-generation task (SRT: M = 5.22; CC: M = 4.11; SED = 0.16), which implied the knowledge that underpinned performance on the SRT generation task was explicit. Across both the generation tasks, overall confidence was very similar between the groups (TD: M = 4.49; ASC: M = 4.85; SED = 0.28). Critically, the difference in confidence between the two tasks was in the same direction for both groups, and as was expected given the TD group's superior performance on the SRT-task, the difference was larger in the TD group (TD: M = 1.43; ASC: M = 0.79; SED = 0.32). A mixed ANOVA on the mean confidence ratings with factors of Group and Generation-Task (SRT vs. CC-Unseen Contexts) confirmed the greater confidence on the SRT task ($F(1, 30) = 48.41$, $p < .001$, $\eta^2_p = .62$), and an interaction between Group and Generation-Task ($F(1, 30) = 4.07$, $p = .05$, $\eta^2_p = .12$) confirmed the interpretation that the TD group displayed a *greater difference* in confidence in favour of the SRT task. Simple effects analysis, looking at the difference in confidence between tasks in just the ASC group separately (ASC: $F(1, 15) = 22.78$, $p < .001$, $\eta^2_p = .60$), confirmed that the ASC group was also more confident during the SRT, and that the interaction must have stemmed from a greater difference in the TD group. There was no evidence of a group difference in overall confidence ($F(1, 30) = 1.71$, $p = .20$, $\eta^2_p = .05$).

Furthermore, both groups classified a greater percentage of answers as memories during the SRT as compared to the CC generation task (SRT: M = 54.97 %; CC: M = 17.58 %; SED = 5.39 %); this also indicated that performance on the SRT generation task was determined by explicit knowledge. Across both tasks, the percentage of memory classifications was similar between the groups (TD: M = 31.37 %; ASC: M = 41.18 %; SED = 6.74 %). More importantly, the difference between the two tasks was in the same direction for both groups, and that difference was larger in the TD group (TD: M = 46.34 %; ASC: M = 28.44 %; SED = 10.45). A mixed ANOVA with factors of Group and Generation-Task on the mean percentage of answers classified as memories corroborated the difference in that percentage between the tasks ($F(1, 30)$

= 51.19, $p < .001$, $\eta^2_p = .63$). However, the interaction failed to reach significance ($F(1, 30) = 2.93$, $p = .10$, $\eta^2_p = .09$). There was no evidence of a group difference in overall memory classification ($F(1, 30) = 2.11$, $p = .16$, $\eta^2_p = .07$).

Altogether, this evidence of accurate subjective knowledge (confidence and classification) relating to generation performance reinforced the conclusion that both groups had explicit sequence knowledge. Additionally, the finding that the TD compared with the ASC group had a greater difference in confidence between tasks provided convergent evidence that the TD group had been better than the ASC group at generating sequence fragments explicitly. This latter conclusion was supported by the fact that in Study III, when there had been no evidence of differences in generation performance, there was no evidence of differences between the groups on the subjective measures.

3.2.5. Direct awareness questions

Subjective measures, RT analyses and generation performance all suggested that sequence knowledge was explicit for both groups by the end of the task. Consistent with this finding, all participants from both groups reported that they believed there was usually a sequence to the order in which they pressed the keys. Further, 15 of the 16 participants in both groups reported that they used the memorised sequence to help them to go faster. Of these 15, 14 of the TD and 12 of the ASC, participants reported using it to help them within the first two blocks. A majority of the participants also demonstrated that they could still repeat the *entire* sequence by correctly producing the 8-digit training sequence at the end of the experiment (15 TD participants and 13 ASC participants). However, there was no additional evidence from these direct questions that could distinguish a group difference in the success with which the sequence was applied.

In contrast to sequence knowledge, there was no convincing evidence from any of the previous analyses that contextual knowledge was explicit. Correspondingly, only a minority of participants from each group claimed to have noticed some regularity in the contexts (4 out of the 16 TD participants and 6 out of the 16 ASC participants), and of those participants only 1 ASC participant reported trying to memorise any of the contexts.

3.2.6. Discussion

In general, Study IV intended to further elucidate ASC differences in explicit processing. Specifically, the aim was to determine whether the reduced attenuation of contextual cueing shown in the ASC group in Study III was a consequence of a difficulty in learning about the actual sequence or poorer application of acquired sequence knowledge. The same method was therefore used but with the inclusion of a critical manipulation: a pre-task learning phase in which all participants memorised the sequence to the same criterion performance level. Consequently, both groups had demonstrably equivalent knowledge of the actual sequence information prior to the start of the hybrid task. Thus, any performance differences during the hybrid task are attributable to differences in the extent with which the groups had learnt to apply that knowledge. Insofar that the two groups did not differ in the degree to which their performance was disrupted by the control sequences in the test block, it might be assumed that the ASC groups were able to apply the trained sequences typically.

However, this conclusion is mitigated by several other pieces of evidence showing poorer application of sequence knowledge. In detail, the RT data indicated that the ASC group were less able to apply their sequence knowledge across blocks 1 & 2 compared to the TD group. This was corroborated by the fact that, even though the majority were able to report the entire sequence at the end of testing, thus demonstrating knowledge of the sequence, their ability to complete sequence fragments and their confidence in the generation task was significantly reduced. Finally, they showed evidence of atypical attenuation of contextual cueing. Therefore, these performance differences imply that ASC individuals are slower at explicitly applying sequence information to sequence learning task success. Additionally, these performance differences imply that the disruption by control sequences, on which there was no evidence of group differences, may not be a sufficiently sensitive measure of the application of sequence knowledge.

Although clear evidence of greater contextual cueing in the ASC but not TD group was observed in Study IV, this evidence emerged in later trial blocks compared to Study III. Given that the only difference in procedure between the two studies was the training on the sequence to a criterion performance level prior to beginning the hybrid task in Study IV, the later emergence of contextual cueing in the ASC group suggests the explicit sequence knowledge did have an effect on contextual cueing in the ASC group early in the task. Presumably their atypical attenuation of contextual cueing was shifted to later trials because the explicit sequence knowledge at the outset of the hybrid task slowed the rate at which the ASC group acquired implicit contextual cueing. However, complete and typical attenuation of the contextual cueing must also be contingent upon learning to apply the sequence knowledge: in Study IV, the group with ASC both demonstrated the greater contextual cueing effect in later trial blocks and were demonstrably worse in applying their sequence knowledge, as evidenced by inferior sequence fragment generation performance. In contrast, by the end of 12 blocks in Study III the ASC group had learnt how to apply the sequence as well as the TD group, since there was no evidence of a difference between the groups on any of the measures of sequence learning, and accordingly there was typical attenuation of contextual cueing. Presumably, the 12 blocks of Study III provided sufficient opportunity for the ASC participants to learn how to apply their sequence knowledge equivalently to the TD group.

Also, in contrast to Study III, the groups were comparably fast in the first block. Presumably, this was also a consequence of the pre-task manipulation. That is, participants were both given the sequence information, and therefore considerable encouragement to apply it. Both groups successfully used the sequence knowledge to their advantage, and this therefore eliminated the difference between the groups in the first block. It was only with time across the blocks, that the TD group's superior application learning came to cause a group difference.

4. Chapter Discussion

Study III used an implicit learning task that encouraged explicit processing to assess whether there were differences in explicit sequence learning between ASC and TD individuals that were independent of IQ. It was argued at the outset that if the poorer ASC performance on those implicit learning procedures that encouraged explicit processing was due simply to lower IQ in the ASC groups (Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000), then we should see no difference in performance in the current IQ-matched groups. The findings of Study III demonstrated that *final* explicit sequence learning in ASC and TD individuals was similar in both magnitude and the extent to which it is explicit, thereby providing no evidence of final differences between the groups when matched for IQ. However, there was evidence that *initial* explicit sequence learning, which had not before been assessed, was atypical in ASC individuals independently of IQ.

The early RT slowness in the ASC group was consistent with the ASC group being less able to learn the sequence across the first two blocks, but the only conclusive evidence came from the atypical attenuation of implicit contextual cueing found in the ASC group during those early blocks. Learning explicitly about the sequence typically leads to the selective attenuation of learning about the context (Jiménez & Vázquez, in press), as demonstrated by the current TD group. Therefore, the absence of the typical attenuation of contextual cueing in the ASC group was indicative of slowed explicit sequence learning. Further, for the remainder of the task, once explicit sequence knowledge had been learnt, the sequence knowledge modulated performance in exactly the same fashion between the two groups: between blocks 3-10, explicit sequence knowledge suppressed contextual cueing in both groups, but during the test block when sequence knowledge was invalidated, a contextual cueing effect emerged equivalently between the groups.

Study IV replicated the early RT slowness and atypical attenuation effect in the ASC group generally, and provided more evidence of these early explicit differences by revealing an ASC difficulty in the SRT generation task and correspondingly less insightful subjective measures. This provision of additional evidence arose through the use of a shortened task which thereby provided additional measures of sequence learning earlier in the task. Moreover, Study IV resolved whether ASC differences in explicit processing stemmed from difficulties in explicitly learning about the sequence or difficulties in learning to apply that explicit sequence knowledge. Specifically, Study IV demonstrated that there was a difficulty in applying explicit sequence knowledge: when learning about the sequence was controlled, such that both groups demonstrated equivalent knowledge about the sequence, differences between the groups remained. This demonstrated that the difference in explicit processing was a consequence of an ASC difficulty in applying explicit sequence knowledge. In contrast, the fact that both groups took the same number of attempts to achieve the sequence knowledge in a pre-task phase, suggested that explicitly learning about a sequence is not impaired.

The finding that ASC groups find it more difficult to apply explicit knowledge to task success may reconcile some of the discrepancies in previous studies. Specifically, this difficulty may be part of the reason why in the past ASC groups have performed worse on implicit tasks that encouraged explicit processing, in contrast with those tasks that did not encourage such processing. Further, it is possible that this difficulty might also account for other findings concerning differences in tasks requiring the quick application of recently acquired explicit knowledge to achieve task success. For example, Study II reported an ASC difficulty in the explicit memorisation phase of the Artificial Grammar Learning task. This required participants to memorise and then reproduce apparently random letter strings, which had only been shown to them for a short period of time. The study found that ASC participants made more errors than the TD participants before correctly reproducing a letter string. Similarly in an explicit reinforcement learning task, Yechiam, Arshavsky, Shamay-Tsoory, Yaniv, & Aharon (2010) found ASC differences in the capacity for recently learnt choice-outcomes to affect behaviour, with ASC performance instead dominated by a cognitive style that placed value on exploratory choices.

This finding of difficulties in applying explicit learning in ASC is perhaps not surprising. Explicit processing requires flexibility and intentional processing (e.g., Cleeremans & Jiménez, 2002) and the current findings resonate with a body of literature concerning impairments in executive functions involving flexibility and intentional processing in ASC (e.g., Baron-Cohen, et al., 2000; Happé & Frith, 2006; Hill, 2004; Russell, 1997a). Furthermore, previous studies have documented an atypical propensity in ASC individuals to rely on explicit strategies when it is not typical to do so (e.g., on a Rotary Pursuit task, Gidley Larson & Mostofsky, 2008; on an Artificial Grammar Learning task, L. G. Klinger, et al., 2007; and, on Theory of Mind tasks, Happé, 1995; Hill & Frith, 2003). Such a propensity, together with the kind of impairment documented in Studies III and IV, could amount to considerable impairment over a large range of learnt skills. It is worth noting that although the Studies III and IV have not documented any ASC propensity for explicit strategies, this is not surprising. These studies had minimal sensitivity to measure such propensity for explicit strategy use because the simplicity of the sequence learning task strongly encouraged all participants to use explicit strategies.

In addition to detecting difficulties in applying explicit learning, both Studies III and IV provided further demonstrations of intact implicit learning in ASC (Study II, Barnes, et al., 2008; Kourkoulou, et al., 2010; Travers, et al., 2010). The contextual cueing observed in the ASC group in both studies was demonstrably implicit in that the improved RTs were accompanied by an inability to perform on the generation task, together with appropriately implicit accompanying subjective measures. The current replication of intact implicit learning, together with the previous demonstrations (Study II, Barnes, et al., 2008; Kourkoulou, et al., 2010; Travers, et al., 2010), pose a challenge to the common assumption that it is deficits in implicit learning that underpin the difficulties observed in ASC in those real-world domains associated with implicit acquisition, such as language, social and motor skills. The solution lies in the obvious fact that intact implicit learning is necessary to the implicit acquisition of real-world skills but it is not sufficient. There are many other processes that might be different in ASC, which would be sufficient to disrupt the implicit acquisition of those skills, in spite of otherwise intact implicit learning mechanisms.

One mechanism that has already been suggested is that there is an ASC overuse of atypical explicit strategies. Another candidate is the well-documented unusual attention allocation in ASC. Unusual attention may disrupt the appropriate sampling of the relevant features of the real world situation for implicit learning to proceed (Courchesne, et al., 1994; Happé & Frith, 2006; Klin, Jones, Schultz, Volkmar, & Cohen, 2002). Indeed, on an adapted version of the contextual cueing procedure, in which the local context was random and only the global context cued participants, ASC performance was found to be inferior to TD performance (M. R. Klinger, Klinger, Travers, & Mussey, 2008). This might be explained by an ASC attentional preference of the local over the global context (Happé & Frith, 2006) that obstructed the learning. Since this thesis documents preserved implicit learning in ASC, it predicts that there might be superior performance by individuals with ASC on implicit learning tasks in which the relevant features for learning are those to which individuals with ASCs have an attentional bias (Heaton & Wallace, 2004; Mottron, et al., 2006). In line with this speculation, Kourkoulou and colleagues (2010) demonstrated enhanced implicit learning of the local context in the contextual cueing paradigm. Further, in a more ecologically valid example, Grossman and Tager-Flusberg (2008) demonstrated enhanced performance on a task involving mouth expertise – an area of the face to which ASC individuals allocate an unusual amount of attention.

Another possible explanation is that the knowledge derived from implicit learning is not applied successfully in the real world. This possibility cannot be assessed easily by the standard implicit procedures that demonstrate learning by indirect assessments or forced choices. In the real world the products of implicit learning must be utilised in ways above and beyond those demanded by these laboratory procedures. For example, according to a theory which understands implicit learning within a graded consciousness framework (Cleeremans, 2006; Cleeremans & Jiménez, 2002), there would be further utility from implicit learning when there is also potential for its products to emerge into awareness and under cognitive control. Equally, in line with ideas and theorising on the role of implicit learning in intuition (Eraut, 2004; Hogarth, 2001), there would be further advantage from implicit learning if it exists in tandem with an ability to know when to act on the implicitly acquired knowledge. Thus, if individuals had difficulties with either of these related capacities, then they would present with difficulties in everyday abilities associated with implicit acquisitions, regardless of the learning mechanisms. Although, this is a unique hypothesis in relation to implicit learning in ASC, I am not the first author to allude to a relevant dissociation between capability and application in ASC (e.g., Minshew, Meyer, & Goldstein, 2002; Soulières, et al., 2007). Further, consistent with this discussion, ASC impairment in the successful application of implicitly acquired information would tessellate with *"a recent shift toward understanding ASC in the context of dysfunctions in introspection or self-referential processing"* (Chiu, et al., 2008, p. 468; e.g., Ben Shalom, et al., 2006; Hill, Berthoz, & Frith, 2004; Iacoboni, 2006; Kennedy, Redcay, & Courchesne, 2006; Lind & Bowler, 2008; Rieffe, Meerum Terwogt, & Kotronopoulou, 2007; Russell, 1997b; Toichi, 2008; Williams & Happé, 2009).

Additionally, there might be impairments in the long-term consolidation of skills associated with an implicit acquisition in ASC. Studies have emphasised the crucial importance of consolidation, or off-line learning, to further improvement after implicit learning, and the role of sleep for determining the relative improvement of implicit and explicit learning contributions (for a review, see Song, 2009). In particular, sleep seems particularly relevant to the subsequent development of insight from implicit learning episodes (U. Wagner, Gais, Haider, Verleger, & Born, 2004). ASC is highly associated with sleep difficulties (American Psychiatric Association, 1994). Therefore, ASC differences in the consolidation of implicitly learnt information may account for some of the ASC deficits in everyday skills associated with implicit acquisition.

Finally, I have already proposed that ASC attentional biases together with intact implicit learning predicts the possibility of ASC superiority in acquiring skills or information that appeals to those biases. Additionally, I propose that atypical explicit strategies can result in similar superiority. Indeed, Studies III and IV provide an empirical example of ASC superiority in what information is learnt implicitly about the context, but not as a consequence of characteristic attentional biases. Namely, the ASC group demonstrated contextual cueing, as a consequence of ASC differences in explicit use of sequence information and thus atypical attenuation of attention to the context. Clearly, the current finding can be regarded as an ASC superiority in the implicit acquisition of contextual cueing compared to the TD group. By contrast, the TD group directed their attention towards the explicit component of the task, thereby preventing the TD group from acquiring implicit contextual cueing to the same degree as the ASC group. Rather than a deficit in implicit learning, it thus appears that there can be ASC superiority in what is learnt implicitly, as a consequence of differences in the information that is processed and attended. I can speculate further about the significance of a superior implicit acquisition of certain information: if it is the case that savant talent results, in part, from implicit learning (Mottron, et al., 2006), then it is clearly possible that the development of a savant skill results from the interaction between atypical explicit processing, attentional biases and typical, intact implicit processing.

V. General Discussion

This thesis began with a review of the implicit learning literature, and concluded that an analysis of functional differences in implicit learning is a valid and important research topic. In particular, the evidence supporting the existence of functional differences is equivocal, and researchers argue that the issue could be resolved, or at least better understood, by further empirical exploration (Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, 1993; A. S. Reber & Allen, 2000). Therefore, this thesis analysed whether functional differences exist in two areas that have produced promising findings: individual differences in typical populations (Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press) and group differences between Autism Spectrum Condition (ASC) and Typically Developing (TD) individuals (e.g., L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). Overall, the results from four studies emphasised a lack of functional differences in implicit learning between individuals. In this final chapter, the key ideas and results already presented will be reiterated, and then discussed within a broader context.

1. Final Summary

The general aim of Study I was to test the claim that there are meaningful individual differences in implicit learning. In order to achieve that aim, it was first necessary to replicate the overlap between implicit learning tests identified by Gebauer and Mackintosh (2010). Similarly, it was necessary to re-establish the independence of implicit learning from IQ-mediated explicit processing (e.g., Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991), and investigate possible relationships between implicit learning and intuitive aspects of personality (Kaufman, et al., in press). Additionally, in order to establish whether implicit learning was related to meaningful differences in everyday performance other than second language acquisition (Gebauer & Mackintosh, 2010; Kaufman, et al., in press), the study investigated whether implicit learning was related to occupational achievement. It has been proposed that tacit knowledge may be the intermediary construct that mediates the influence of implicit learning influence on behaviour (Mackintosh, 1998). Therefore, the study also examined the relationship between occupational tacit knowledge and implicit learning. Finally, in order to understand fully the implications of a tacit knowledge and implicit learning relationship, the study explored contentious issues in the tacit knowledge literature, such as the generality of tacit knowledge and its relationship with IQ, personality and practice (e.g., Gottfredson, 2003a, 2003b; McDaniel & Nguyen, 2001; McDaniel & Whetzel, 2005; Sternberg, 2003). To address all these issues, data were collected from 103 academic psychologists, who completed three implicit learning tasks (SRT, AGL, IFL tasks), two IQ sub-tests (DAT verbal and analogical reasoning tests), one personality questionnaire (Big Five Inventory), three Tacit Knowledge Inventories (Academic Psychology, Business Management and CSQ) and one General Questionnaire pertaining to their educational and occupational histories.

Critically, there was no evidence of inter-correlation between the implicit learning tasks, nor was there any evidence to relate performance on any of the implicit learning tasks to IQ, occupational achievement, personality or tacit knowledge. Therefore, the results implied that there are not substantial individual differences in implicit learning. The study did replicate a finding that is important to the distinction between implicit and explicit learning: indices of explicit processing, but not performance on implicit learning tasks, were correlated with IQ (e.g., Carroll, 1993; Gebauer & Mackintosh, 2007, 2010; Kaufman, et al., in press; A. S. Reber, et al., 1991). Finally, Academic Psychology and Business Management Tacit Knowledge Inventories were found to measure knowledge that predicted occupational achievement in academic psychology incrementally to IQ and personality, and was general to both occupations. Importantly, however, tacit knowledge appeared to be acquired primarily as a function of practice and experience, rather than individual differences in implicit learning.

Overall, Study I represents one of four large-scale studies to explore the possibility of individual differences in implicit learning. All four studies dissociated implicit performance from explicit, IQ related performance, while two of the studies also found individual relationships between implicit learning tasks and real-world measures (second language acquisition and personality). However, critically, three of the four studies have now failed to find inter-relationships between implicit learning tasks (Study I, Gebauer & Mackintosh, 2007; Kaufman, 2009). Gebauer and Mackintosh (2010) did find evidence of significant relationships between several implicit learning tasks, and related the general implicit component to second language acquisition. This represents the only evidence for the idea that implicit learning is a general ability in the typical population that underpins meaningful individual differences. Gebauer and

Mackintosh (2010) suggested that the shared variance was uniquely apparent in their study because of the large number of implicit learning measures employed; 15 different indices of implicit learning were inter-correlated. However, the authors still described the overlap between their tasks as *"modest"* (for example, only twenty-seven of the one-hundred and five correlations between the indices were significant) and noted that further replications were necessary to establish the result. Additionally, the relationship between the ability and second-language was small (r = .15). Thus, the evidence for important individual differences in implicit learning is weak. Instead, I assert that overall the evidence is consistent with A. S. Reber's (1993) prediction that individual differences in implicit learning are minimal.

Concurrently to the investigation in Study I, the issue of functional differences in implicit learning was explored using a group-differences approach, which compared implicit learning in ASC and TD children. The diagnosis of ASC is dependent on the presence of social, communicative and motor impairments, which are all areas of functioning considered to be acquired, at least in part, by implicit processes. Thus, if ASC individuals also demonstrated a general deficit on implicit learning tasks, then there would be evidence that general implicit learning differences have important, functional consequences for behaviour. In order to assess whether ASC individuals have a general deficit in implicit learning, it was necessary to compare groups of ASC and TD individuals on a range of implicit learning tasks. The range was important to control for variations in task demands and to allow conclusions about implicit learning in general. Additionally, it was important to compare the groups on an overtly explicit learning task. I argued that in several previous attempts to assess implicit learning in ASC explicit, rather than implicit, learning was unintentionally measured, and that in groups unmatched for IQ, it was the explicit processes that were responsible for the observed ASC performance deficits (e.g., Gordon & Stark, 2007; L. G. Klinger & Dawson, 2001; L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). The validity of this alternative interpretation of previous studies' results was tested by comparing the relative patterns of implicit and explicit learning performance in groups of children with ASC and TD children, both matched and unmatched for IQ. Lastly, in order to assess the possibility that any implicit learning deficit underpinned the poor social, communicative and motor abilities prominent in ASC, the study included a quantitative index of ASC symptomatology, which could have been correlated with any performance deficits. Therefore, in Study II data were collected from ASC and TD individuals, who completed four implicit learning tasks (CC, SRT, AGL, and PCL tasks), one explicit learning task (PAL task), an IQ test (WASI) and an index of ASC symptomatology (SCQ).

Most importantly, there was convincing evidence that implicit learning is intact in ASC: performance on each of the four implicit learning tasks was equivalent between the two groups. It was argued that deficits reported in previous studies must have resulted from the differences between their task procedures and those used here (e.g., L. G. Klinger, et al., 2007; Mostofsky, et al., 2000). In particular, I argued that those studies that had found deficits used procedures that encouraged explicit strategies, which specifically disadvantaged the ASC groups who had not been matched for IQ. Statistical comparisons of matched and unmatched groups from Study II supported this interpretation of previous studies. Specifically, performance on the explicit learning task was not significantly different between the ASC and TD groups as far as they were matched for IQ, but an ASC deficit in explicit learning performance was revealed when the full (non-IQ-matched) samples were considered. In direct contrast, the evidence of equivalent ASC and TD implicit learning performances remained. This contrast demonstrated that a lower IQ was a disadvantage to the ASC group on explicit but not implicit learning tasks.

In order to determine whether the previous reports of implicit learning deficits in ASC resulted *just* from differences in IQ, or whether there was also a contribution from an ASC difficulty in explicit learning that was independent of IQ, Study III compared ASC individuals with IQ-matched TD individuals on an implicit learning task that encouraged explicit strategies. Specifically, the study used a simple sequence learning procedure that had been found to result in a considerable amount of explicit knowledge. This SRT procedure was combined with a contextual cueing task that provided an indirect, ongoing index of the extent to which sequence learning was explicit. Essentially, the contextual cueing effect is attenuated only when the learning and use of sequence information is explicit (Jiménez & Vázquez, in press).

The two groups achieved a significant and similar final level of explicit sequence learning, and thereby implied that there were no differences between ASC and TD individuals in final explicit sequence learning when matched for IQ. However, there was also evidence that ASC individuals were slower to learn and/or apply the sequence explicitly, irrespective of IQ. Specifically, there was a suggestion that the ASC group were initially slower. This reduced explicit processing was corroborated by the atypical attenuation of implicit contextual cueing in the ASC group during the first two blocks of the task. In order to verify that the attenuation was atypical, direct comparisons were made with the contextual cueing effects of the groups from Study II. Those analyses suggested that the presence of a sequence had inhibited contextual cueing in the initial, equivalent blocks in TD individuals. In contrast, there was no evidence that the sequence had any effect on the contextual cueing of ASC individuals during the initial, equivalent blocks.

Overall, the findings of Study III indicated a difference in initial explicit sequence learning in ASC. However, the nature of the difference was not clear. It was possible that the reduced attenuation of contextual cueing in the ASC group was a consequence of either a difficulty in the initial acquisition of the actual sequence information or poorer initial application of that acquired sequence knowledge. Study IV attempted to tease apart whether the reduced effect of explicit processing on contextual cueing in the ASC group was due to slower explicit learning about a sequence or reduced ability to apply explicit sequence knowledge. In order to distinguish these possibilities, a similar procedure was used but with the critical inclusion of a pre-task learning phase, during which all participants memorised the sequence to the same criterion performance level. Having eliminated the possibility for differences in learning about the sequence with this manipulation, remaining performance differences would imply that ASC individuals are slower at explicitly learning to apply sequence information to sequence learning task success. Additionally, the differences between the groups had been identified early in the task in Study III. Thus, in Study IV, in order to provide additional measures of sequence learning earlier in the task, the task was shortened such that the third block was the test block, and the generation tasks were completed after the fourth block.

Although the two groups did not differ in the degree to which their performance was disrupted by the control sequences in the test block, there were several measures that implied there was still an ASC difficulty. Study IV provided a general replication of the early RT slowness and atypical attenuation of the contextual cueing effect in the ASC group. Additionally, there was an ASC difficulty on the SRT generation task, and correspondingly less insightful subjective measures. Thus, several performance differences existed between the ASC and TD groups. The pre-task phase had controlled for any group differences in explicit learning about the sequence by enforcing a criterion performance level, which ensured that all participants had equivalent explicit sequence knowledge prior to beginning the task phase proper. Therefore, the performance differences during the task must have stemmed from an ASC difficulty in learning to apply that explicit sequence knowledge. In contrast, the criterion performance level enforced in the pre-task phase was reached in a similar number of attempts by the two groups, which demonstrated that explicitly learning about sequence information was not impaired in ASC. Thus, Study IV had replicated the ASC difficulty identified in Study III, and elaborated the nature of that difficulty: ASC individuals were able to learn sequence information explicitly but they had a specific difficulty with learning to apply that explicit information.

In addition to providing insight into explicit sequence learning in ASC, the contextual cueing effect in the ASC group in Studies III and IV also represented further evidence that implicit learning was intact. Therefore, Studies II, III and IV had all provided evidence of intact implicit learning in ASC. Some researchers have previously argued that ASC individuals use explicit, IQ-related strategies to compensate for their deficits in implicit learning (L. G. Klinger, et al., 2007), and thus might contend that the current demonstrations of intact implicit learning in ASC reflect explicit compensation. However, this argument is repudiated by three sets of results across the three studies. First, in two examples of intact implicit learning, the contextual cueing effects in Studies III and IV, the ASC individuals could not explicitly generate examples of the contexts on the CC generation task. Second in Study II, the introduction of additional participants into the analysis, which resulted in an ASC group with a lower IQ than the TD group, had a different effect on the group comparisons of the implicit and explicit learning performances. Insofar that the ASC implicit learning performance was actually underpinned by explicit strategies, this lack of IQ matching between the two groups should have resulted in poorer implicit *and* explicit task performance being observed in the ASC relative to the TD group. Instead, the ASC group were disadvantaged by a lower IQ on the explicit, but not implicit, learning tasks. Third, there are several pieces of evidence to suggest that explicit learning is actually worse in ASC, independently of IQ. For example, the IQ-matched ASC group was significantly worse than the typical group on the explicit memorisation phase of the AGL task. Moreover, in Studies III and IV the ASC groups had difficulty on the SRT task when the learning was more explicit, as a consequence of a difficulty with applying their explicit sequence knowledge.

Thus, there is good evidence that implicit learning performance in ASC is not achieved by compensatory explicit strategies. Instead, implicit learning is intact in ASC and in fact ASC individuals appear to have some difficulties with explicit processing. At this point, it is worth reflecting upon the ASC difficulty that was observed in applying explicit sequence knowledge in Studies III and IV. The fact that there was no evidence of this difficulty after 12 blocks of training in Study III shows that the initial difficulty was transient in this particular task. However, it clearly raises the possibility that in more complex contexts (e.g., on-going social interactions), subtle difficulties in applying explicit knowledge could have a much more detrimental effect on behaviour. Thus, this finding is relevant within a broader context because it insists that research attention should be shifted away from the possibility of difficulties in implicit learning and back towards how differences in more explicit, cognitive, executive strategies emerge and affect autistic behaviour. This idea that ASC individuals actually have more difficulty with explicit than implicit learning corresponds with ASC literature concerning impairments in executive functions, which require flexible and intentional processing (e.g., Baron-Cohen, et al., 2000; Happé & Frith, 2006; Hill, 2004; Russell, 1997a)

An additional consequence of establishing that implicit learning is intact in ASC is that ideas about the role implicit learning might play in savant skills can be more deeply explored (e.g., Mottron, et al., 2006). Intact implicit learning combined with attentional biases towards a subset of information, which happen to be critical for task success, and atypical explicit strategies (which may produce such attentional biases) certainly present a plausible explanation for the unusual acquisition of skill in one particular area, i.e. a savant skill. In line with that possibility, Studies III and IV have demonstrated superior contextual cueing in the first two blocks as a consequence of atypical explicit strategies. Similarly, Kourkoulou and colleagues (2010) demonstrated enhanced implicit learning of features appealing to an ASC attentional bias. Specifically, ASC individuals learnt more than TD individuals about the local context in a contextual cueing paradigm.

Finally, the finding that implicit learning is intact in ASC might appear incongruous with the observation that ASC individuals have diagnostic impairment in skills associated with an implicit acquisition such as language, social and movement skills. The two findings are reconciled by the idea that the implicit acquisition of skills depends on more than *just* an intact implicit learning. A number of additional factors have been discussed that might be particularly relevant in ASC: interference due to abnormal attentional biases or the overuse of explicit strategies; difficulties with the application of implicitly acquired knowledge; and atypical consolidation following the learning. It is hoped that this discussion will promote further research into whether those factors do play a specific role in ASC difficulties in social, language and movement skills. Such research might also springboard a deeper understanding of the broader relationship between what people can learn implicitly and what they actually do learn implicitly in the real world.

In summary, the thesis provided no evidence for the proposal that there are functional differences between individuals in implicit learning. Instead, the thesis was consistent with the idea that individual differences in implicit learning are minimal.

2. Discussion

2.1. The Generality of Implicit Learning

Within the psychometric tradition, ability must be defined in reference to performance (e.g., Carroll, 1993). Whenever performance on a task varies between individuals, it would be valid to conclude that those individuals differed in their specific ability to perform that particular task at that given point in time. However, talking about a specific ability to perform a specific task at a specific point in time is of little explanatory value. The theoretical utility arises when it is believed there is an ability that refers to reliable performance on a variety of similar tasks. Therefore, the psychometric foundation for demonstrating the existence of general abilities is the inter-correlation between performances on multiple different tasks; a positive manifold. The finding that implicit learning performances in Study I did not inter-correlate, and my assertion that the wider literature implies that such inter-correlation is minimal, indicates that, according to psychometric principles, there is no general ability underpinning implicit learning.

At the end of Chapter II, I discussed how general, prerequisite processes might be always necessary for implicit learning, but without those processes determining the variation in how much was learnt implicitly. Specifically, I argued that providing the prerequisite processes remained intact, the performance variance would depend on differences in other processes and factors relating to the specifics of the situation. Within such a framework, the prerequisite processes would not constitute a psychometric ability but could be conceptualised as general implicit learning processes. Finally, I argued that in order to make an empirical case for this theoretical position, it would be necessary to identify an atypical population who consistently demonstrated profound deficits on all implicit learning tasks and skills associated with an implicit acquisition. However, there is currently no convincing evidence that such a group exists (see review at end of Chapter I). At the beginning of Chapter III, I argued that ASC was a plausible candidate. The three studies presented in Chapters III and IV, together with other recent research, has now established that ASC individuals can learn implicitly. The ASC population has become the latest in a long line of atypical populations to have been shown to be capable of implicit learning performance on at least one implicit learning task. Consistent with such findings, A. S. Reber predicted that general, prerequisite implicit learning processes would be so fundamental to life that they would be highly robust to all neurological impairment (A. S. Reber, 1993). While this idea of prerequisite and robust processes for implicit learning might be true, insofar that *no* population has been identified without such processes, the idea is unsupported. Taken together with the evidence to suggest implicit learning performance does not inter-correlate, it is parsimonious to conclude that there is neither a general implicit learning ability, nor general, prerequisite implicit learning processes.

This conclusion should force some researchers to re-evaluate what it is they mean, or at least take more care, when they invoke the term implicit learning. I assert that insofar that implicit learning does not refer to a general ability or general processes it can only be a descriptive label of the manner in which a wide variety of processes are differentially engaged depending on the circumstances. Moreover, the key aspect of the description must be defined by the absence, or minimal influence, of explicit processing. If not defined by an absence, researchers should have found evidence of an ability or prerequisite process.

Finally, within the psychometric exploration of mental ability, this absence of generality in implicit learning means that there is still little evidence of general mental abilities that are completely independent of IQ, and reliably related to differences in intelligent behaviour. This continuing lack of evidence reinforces IQ tests as the best, and maybe only, indicators of general cognitive abilities, which can successfully predict some differences in intelligent behaviour. This does not rule out a variety of other important factors in intelligent behaviour, such as motivation, personality, tacit knowledge, experiential learning and so on. Instead, the implication is focused on the lack of evidence for the conception of other factors as general abilities.

2.2. The Validity of the Implicit-Explicit Distinction

In Chapter I, the implicit learning literature was reviewed. This thesis asserted that there is a consensus that people can learn when they are not primarily engaged in trying to learn explicitly and deliberately, and are consequently unable to report verbally on how or what they learnt. The inability of participants to provide insightful descriptions of how or what they learnt during the implicit learning tasks they completed in Study I, II, III, and IV was consistent with those earlier assertions about the implicit-explicit distinction. Additionally, the results from the CC task in Studies III and IV provided demonstrations of implicit contextual cueing without evidence of successful explicit generation performance. The power of any generation task can be questioned, and it is acknowledged that a more powerful generation task might have provided evidence of generation performance (e.g., Smyth & Shanks, 2008). Nonetheless, I assert, as I did in the general introduction, that while the counter-evidence from a variety of methodologies, such as a highly powerful generation task, might question the definitive absence of consciousness during learning, such evidence is indicative of something less than the actual definition of consciousness that inspired the methodologies. For example, generation tasks are inspired by the idea that a conscious mental state is critically defined by the *"availability for use in reasoning and for rationally guiding speech and action"* (Block, 1995, p. 227). The detection of generation performance only when the task is extremely powerful does not suggest that the knowledge is readily available to influence behaviour rationally; instead the result suggests that the influence on behaviour is probabilistic and not fully conscious.

In addition to these arguments, this thesis asserted that functional differences between implicit and explicit learning provide further reason for retaining the distinction between them. In particular, this thesis identified the existence of plausible comparative and evolutionary frameworks; the differences in computational models that explain much of the different types of learning; different neural sites associated with the different modes of learning; and contrasting relationships of implicit and explicit learning with durability, age and IQ. In the empirical chapters, the contrasting relationship with IQ was replicated: specifically, in Studies I and II explicit, but not implicit, learning was related to IQ. Additionally, Studies II, III and IV provided another functional distinction between implicit and explicit learning: ASC individuals have difficulties with aspects of explicit but not implicit learning.

In summary, this thesis provides evidence in favour of retaining the distinction between implicit and explicit learning. When evaluated together with previous literature, which was reviewed in Chapter I, there should be no doubt that a descriptive distinction between explicit and implicit learning is both valid and useful. This remains true even when this thesis has asserted that implicit learning is defined by the absence, or minimal influence, of explicit processing rather than the general presence of an implicit learning ability or processes.

2.3. Disagreements on Implicit Learning

At the outset of the thesis, it was acknowledged that there is fierce debate within the implicit learning literature on a number of issues such as the role of awareness in learning, the nature of consciousness and the modularity of learning systems. However, it was asserted that there were also areas of agreement, such as the existence of a conservative definition of implicit learning and some functional distinctions from explicit learning, which therefore legitimised the functional analysis of differences in implicit learning adopted by this thesis. Nonetheless, I correctly anticipated that my functional investigation might also indirectly contribute to some areas of fierce debate.

For example, the conclusion that implicit learning does not reflect a general ability or general processes, in contrast to the well-established generality underpinning explicit, IQ-mediated learning, informs debate on the modularity of learning systems. Specifically, this conclusion argues against the strong position that there are two distinct, **general-purpose** learning systems (e.g., Gebauer & Mackintosh, 2010). However, the findings do not distinguish between several alternative ideas about the broad structures of learning systems. For example, the findings are consistent with the multifaceted proposal that learning occurs through connectionist-type networks; that explicit propositions can emerge from the basic operations of those networks; and that explicit propositions are capable of top-down influence on those networks (e.g., Shanks, 2009). In this scenario, whenever global, explicit propositions exert top-down influence on a network, performance would correlate with other explicit performance and global characteristics, such as IQ. However, in scenarios in which explicit, top-down influences are relatively minimised, the relevant connectionist network would learn according to the specifics of the inputs into that system, and its basic pre-existing architecture, and would therefore vary substantially between different implicit learning tasks for the same individual.

Thus, the contrasting generality between implicit and explicit learning finding is consistent with this idea of a learning system: the idea retains distinctions between implicit and explicit learning but specifies only one source that causes similarities between performances.

However, the finding of contrasting generality cannot rule out the possibility that learning could also occur according to reasoning/hypothesis-testing with explicit propositions, which could function independently of connectionist-type architectures (e.g., Scott & Dienes, in press). In this scenario there would still be only one source of generality: performance would inter-correlate only when either the explicit-proposition based system was utilised or when there was a significant top-down influence from the explicit proposition based system onto connectionist architecture.

Finally, another possibility that the finding of contrasting generality cannot completely dismiss is the primacy of a propositional learning system (e.g., De Houwer, 2009; Mitchell, et al., 2009). In this scenario, perhaps the complex information presented in implicit learning tasks is unsuited to reasoning with propositions, and that as a consequence learning is fragmentary and unsystematic. In combination with the lack of instruction about what, or even whether, to learn, the overall result is that performance is extremely idiosyncratic and noisy, and therefore uncorrelated across different implicit learning tasks. However, the success of connectionist models in simulating performance on implicit learning tasks argues against a framework that disregards the connectionist framework completely, such as this predominantly propositional approach to learning.

In relation to the nature of consciousness, this thesis can only offer a modest contribution: the findings re-emphasised the global, pervasive nature of consciousness (e.g., Block, 1995). Specifically, in Study I of this thesis, when learning had been explicit and thus influenced by consciousness, performance had been related to other high-level, global characteristics such as IQ. Additionally, explicit learning was linked with ASC, which is associated with differences in global, cognitive functions. In contrast, when conscious input into learning was minimal, or absent, there seemed to be little relationship between performance and global characteristics. Thus, consciousness was emphasised as global and related to reliable, global characteristics, which are critical to mediating some important differences between people.

Lastly, this thesis is unable to make a novel contribution to the debate about the role of awareness in learning. Instead, findings that have been cited as demonstrations of learning without awareness were replicated. For example, performance on all the implicit learning tasks in this thesis demonstrated that people could learn when they were not primarily engaged in trying to learn, and that consequently they were unable to report verbally on how or what they learnt. Additionally, in Studies III and IV, individuals demonstrated contextual cueing effects but provided no evidence that they were able to perform above chance on the associated generation task. This result implied that the contextual cueing knowledge, which underpinned the contextual cueing effect, was learnt without awareness because it was not available to be used in another context. However, there is no novel evidence that might convince researchers who had been sceptical of such evidence in the past. In these particular cases, the argument still exists that tests more sensitive than verbal reports, and generation tasks more powerful than the task used in Studies III and IV, could provide evidence of some relevant knowledge.

More generally, the broader arguments reviewed in Chapter I also persist. For example, what criteria should be used to evaluate whether a learning performance demonstrates the objective absence of consciousness; what is the definition of consciousness; and to what extent do methodologies actually embody those definitions? As a result of this thesis providing no new evidence to address these questions, I reiterate my earlier interpretation that a definitive demonstration of learning without awareness might be intractable until the field has a better idea and understanding of consciousness. However, I also reassert that this conclusion does not concede that all learning is fully conscious; I argue that all the counter-evidence, which questions the definitive absence of consciousness, demonstrates something less than the actual definitions of consciousness that inspired each of the related methodologies. This assessment implies that there is still a distinction between implicit and explicit learning; a position which is supported by the existence of functional differences between implicit and explicit learning. Perhaps, the idea of ‘fringe consciousness’ is useful to researchers willing to acknowledge a distinction but reluctant to classify implicit learning as completely unconscious (e.g., Norman, Price, & Duff, 2006).

2.4. Implications for Future Functional Investigations of Implicit Learning

In the context of the limited importance of individual differences in general implicit learning, it is worth reflecting upon the value of further research into the possibility. This is a particularly relevant concern because of the large sample size and large number of tasks required for this kind of investigation. If such research is pursued, then the use of subjective measures should be used to help provide a more accurate estimate of implicit learning (e.g., Dienes, 2008). These measures dissociate exactly which aspects of a performance reflect implicit knowledge by classifying answers according to subjective criteria of consciousness. However, this technique is only possible where performance and subjective measures can be provided simultaneously, such as the test phases of the AGL, PCL and IFL.

Another important implication is that if implicit learning is investigated in atypical populations again, then researchers should be hesitant to talk about a general deficit in 'implicit learning'. If there is a deficit in performance on one or two implicit learning tasks, there would be a strong possibility that the deficits were actually reflecting a difference in other cognitive processes, such as attention or perceptual processing. A conclusion relating to a general deficit in implicit learning would be justified only if performance on a large number of diverse implicit learning tasks was catastrophically impaired, and that the population were also associated with deficits in implicit skills. Additionally, such a finding would be sufficient to reconceptualise implicit learning. The finding would imply that a minimum number of prerequisite processes are always necessary for implicit learning, and are affected in the relevant patient group, but that once those prerequisite processes are intact, the variance in how much is learnt implicitly is dependent on a variety of other processes.

However, these implications for both the individual- and group-differences approaches to implicit learning might be re-evaluated as new tasks are developed. Dienes, Baddeley and Jansari (2010) have argued that insofar that implicit learning does reflect any general parameters of a connectionist/neural network, such as learning rate, then implicit learning tasks are likely to provide poor estimations of such parameters. For example, neural network modelling has shown that different learning environments specify different optimal learning rates, and thus measuring and comparing overall performance across a number of different scenarios will not provide an estimation of parameters, such as learning rate, which might be more general.

The authors have developed a task, and have argued that it measures learning rate, rather than overall performance. On the task participants have to make a series of binary predictions as to whether a stimuli will appear on the left or right. The stimuli actually appear randomly but where the stimuli have appeared on preceding trials affects participants' predictions. A learning rate defines how much each trial changes the strength of prediction, and thus how much each preceding trial influences the current prediction. The learning rate, rather than performance, is estimated by calculating the average correlations of the current prediction with where the stimulus was from one to ten trials backwards in time. If participants have a large learning rate, more distant trials have a relatively smaller influence. Correlations of the current prediction with recent trials would be relatively large and correlations of the current prediction with distant trials would be relatively small. In contrast, if a participant has a small learning rate each new trial has a small effect and distant trials (thus prior knowledge) have a relatively strong influence, and the pattern of correlation would be relatively reversed.

The task was demonstrated to reflect implicit learning: on trials on which participants claimed to be guessing, there were correlations between the prediction and where the stimulus actually appeared ten trials previously. Additionally, differences in learning rate were argued to be important: both amnesia and negative mood were associated with large learning rates. However, it is important to note that learning rates themselves are unlikely to be completely general: people probably adjust learning rates to different situations (Dienes, et al., 2010). It is possible that there might be some meta-generality in which people have propensities to over- or under-estimate suitable learning rates, or have difficulties only in scenarios that optimally require high, middling or low learning rates. If this were true, then this would fit with my assertion that there are no individual differences in overall performance on implicit learning tasks: the different tasks are associated with a variety of optimal learning rates (Dienes, et al., 2010).

Finally, in the event that there is little generality about implicit learning, even in parameters relating to learning rate, there would still be a case for understanding which real-world skills are likely to have been learnt implicitly. Within that scenario, knowing about implicit skills could provide no general information about an individual's ability to learn another skill implicitly. However, there would still be advantages: for example, it would be useful to know that low or high achievement in certain skills were unlikely to be related to differences in explicit, IQ-related potential. I only use the word 'unlikely' because information can be acquired implicitly but what and how much is learnt might actually be a function of differences in explicit strategy and attention. For example, Studies III and IV demonstrated that ASC individuals implicitly learnt more about the context as a consequence of initial difficulties in learning to apply explicit sequence knowledge. This idea resonates with Ackerman's (1988) finding that the initial stages of certain skill acquisitions correlated with IQ even when the advantage of a high IQ disappeared with continued practice.

Generally, this type of approach, in which researchers try to establish whether a specific skill was learnt implicitly, has already been fruitfully exploited. For instance, researchers have established that ball-catching skills are learnt implicitly. When participants report how they know whether to move towards, or away, from a moving ball, they typically give an uninformative strategy, or one that would guarantee they would not catch the ball (Reed, McLeod, & Dienes, 2010). Additionally, when asked to consciously recognise a description of how their angle of gaze changed just after a catch, some participants confidently chose incorrect descriptions.

3. Final Conclusion

In conclusion, this thesis provided no evidence for the proposal that there are functional differences between individuals in implicit learning. I assert that taken together with equivocal evidence in the wider literature, it is parsimonious to conclude that there is neither a general implicit learning ability, nor general, prerequisite implicit learning processes. However, in line with previous literature, the thesis did support functional distinctions between implicit and explicit learning: explicit, but not implicit, learning was related to IQ; and ASC individuals have difficulties with explicit but not implicit learning. Therefore, I assert that a descriptive distinction between explicit and implicit learning is both useful and valid. This is true even though implicit learning seems to be defined by the absence, or minimal influence, of explicit processing rather than the general presence of an implicit learning ability or processes. Additionally, I argue that this thesis makes some modest, but not decisive, contributions to some of the fierce debates in the implicit learning literature. For example, the results suggested that there cannot be two distinct, completely general-purpose learning systems; re-emphasised the global, pervasive nature of consciousness; and replicated some findings that are cited as demonstrations of learning without awareness. In the latter case, I acknowledge that these replications do not represent definitive demonstrations of learning without awareness and would not convince researchers previously sceptical of such evidence. Finally, I identify some implications and make recommendations for future research into individual differences in implicit learning. First and foremost, I urge researchers to consider this research carefully given the required number of tasks and sample sizes that would be required to identify any generality in implicit learning. Where possible, researchers should use subjective measures to help provide more accurate estimates of implicit learning performance (e.g., Dienes, 2008). Additionally, researchers should use a whole range of implicit learning tasks before identifying general differences in implicit learning. Otherwise, differences might reflect variation in other cognitive processes. Insofar that implicit learning reflects the operations of connectionist-type networks, new tasks, which measure learning rate directly rather than overall performance, might have much more success in estimating any truly general parameters or propensities relating to implicit learning (e.g., Dienes, et al., 2010). If there remains little that is truly general about implicit learning, in spite of new tasks, then approaches that identify which skills are learnt implicitly and investigate the specific details of the different acquisitions would still reveal much about human cognition and learning environments (e.g., Reed, et al., 2010).

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Appendix A: Additional Materials Information

1. General Questionnaire used in Study I

UNIVERSITY OF CAMBRIDGE

Dr Francesca Greenford

General questionnaire

Thank you for agreeing to take part!

The purpose of this study is to assess occupational knowledge, or occupational common sense, and factors relating to their acquisition. To do this, I need to collect some background data on you, before asking you to proceed with the main part of the investigation. So, we would greatly appreciate your taking just a few moments to answer some preliminary questions. Please note that all information that you provide, in any aspect of the study, is totally confidential.

The brief questionnaire that follows should take approximately 5-10 minutes to complete, and for technical reasons needs to be completed in one sitting. So please make sure that, where possible and applicable, you have the following to hand or are able to make an informed estimate about them:

- Year you joined your current academic department
- Time you have been involved in academic psychology
- Your grade and spinal point
- Your current gross annual salary band and gross annual salary band three years ago
- Your number of publications
- The number of times your work has been cited
- Your awards, medals, or distinctions
- The number of papers you have presented at conferences and how often you have been a keynote speaker
- Likely rating of your work for the 2008 Research Assessment Exercise
- The number of PhD students you have supervised and how often you have acted as a doctoral external examiner
- An estimate of research council funding and other research income obtained in the past 5 years
- The number of research staff for whom you are responsible

When you are aware of as much of this information as possible and are able to spare this amount of time, please click on the button below to begin.

Before you begin, please note that the questionnaire is not tailor-made to every possible occupation. Therefore, some questions may be inappropriate. Even so, please answer all the questions, remembering that the answers "None" and "Not applicable" are valid responses.

If you are really unsure as to how to answer any of the questions, please get in touch on expertise@psychol.cam.ac.uk.

Prof Nicholas Mackintosh, Dr Kate Plaisted, and Jamie Brown.

[Click here to begin the questionnaire]

Privacy statement

All the information sought here is requested solely for research purposes. This information will be analysed anonymously and at group level, and will involve a correlation of the information with performance on the other tasks and questionnaires completed during participation in this study. Your personal information will only be made available to researchers in our research group, and will not be passed to any third parties outside the group. Data is collected with regard to the terms of the Data Protection Act 1998. Completion of the following form will be taken as confirmation that you have read and accepted these terms.

UNIVERSITY OF CAMBRIDGE

Dr Francesca Greenford

General questionnaire

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Your name Dr Francesca Greenford

Sex ○ male ○ female

Ethnicity [*** Please select ***]

Date of birth [** Date **] [** Month **] [** Year **]

With which hand do you write? ○ left ○ right

[Save this information]

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Dr Francesca Greenford

General questionnaire

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Number of years of full-time education after the age of 15
(not including those in which you exclusively studied psychology) [** Please select **]

Number of years of part-time education, not including those in which you exclusively studied psychology
(estimate the time taken if the courses could have been studied full-time) [** Please select **]

GCSE / O-Level grades
*(or equivalent; e.g. Five "A*s", two "Ds")*

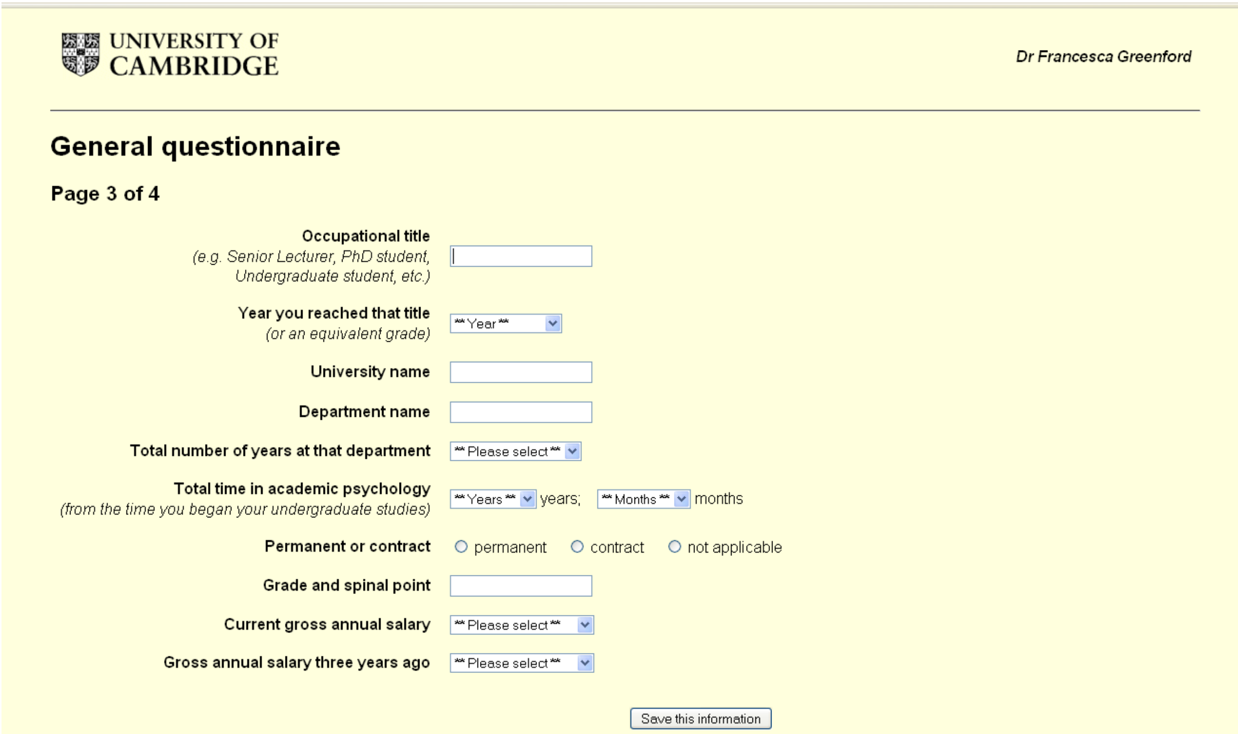
A-Level grades
(or equivalent)

Vocational qualifications
(e.g. OND distinction; GNVQ Advanced merit)

Degree
(subject and classification)

Any post-graduate qualifications
(subject, level and classification)

[Save this information]



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Dr Francesca Greenford

General questionnaire

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Occupational title
(e.g. Senior Lecturer, PhD student, Undergraduate student, etc.)

Year you reached that title
(or an equivalent grade)
** Year **

University name

Department name

Total number of years at that department
** Please select **

Total time in academic psychology
(from the time you began your undergraduate studies)
** Years ** years; ** Months ** months

Permanent or contract
permanent contract not applicable

Grade and spinal point

Current gross annual salary
** Please select **

Gross annual salary three years ago
** Please select **

Save this information

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Dr Francesca Greenford

General questionnaire

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Year you completed your PhD	** Year **
Any fellowships of academic societies *(e.g. Royal Society -- please specify)*	
Number of all publications *(on which you were a named author)*	
Number of times these publications, and other work, have been cited	
Any awards, medals, or distinctions	
Number of papers presented at conferences	
Number of times you have been a keynote speaker	
Likely rating of your work for the 2008 Research Assessment Exercise	** Please select **
Number of PhD students supervised *(including current students)*	
Number of times you have acted as a doctoral external examiner	** Please select **
Number of research staff for whom you are responsible	
Estimate of research council funding obtained in the past 5 years	£
Estimate of other research income obtained in the past 5 years	£
Please estimate the relative proportion of your time spent in these three activities *(This question not to be answered by undergraduate students)*	Research: ** Please select ** % Teaching: ** Please select ** % Admin: ** Please select ** %

Save this information

Note: *Dr Francesca Greenford is a fictional person, and is included to demonstrate where the name of each participant appeared during their completion of the General Questionnaire.*

2. Letter Strings from the AGL Task Used in Studies I and II

Learning Phase Strings	
PVV	PVPXVPS
TXS	TSSXXVV
TSXS	TSXXTVV
PTTVV	TXXTVPS
PTVPS	PVPXTVPS
PVPXVV	TSSSXXVV
TSSSXS	TSSXXVPS
TXTVPS	TSXXTVPS
PTTTVPS	TXXTTTVV
PTVPXVV	TXXVPXVV

Test Phase Strings				
Correct Answer: Grammatical				
PVV	TXXVV	TSXXVV	PTTTTVPS	PTTVPXVV
TXS	PTTTVV	TXXTVPS	TSXXTTVV	TSXXTVPS
TPVV	PTTVPS	TSXXVPS	TSSXXTVV	PVPXTVPS
PVPS	TXXTVV	TXXTTVV	PTTTTTVV	PTVPXVPS
TSSXS	PVPXVV	TSSSSXS	PVPXTTVV	TSSXXVPS
Correct Answer: Ungrammatical				
TXV	PTTPS	PTTTVT	PTVPPPS	PTTTVPVS
TTVV	XXSVT	TSXXPV	SVPXTVV	TSSXXVSS
PSXS	TXXVX	SXXVPS	PVTTTVV	PVXPVXPX
TXPV	TXVPS	PTVVVV	VSTXVVS	PTVPXVSP
PVTVV	TPTXS	VPXTVV	TXXTVPT	PXPVXVTT

3. Number Strings from the IFL Task Used in Studies I and II

Learning Phase Strings	
Correct Answer: Left Two Digits	Correct Answer: Right Two Digits
1632	1232
2823	1683
3421	2137
3541	2463
3761	2838
4723	3141
5314	3158
7434	4234
8763	4329
9643	7138

Test Phase Strings			
Correct Answer: Left String		Correct Answer: Right String	
2183	2717	2165	8361
2391	5491	4819	6483
2453	8419	5264	8375
3641	8671	5419	3581
3871	2461	5471	5735
4736	9147	5487	6283
5316	1581	5859	2351
5463	4274	6561	7132
5738	6814	7261	5783
6394	2624	7421	5834
6513	5958	7494	7831
6863	4629	7691	9328
7583	5246	8721	2435
9234	7461	9242	2835
9536	5767	9412	1326

4. Tacit Knowledge Inventories Used in Study I

4.1. Academic Psychology

Academic Psychology Tacit Knowledge Measure

Directions for completing task:

This task asks you about your views on matters pertaining to the work of an academic psychologist. Please complete this task regardless of whether this relates to your chosen occupation. Questions 1 through 12 ask you to rate either the importance or quality of various items in making work-related decisions and judgments. Please use the 1- to 7-point rating scale. For questions that ask you to rate the quality of various items, a 1 should signify "extremely bad", a 7 should signify "extremely good", and a 4 should signify "neither good nor bad". For questions that ask you to rate the importance of various items, a 1 should signify "extremely unimportant", a 7 should signify "extremely important", and a 4 should signify "neither important nor unimportant".

Please try to use the entire scale when responding, although not necessarily for each question. For example, you may decide that none of the items listed for a particular question are good or important, or that they all are. There are, of course, no "correct" answers. You are asked to scan briefly the items of a given question before responding to get some idea of the range of the quality or importance of the items.
You will be asked to make two ratings for each item, an actual and an ideal rating.
The actual rating asks you to rate how important or how good the response alternative actually is, given the realities of the academic world as you know it.
The ideal rating asks you to rate how important or good the response alternative should be. In other words, how important it would be in one's ideal academic world.

BEGIN

Here is an example:

You are a first-year member of the psychology faculty. A senior colleague has asked you to read her latest paper. You think the paper is terrible. You have noticed previously that this colleague does not take criticism well, and you suspect she is looking more for reassurance than for an honest opinion.
Given the present situation, rate the quality of the following reactions you might display on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
4	1	Tell her you think the paper is great.
4	7	Tell her you think the paper is terrible.

Ratings of the first response indicate that telling her you think the paper is great is neither good nor bad given the realities of the situation, but ideally, it is an extremely bad idea.
Ratings of the second response indicate that telling her you think the paper is terrible also is neither good nor bad given the realities of the situation, but ideally, it is an extremely good idea.

Please enter your responses using the keys 1 to 7 on your keyboard. Note that the red box is the one currently selected. You may change your answers whilst on a page by clicking on a previous answer and choosing again.

BEGIN

1

It is your second year as an assistant professor in a prestigious psychology department. This past year you published two unrelated empirical articles in established journals. You don't, however, believe there is yet a research area that can be identified as your own. You believe yourself to be about as productive as others. The feedback about your first year of teaching has been generally good. You have yet to serve on a university committee. There is one graduate student who has chosen to work with you. You have no external source of funding, nor have you applied for funding.
Your goals are to become one of the top people in your area of the field, and to get tenure in your department. You believe yourself to be a hard worker but find that you do not have enough time to get the important things done. You believe that you have not given enough thought to the relative importance of the tasks you find yourself engaged in, and therefore are developing an agenda of things to do in the next two months that will increase the chances of success in your career.
The following is a list of things you are considering doing In the next two months. You obviously cannot do them all. Rate the importance of each by its priority as a means of reaching your goal:

1	2	3	4	5	6	7
Extremely Unimportant			Neither Important Nor Unimportant			Extremely Important

Actual	Ideal	
		Improve the quality of your teaching.
		Write a grant proposal.
		Begin long-term research that may lead to a major theoretical article.
		Serve on a committee studying university-community relations.
		Participate in a series of panel discussions to be shown on the local public television station.
		Write a paper for presentation to an upcoming American Psychological Association meeting.
		Adjust your work habits to increase your productivity.
		Concentrate on recruiting more students.
		Begin several short-term research projects, each of which may lead to an empirical article.

2

On a regular basis, you are asked to review manuscripts being considered for possible publication. You have decided to write down your criteria for evaluating manuscripts and to determine the importance of each. Your list of criteria for evaluating manuscripts follows. Rate the importance of your criteria:

1	2	3	4	5	6	7
Extremely Unimportant			Neither Important Nor Unimportant			Extremely Important

Actual	Ideal	
☐	☐	There are many tables and figures.
☐	☐	The questions addressed are important.
☐	☐	The research design is clever.
☐	☐	There are no grammatical errors or misspelled words.
☐	☐	The literature review is good.
☐	☐	There are no flaws in the experimental design.
☐	☐	The data have been analyzed properly.
☐	☐	There is a clear theoretical motivation for the research.
☐	☐	The experimental materials and procedures reflect everyday life (i.e., "ecological validity")
☐	☐	The length of the manuscript is appropriate to the importance of its content.

3

You recently have been discussing with your colleagues why some seminars seem to work well whereas others fail miserably. You believe that the students themselves have a lot to do with how well a seminar goes, but that nevertheless, the role of the professor in managing the interactions of the participants is a nontrivial determinant of whether a seminar will be successful or not. Rate the quality of the following considerations regarding managing students in a seminar situation:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	When students don't participate, it is often because you have inadvertently monopolized the discussion.
☐	☐	Surprise quizzes are useful for getting participants to do the reading in advance.
☐	☐	One good way to increase student involvement is to have each student responsible for leading the seminar for one meeting.
☐	☐	Do not permit criticism of others' points of view unless it is clearly constructive.
☐	☐	In your role as leader of the seminar, you should attempt to subdue an individual who monopolizes the discussion and draw an individual who says nothing into the discussion.
☐	☐	Be more accepting than you might otherwise be of the first few comments made by a student who is just beginning to participate.
☐	☐	Provide a list of discussion questions in advance.
☐	☐	If there is little participation, tell the students how disappointed you are in them.
☐	☐	Let students know of your plan to rank them on the amount and quality of their participation and give grades accordingly.
☐	☐	If things start slowly, call on students by name to answer questions.

4

Rate the quality of the following recommendations about writing papers:

1 Extremely Bad	2	3	4 Neither Bad Nor Good	5	6	7 Extremely Good

Actual	Ideal	
☐	☐	Cite the work of distinguished researchers who have done work in the area even if their work seems only tangentially related to your own.
☐	☐	What you say, not how you say it, is what really matters.
☐	☐	Get comments on your paper from distinguished researchers in your area of the field.
☐	☐	It is better to be conservative than liberal in citing the work of others.
☐	☐	Be critical of past work to draw attention to your work.
☐	☐	Emphasize the results that "came out" and only mention in passing what didn't work.
☐	☐	Where possible, stress how your work adds to, rather than negates, previous work in an area.
☐	☐	Be especially conservative in any claims you make about your results.
☐	☐	Be careful not to put your best work in chapters that are usually read by relatively few.

5

A number of considerations enter into the decision of where to submit a manuscript for possible publication. Rate the quality of the following considerations in deciding where to submit a manuscript:

1 Extremely Bad	2	3	4 Neither Bad Nor Good	5	6	7 Extremely Good

Actual	Ideal	
☐	☐	You believe your visibility (i.e., how well you are known) to the audience of the journal is low.
☐	☐	Having a manuscript accepted for publication in the journal would enhance your prestige.
☐	☐	You are reluctant to submit a manuscript to the journal because the last manuscript you submitted to the journal was rejected.
☐	☐	Circulation (number of readers) of the journal in your specific area of the field is high.
☐	☐	Prestige of the journal in the field of psychology as a whole is high.
☐	☐	You don't believe the manuscript to be one of your best efforts so you plan to use it for an invited chapter in a series that is not widely read.
☐	☐	You decide not to submit to your first-choice journal because the rate of rejection is very high.
☐	☐	The publication lag (i.e., the time between having a manuscript accepted and its actually being published) is long and you will be coming up for tenure next year.
☐	☐	The editor who is likely to be assigned the paper is a personal friend.
☐	☐	The editor who is likely to be assigned the paper shares your interest in and point of view on the problem you have investigated.

6

You have been asked to give a brief talk on tips for good writing. Rate the quality of the following pieces of advice about writing you are considering including in your talk:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Write papers so that the main points will be understood by a reader who has time only to skim your paper.
☐	☐	Explain, in the first few paragraphs, how the paper is organized.
☐	☐	Use everyday language and avoid the use of jargon.
☐	☐	Work hard to convey your message in the fewest words possible.
☐	☐	Consider carefully who you are writing for.
☐	☐	Write carefully the first time around to avoid having to rewrite.
☐	☐	Be formal rather than informal in your style.
☐	☐	Avoid visual aids, such as figures, charts, and diagrams, because they often oversimplify the message.
☐	☐	Use the passive rather than the active voice (e.g., write "30 students were interviewed" rather than "we interviewed 30 students").
☐	☐	Avoid using the first person (e.g., write "it is recommended" rather than "I recommend").

7

You are writing a chapter with a student you advise. You are a little uneasy because the student has a reputation for failing to meet deadlines and you have promised the editor that the chapter absolutely will be sent by the end of next week.
The student's problem does not appear to be lack of effort. Rather, he appears to lack certain organizational skills necessary to meet a deadline and also is quite a perfectionist. As a result, too much time is wasted coming up with the "perfect" idea or paper.
Your goal is to produce the best possible chapter by the deadline at the end of next week. Rate the quality of the following strategies for meeting your goals:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Tell him that if his part is late, you will do the chapter alone and will never ask him to write with you again.
☐	☐	Politely tell him to be less of a perfectionist.
☐	☐	Set deadlines for completing each part of the chapter, and accept what you have accomplished at each deadline as the final version of that part of the chapter.
☐	☐	Ask the editor to call the student to check on his progress (after explaining why).
☐	☐	Praise him (the student) verbally for completing parts of the assignment.
☐	☐	Get angry with him at the first sign of his getting behind schedule.
☐	☐	If the student falls behind, take responsibility for doing the chapter yourself, if need be, to meet the deadline.
☐	☐	Point out firmly, but politely, how he is holding up the chapter.
☐	☐	Avoid putting any pressure on him because it will just make him fall behind even more.
☐	☐	If the chapter is late because of him, send a note to the editor explaining the situation so you are not blamed.

8

Procrastination, the problem of being unable to start and complete tasks we need to get done on a given day, is common in varying degrees to many individuals. Rate the quality of the following strategies for overcoming procrastination:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Force yourself to spend at least 15 minutes a day on a given task, in the hope that once you have started you will keep working for longer.
☐	☐	Spend some time considering just what it is about a given task you dislike and then try to change that aspect of it.
☐	☐	Reward yourself every time you get started on a given task.
☐	☐	Imagine the negative things that will happen if you do not complete a given task on time.
☐	☐	Wait to begin a given task until you really want to do it.
☐	☐	Get rid of all distractions so there is nothing else you can do but a task you must complete.
☐	☐	Picture how good you will feel when you have finished a given task and can do something you want to do.
☐	☐	Don't hold out for perfection because most tasks are not worth it.
☐	☐	Get others to check on your progress as a means of motivating yourself.

9

Consider the following recommendations for guiding the graduate careers of your students and rate their quality:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	In written letters of recommendation for your students, give equal weight to their good and bad points.
☐	☐	Remember that one important source of your reputation in the field is the opinion of past and present students.
☐	☐	Give your students personalized progress reports at intervals more frequent than once a year.
☐	☐	Do everything you can to promote the careers of your students, even at the expense of downplaying the importance of your role in working with them.
☐	☐	Always expect from your students just a little more than you think they are capable of producing.
☐	☐	Be tactful but honest in your evaluation of those who are doing poorly.
☐	☐	Be only mildly positive in evaluations of your best students so they do not become complacent.
☐	☐	Socialize with your students whenever possible out of the school setting to avoid being viewed as aloof or as a snob.
☐	☐	Avoid showing a personal interest in the non-school-related concerns of your students.
☐	☐	Ask your students for evaluation of your performance in areas relating to them.

10

Rate the quality of the following strategies of handling the day-to-day work of an academic psychologist:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Think in terms of tasks accomplished rather than hours spent working.
☐	☐	Use a daily list of goals arranged according to your priorities.
☐	☐	Reward yourself upon completion of important tasks for the day.
☐	☐	Be in charge of all phases of every task or project you are involved in.
☐	☐	Take frequent but short breaks (i.e., a quick walk to the mail room) throughout the day.
☐	☐	Only delegate inconsequential tasks, since you cannot guarantee the tasks will be done properly and on time unless you do them yourself.
☐	☐	Do only what you are in the mood to do to maximize the quality of your work.
☐	☐	Take every opportunity to get feedback on early drafts of your work.
☐	☐	Set your own deadlines in addition to externally imposed ones.
☐	☐	Do not spend much time planning the best way to do something because the best way to do something may not be apparent until after you have begun doing it.

11

After having received tenure in your department, you find yourself not being as successful in your research career as you would like. You believe that part of the problem is your relatively heavy teaching load and the fact that your department is neither known for, nor very supportive of, first-class research.
You have begun to be approached with job offers by other psychology departments. Rate the quality of the following reasons for accepting a new position:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	The department is somewhat less prestigious than your present one but you like the individuals you have met from the new department better than you like your present colleagues.
☐	☐	The position is perceived by others to be a step up in terms of prestige.
☐	☐	The salary is roughly twenty percent more than you presently earn.
☐	☐	You do not get along with your current secretary.
☐	☐	The graduate students seem to be better in the new department.
☐	☐	You recently had an argument with the chair of your department (the position of chair in your department is a permanent rather than a rotating assignment).
☐	☐	You would be a "bigger fish in a smaller pond" in the new department.
☐	☐	The new department has a colloquium series that makes it easy to meet the best people in your area of the field.
☐	☐	The new university has a very strong undergraduate student body.

12

You have been asked to serve as the Director of Graduate Studies for the department. Your role includes giving advice to graduate students to maximize their career development while in graduate school. Rate the quality of the following pieces of advice you might give to graduate students for the purpose of maximizing their career development:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Your most important role in graduate school is to do well in your classes.
☐	☐	Be sure to work with at least three members of the faculty at some time in your graduate career.
☐	☐	Take every opportunity to meet successful researchers in your area of the field when they visit the department.
☐	☐	The major task of graduate school is learning how to be a good instructor—you will have your entire career to develop your research skills.
☐	☐	It is important to present talks at major conferences while a graduate student.
☐	☐	Succeeding as a graduate student is not much different from succeeding as an undergraduate.
☐	☐	To broaden your training, take a large number of courses from departments other than your own.
☐	☐	Perhaps the most important determinant of success in graduate school is how hard you work.
☐	☐	Take every opportunity you can to get teaching experience while a graduate student.
☐	☐	It is better to do research in a number of different areas rather than focusing on one area in particular.

4.2. Business Management

Business Management Tacit Knowledge Measure Directions for Completing Task

Directions for completing task:

This task asks you about your views on matters pertaining to the work of a manager. Questions 1 through 12 ask you to rate either the importance or quality of various items in making work-related decisions and judgments.
Please use the 1- to 7-point rating scale. For questions that ask you to rate the quality of various items, a 1 should signify "extremely bad", a 7 should signify "extremely good", and a 4 should signify "neither good nor bad". For questions that ask you to rate the importance of various items, a 1 should signify "extremely unimportant", a 7 should signify "extremely important", and a 4 should signify "neither important nor unimportant".
Please try to use the entire scale when responding, although not necessarily for each question. For example, you may decide that none of the items listed for a particular question are good or important, or that they all are. There are, of course no "correct" answers. You are asked to scan briefly the items of a given question before responding to get some idea of the range of the quality or importance of the items.
You will be asked to make two ratings for each item, an actual and an ideal rating.
The actual rating asks you to rate how important or how good the response alternative actually is, given the realities of the business world as you know it.
The ideal rating asks you to rate how important or good the response alternative should be, in other words, how important it would be in one's ideal company.

BEGIN

Here is an example:

Your superior has asked for your opinion on a new promotional campaign that she has developed. You think the promotional campaign is terrible, and that using it would be a big mistake. You have noticed previously that your superior does not take criticism well, and you suspect she is looking more for reassurance than for an honest opinion.
Given the present situation, rate the quality of the following reactions you might display on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
4	1	Tell her you think the campaign is great.
4	7	Tell her you think the campaign is terrible.

Ratings of the first response indicate that telling her you think the campaign is great is neither good nor bad given the realities of the situation, but ideally, it is an extremely bad idea. Ratings of the second response indicate that telling her you think the campaign is terrible also is neither good nor bad given the realities of the situation, but ideally, it is an extremely good idea.

Please enter your responses using the keys 1 to 7 on your keyboard. Note that the red box is the one currently selected. You may change your answers whilst on a page by clicking on a previous answer and choosing again.

BEGIN

1

You have been asked to take over another department. You have a reputation for not only getting the most from your employees, but for getting along with them as well. You were asked to take on this new job because of rather serious personnel-related problems in the new department. Morale in the new department is low. The department is divided into those who are sorry the former head was asked to leave, and those who are sorry the former head was not asked to leave sooner. Performance ratings for the department have been below expectations.

The problems have been around for some time, and you realize that solving them won't happen overnight. You also believe this to be a chance to show your superiors what you can do in a tough situation, and you hope that by doing well you will improve your opportunities for advancement.

Rate the quality of the following actions you are considering taking in your new role:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Follow the advice of your new superior by announcing a major reorganization of the department that includes getting rid of individuals whom you believe to be "dead wood."
☐	☐	Give your superiors frequent progress reports on the situation.
☐	☐	Institute a policy of making your employees feel completely responsible for their work.
☐	☐	Give negative performance ratings to those who have earned them, even at the risk of making enemies.
☐	☐	Write a memo to your employees telling them that they are paid to work, not to enjoy their work.
☐	☐	Ask employees for suggestions about how things could be made better.
☐	☐	Let the employees know that their jobs are on the line.
☐	☐	Ask a former mentor you trust for advice on how best to handle the situation.
☐	☐	Let your employees know that you are here to work with them, but that you won't tolerate the foolishness that went on before, regardless of its cause.
☐	☐	Be sure your superiors are aware of how bad the situation really was so they will appreciate even modest improvement.

2

Rate the quality of the following strategies for handling the day-to-day work of a business manager:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Think in terms of tasks accomplished rather than hours spent working.
☐	☐	Use a daily list of goals arranged according to your priorities.
☐	☐	Reward yourself upon completion of important tasks for the day.
☐	☐	Be in charge of all phases of every task or project you are involved in.
☐	☐	Take frequent but short breaks (i.e., a quick walk to the mail room) throughout the day.
☐	☐	Only delegate inconsequential tasks, since you can not guarantee that the tasks will be done properly and on time unless you do them yourself.
☐	☐	Do only what you are in the mood to do to maximize the quality of your work.
☐	☐	Take every opportunity to get feedback on early drafts of your work.
☐	☐	Set your own deadlines in addition to externally imposed ones.
☐	☐	Do not spend much time planning the best way to do something because the best way to do something may not be apparent until after you have begun doing it.

3

You have been notified that because of a recently installed computerized accounting system, a new procedure for making weekly written reports has just been instituted for employees in your department. Neither you nor your employees have had input in the decision to change reporting procedures. The new reporting procedure will require somewhat more time and effort on the part of your employees, but your superiors and you yourself believe the new procedure will benefit the company. You have called a meeting of your employees to inform them of the new procedure.
Rate the quality of the following things you might do at such a meeting:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Get a representative from the department responsible for instituting the new procedure to introduce it.
☐	☐	Begin by pointing out that the new procedure is required by higher ups in the company, so everyone will just have to make the best of it.
☐	☐	Ask for group discussion about the worth of the new procedure and whether or not your department should go along with it.
☐	☐	Give your employees the name and number of your superior who is responsible for the new procedure, so they may complain to him or her directly.
☐	☐	Tell them you wish that you and they had been consulted about the new procedure first, but for now, everyone simply must accept the changes.
☐	☐	Have the employees complete a sample written report in the meeting to show them that it is not very difficult to do.
☐	☐	Pick an employee you trust to introduce the new procedure to his or her coworkers at the meeting.
☐	☐	Since the new procedure will probably get an unpleasant reception anyway, use the meeting for something else and inform the employees about the new procedure in a memo.
☐	☐	Show, in as much detail as possible, how the new procedure will benefit the company.
☐	☐	Promise to make their concerns known to your superiors if they will make a good faith effort by first trying the procedure for three weeks.

4

You have been asked to give a talk to managers in the company on tips for good business writing.
Rate the quality of the following pieces of advice about business writing that you are considering including in your talk:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Write reports so that the main points will be understood by a reader who only has time to skim the report.
☐	☐	Explain, in the first few paragraphs, how the report is organized.
☐	☐	Use everyday language and avoid all business jargon.
☐	☐	Work hard to convey your message in the fewest number of words.
☐	☐	Consider carefully who you are writing for.
☐	☐	Write carefully the first time around to avoid having to rewrite.
☐	☐	Be formal rather than informal in your style.
☐	☐	Avoid visual aids, such as figures, charts, and diagrams, because they often oversimplify the message.
☐	☐	Use the passive rather than the active voice (e.g., write "30 managers were interviewed" rather than "we interviewed 30 managers").
☐	☐	Avoid using the first person (e.g., write "it is recommended" rather than "I recommend").

5

A task faced by most managers is making an oral presentation, and when making an oral presentation, you convey perhaps as much information about yourself as you do about the subject of your presentation. Long-lasting impressions that may be consequential to your career success can be formed at least in part on the basis of your speaking ability. For example, we may question the management ability of someone whose halting voice betrays his or her extreme nervousness when speaking, compared with someone who speaks confidently.
Rate the quality of the following statements about aspects of speaking that may convey impressions about yourself that could be consequential to your career success:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Don't be afraid of using a rare word on occasion—it helps to convey to your audience that you have a well-developed vocabulary.
☐	☐	Remember that talks are formal occasions—speaking informally tends to lessen the respect your audience will show you.
☐	☐	If your message is important, assume your audience will see its Importance without your having to convince them.
☐	☐	Make every effort to say at least one or two funny things to show that you have a sense of humour.
☐	☐	What you say, rather than how you say it, is what really matters.
☐	☐	Reading a talk that you have completely written out beforehand is a good idea because most of us write better than we speak.
☐	☐	Whatever you present, work at presenting it in as interesting a manner as possible.
☐	☐	When time permits, practice giving your talk to insure that your delivery will be natural and relaxed.
☐	☐	Be sure your talk is tightly organized, since giving a talk is an opportunity to demonstrate your organizational skills.
☐	☐	Be sure to maintain eye-contact with members of your audience.

6

Procrastination, the problem of being unable to start and complete tasks we need to get done on a given day, is common in varying degrees to many individuals.
Rate the quality of the following strategies for overcoming procrastination:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Force yourself to spend at least 15 minutes a day on a given task, in the hope that once you have started you will keep working for longer.
☐	☐	Spend some time considering just what it is about a given task you dislike and then try to change that aspect of it.
☐	☐	Reward yourself every time you get started on a given task.
☐	☐	Imagine the negative things that will happen if you do not complete a given task on time.
☐	☐	Wait to begin a given task until you really want to do it.
☐	☐	Get rid of all distractions so there is nothing else you can do but a task you must complete.
☐	☐	Picture how good you will feel when you have finished a given task and can do something you want to do.
☐	☐	Don't hold out for perfection because most tasks are not worth it.
☐	☐	Get others to check on your progress as a means of motivating yourself.

7

You have been assigned to revise the policy manual for your division of the company. You have six weeks to complete this assignment. The old policy manual was too vague, resulting in several individuals attending to matters only one need handle, and other important matters receiving the attention of no one. Responsibility for the new policy manual is completely yours. The assignment is somewhat of a "hot-potato" because of the effects of division policy on the importance of particular management positions in the division. You believe that how this assignment turns out could have important positive or negative consequences for your career. Rate the quality of the following courses of action you might take in terms of their leading to positive consequences for your career:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Decide right away if you can come up with a reasonable product that would be satisfactory to most—if not, try to get out of the assignment.
☐	☐	Learn as much as possible about your superiors' views on policy covered by the manual.
☐	☐	Stick with revisions your superiors favour or probably could be sold on.
☐	☐	Get feedback from your superiors on drafts of new policy under consideration.
☐	☐	Get feedback from those affected by the policy manual on drafts of new policy under consideration.
☐	☐	Form a committee with representation from every department that will share responsibility for the assignment.
☐	☐	Find out, if you can, why you, specifically, were chosen for this assignment.
☐	☐	Use this opportunity to reduce the power of those in the division who do not support you, so long as you can avoid being obvious about it.
☐	☐	Avoid mentioning by name individuals whose poor performance is the cause for a particular policy revision.
☐	☐	Don't worry if you miss the deadline for the new policy manual so long as you are making progress.

8

After five years with your present employer, you are getting bored with your job and are looking for a change in employment. You believe yourself to be capable but you do not appear to be advancing in the company at this time.
You have begun to be approached with job offers by other companies.
Rate the quality of the following reasons for accepting a job offer:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	The company is smaller and less prestigious than your present company but you like the individuals you have met from the new company better than you like your present co-workers.
☐	☐	The salary is roughly thirty percent more than you currently earn.
☐	☐	The job is at a lower level of management than your present level but the company is larger and more prestigious than your current one.
☐	☐	The job is perceived by others to be a step up with respect to prestige and responsibility.
☐	☐	The job is essential to the day-to-day operation of the company, although it is not perceived to be as essential as it actually is.
☐	☐	You do not get along with your current secretary.
☐	☐	In your present position, there does not appear to be much room for advancement.
☐	☐	You recently had an argument with your superior.
☐	☐	You would be a "bigger fish in a smaller pond" if you took the job.
☐	☐	You read in a book on career success that if you haven't moved up in five years you should move out.

9

You are responsible for awarding a contract for a new heating system for your plant. As is true for most decisions, the information you have is neither perfectly reliable nor complete.
Rate the importance of the following pieces of information in making your decision to award the contract to the Jackson Heating Company:

1	2	3	4	5	6	7
Extremely Unimportant			Neither Important Nor Unimportant			Extremely Important

Actual	Ideal	
☐	☐	The Better Business Bureau reports no major complaints about the company.
☐	☐	The bid of the company is $3,000 less than that of any other bid (approximate cost of the system is $65,000).
☐	☐	The company advertises their heating system as being the most reliable heating system you can buy for the price.
☐	☐	Former customers whom you have contacted personally are favourably impressed with the company and its product.
☐	☐	The company's estimate of cost of operation of the heating system was lower than that of competing companies.
☐	☐	The company is new.
☐	☐	The company promises a very quick installation.
☐	☐	The company has provided letters from former customers attesting to the quality of their heating system.
☐	☐	The company has done good work for your company in the past.
☐	☐	A competitor of your company has recently purchased the same heating system from the same company you are considering awarding the contract to.

10

You are looking for a new project to tackle in the coming year. You have considered a number of possible projects and desire to pick the project that would be best for you.
Rate the importance of the following considerations when selecting new projects:

1	2	3	4	5	6	7
Extremely Unimportant			Neither Important Nor Unimportant			Extremely Important

Actual	Ideal	
☐	☐	The project is the one my immediate superior most desires to be completed.
☐	☐	Doing the project would require my developing skills that may enhance my future career success.
☐	☐	The project should attract the attention of the local media.
☐	☐	Doing the project should prove to be fun.
☐	☐	The risk of making a mistake is virtually nonexistent.
☐	☐	The project will require my interacting with senior executives whom I would like to get to know better.
☐	☐	The project is valued by my superior even though it is not valued by me.
☐	☐	The project will enable me to demonstrate my talents that others may not be aware of.
☐	☐	The project is in an area with which I have a lot of experience.
☐	☐	The project is the one I most want to do.

11

You and a co-worker jointly are responsible for completing a report on a new product by the end of the week. You are uneasy about this assignment because he has a reputation for not meeting deadlines. The problem does not appear to be lack of effort. Rather, he seems to lack certain organizational skills necessary to meet a deadline and also is quite a perfectionist. As a result, too much time is wasted coming up with the "perfect" idea, product, or report.
Your goal is to produce the best possible report by the deadline at the end of the week.
Rate the quality of the following strategies for meeting your goals:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Divide the work to be done in half and tell him that if he does not complete his part, you obviously will have to let your superior know it was not your fault.
☐	☐	Politely tell him to be less of a perfectionist.
☐	☐	Set deadlines for completing each part of the report, and accept what you have accomplished at each deadline as the final version of that part of the report.
☐	☐	Ask your superior to check upon your progress on a daily basis (after explaining why).
☐	☐	Praise your co-worker verbally for completion of parts of the assignment.
☐	☐	Get angry with him at the first sign of getting behind schedule.
☐	☐	As soon as he begins to fall behind, take responsibility for doing the report yourself, if need be, to meet the deadline.
☐	☐	Point out firmly, but politely, how he is holding up the report.
☐	☐	Avoid putting any pressure on him because it will just make him fall even more behind.
☐	☐	Offer to buy him dinner at the end of the week if you both meet the deadline.
☐	☐	Ignore his organizational problem so you don't give attention to maladaptive behaviour.

12

Consider the following recommendations for managing your subordinates and rate their quality:

1	2	3	4	5	6	7
Extremely Bad			Neither Bad Nor Good			Extremely Good

Actual	Ideal	
☐	☐	Never forget that one important source of your reputation in the company is the opinion of past and present subordinates.
☐	☐	Give your workers personalized progress reports at intervals more frequent than the annual performance evaluation.
☐	☐	Do everything you can to promote the careers of your workers, even at the expense of losing them to another department upon promotion.
☐	☐	In written letters of recommendation for employees seeking employment elsewhere, give equal weight to their good and bad points.
☐	☐	Always expect from your workers just a little more than you think they are capable of producing.
☐	☐	Be tactful but honest in your evaluation of those who are doing poorly.
☐	☐	Be only mildly positive in your performance evaluations of your best workers so they do not become complacent.
☐	☐	Socialize with your subordinates whenever possible after business hours to avoid being viewed as aloof or as a snob.
☐	☐	Avoid showing a personal interest in the non-job-related concerns of your subordinates.
☐	☐	Ask your subordinates for evaluation of your performance in areas relating to them.

4.3. Common Sense Questionnaire

The following survey consists of descriptions of various situations encountered by many people. After each situation, there are several options for handling the situation. For each option listed, please rate the quality of the option using the following 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

Select the number corresponding to your answer, and enter it in the box preceding the option using the numbers on your keyboard. You may change your answers whilst on a page by clicking on a previous answer and choosing again. Note that the red box is the one currently selected.

Remember that some or all of the options listed for a particular question may be good, some or all of the options may be bad, and some or all of the options may be neutral (neither bad nor good). There is no one "right" answer-the options are simply things that people might do in the situation described. Please rate each individual option for its quality in achieving the goal or solving the problem. If you think all of the options are good, bad, or neutral, rate them accordingly. You may or may not have any experience with a particular situation or a particular type of activity described. Simply indicate your "best guess" about the quality of the different options. In addition, you may feel that, to some extent, the quality of a particular option would vary, depending on the specifics of the situation. Indicate your estimation of the option in general or in most cases.

BEGIN

1

It's a hot day in the middle of July, and you don't want to wear a suit to work like you always do, day in and day out.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Wear a suit but bring a pair of shorts to change into during the hottest hours of the afternoon.
- ☐ Call your boss and ask if it would be okay to wear casual clothes.
- ☐ Wear something more comfortable to work so that you will be happier and more productive.
- ☐ Wear a suit but write and pass around a petition for a "casual-dress day."
- ☐ Wear a suit but don't wear a dress shirt/blouse so that you will be somewhat more comfortable.
- ☐ Wear a suit but vow to complain loudly at work so that maybe somebody will do something.
- ☐ Wear a suit for the day and just accept the fact that sometimes you are going to be hot.
- ☐ Call in sick and spend the day keeping cool at the movies.

2

It's the day before Christmas, and you are supposed to have the day off. You are planning to meet some friends for lunch and then do a little shopping. However, you receive a call from your boss. He wants you to come in and work after all.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ You should politely tell your boss that it is too late for you to change your plans.
- ☐ You should tell your boss that you'll come in, but speak in an angry tone, so s/he'll know that you are displeased.
- ☐ You should tell your boss you'll think about it and come in later if you feel like it.
- ☐ You should agree to come in, even though you don't want to, if your boss thinks it's essential.
- ☐ You should simply tell your boss that you're sick.
- ☐ You should forcefully declare that there is no way you are going to work the day before Christmas.
- ☐ You should ask your boss what he will do for you in return if you do come in.
- ☐ You should suggest to your boss some other names of other employees who could do the work instead of you.

3

You go to the interview, but you wait and wait and the interviewer does not show up. Now, it is 30 minutes after your interview was supposed to begin, and still nobody is there to interview you.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Leave a note explaining that you were there and will call later.
- ☐ Continue to wait longer, even though it may interfere with your other commitments.
- ☐ Leave a stern note that makes your displeasure clear.
- ☐ Take a walk through the rest of the building and ask everyone you see if they know where your interviewer is.
- ☐ Vow to give up trying to find any job anywhere; obviously, you are not worth any employers' time.
- ☐ Go out and return 30 minutes later to see if your interviewer is there.
- ☐ Leave and don't call; obviously this company is not really interested in you.
- ☐ Call a friend and ask him or her what you should do.

4

You are up for a promotion at your job, along with two other workers who have been there just as long and have similar qualifications. One day, you walk into a room and overhear these two competitors say your name, but you do not know what they are talking about.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Ask the two competitors in a pleasant tone of voice why they are talking about you.
- ☐ Sharply request that the two competitors not talk about you behind your back.
- ☐ Sternly ask the two competitors why they are talking about you, so that your displeasure will be known.
- ☐ Smile pleasantly at the two competitors and simply go about your day as you usually would.
- ☐ Call one of the competitors aside later in the day and ask her why the two were discussing you earlier.
- ☐ Frown at the competitors to make your displeasure clear, but do not say anything.
- ☐ Write and distribute a note to the two competitors explaining that you think it is important for morale for all of the employees up for the promotion not to discuss it at work.
- ☐ Ask your other friends at work if they know what the two competitors are saying about you.

5

Your boss is out of the office and you receive a phone call from an important customer demanding an immediate answer to a question.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Promptly tell the caller the first answer that comes into your head in order to get him off the phone.
- ☐ Tell the caller to call someone else in the company and ask them.
- ☐ Ask the caller to wait on hold until your boss comes back.
- ☐ Sternly tell the customer that he will just have to call back later.
- ☐ Tell the customer what you think the answer is, but warn him that you could be wrong.
- ☐ Take a poll among the other workers and tell the customer what the majority of the workers think the answer is.
- ☐ Even though it will displease the customer, tell him politely that you will have to call him back with an answer after your boss returns.
- ☐ Pretend that you have accidentally disconnected the caller and then don't answer when he calls back.

6

You've been given an incredibly tedious task. You really don't want to do it. Just the thought of doing the project makes you yawn with boredom!
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Take a break and put off the task until you feel more inspired.
- ☐ Find some people to talk to so you can express your negative feelings about the task.
- ☐ See if you can find someone else to do the task.
- ☐ Start working on the task immediately to get it over with.
- ☐ Play music quietly in the background to make the task a bit more pleasant.
- ☐ Do a very sloppy job on the task so that you will never be asked to do it again.
- ☐ Look at the work in front of you and think about all the times in your life when you have had to do boring work.
- ☐ Do the work but grumble loudly so everybody will know how displeased you are.

7

You want to ask for a raise and know you need to develop a good strategy.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Decide to wait until the busy Christmas season to ask for a raise.
- ☐ Decide to ask your best friend to ask for the raise for you.
- ☐ Decide to resign and look for a better-paying job.
- ☐ Decide to inform your employer that you are going to stay home from work until you are offered better pay.
- ☐ Decide that you will ask your boss for a raise as soon as you see him in the lounge in the morning.
- ☐ Write a letter to your boss asking for a raise.
- ☐ Decide to call your boss at home and say that you need a raise.
- ☐ Sit down and write out a plan for what you will say to your boss once you are able to arrange a private meeting with him.

8

Suppose that you need to write a section of a resume or job application describing your social skills.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ People really love me, and I love everybody.
- ☐ I'm cool--ask anybody who knows me! Everybody I know will tell you that I've always run with the most popular crowd.
- ☐ I enjoy interacting with people and get along well with others.
- ☐ I prefer to work with people who are just like me.
- ☐ I work well with people, but I prefer men over women.
- ☐ I only argue with people when they deserve it.
- ☐ I am very social and love to talk.
- ☐ I prefer to work on my own.

9

Your boss has left you a long list of work to do for the day. However, the list includes work that is really for your boss's second employer--he teaches at a local community college in the evenings--rather than for the company that pays your salary.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Decide that you will do the work that is outside of your job description only if you have time at the end of the day.
- ☐ Resolve that you will do all of the work this time but must talk to the boss and voice your concerns about doing any work in the future that is not part of your job description.
- ☐ Decide to take a survey of your coworkers and see what they would do in a similar situation.
- ☐ Resolve to report your boss to the president of the company.
- ☐ Decide to just buckle down and do all of the work and keep quiet about it.
- ☐ Resolve to do the extra work first to get it out of the way so that it won't make you angry for the rest of the day.
- ☐ Decide that you will only do the work that is for the company that pays you; you will write a note to your boss explaining the situation to him.
- ☐ Decide to ask some of your coworkers to split the boss's extra work with you so that the burden will be shared by many.

10

You are part of a team of workers. Your team has been given specific instructions to complete a series of tasks in a particular order. Your fellow workers, however, start to do the tasks in a different order. Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Do the tasks in the same order that your fellow workers are doing them, so that you will at least all be "in sync," but warn the others that they will get the whole team in trouble.
- ☐ Do your own work in the order that you were instructed to do it and say nothing to the others.
- ☐ Remind the others, in a respectful tone, of the order in which the team is supposed to do its tasks.
- ☐ Go and tell the Supervisor right away what is happening.
- ☐ Refuse to start work and scold your coworkers for their stupidity.
- ☐ Go find another coworker to talk to, tell the people on your team what they are doing wrong.
- ☐ Make an agreement with the others on your team that you will all tell the boss that he told you to do the project the way the team is actually doing it; the boss will think that he made a mistake.
- ☐ Ask your fellow team members if they are certain that this is the way you should all be doing the project.

11

You've been given directions for the day's project. But somehow you lost the directions. Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- ☐ Ask one of your coworkers to do the project for you.
- ☐ Look at the materials involved in the project and see if you can figure out what it is you are supposed to be doing with them.
- ☐ Do some other work, but do a really good job so nobody will blame you for not doing the task you were originally assigned.
- ☐ Since you cannot do the task assigned, make good use of your time by relaxing so that you will be refreshed for the next day's work.
- ☐ Follow the directions for the previous day's project.
- ☐ Write a note explaining why you were unable to do the day's project.
- ☐ Ask one of your coworkers to write a new list of instructions for you to follow.
- ☐ Do the project in what seems to you to be the most interesting way.

12

You have an interview for a new job, but the interviewer shows up 35 minutes late. On the same day, you have another interview scheduled in 45 minutes and are concerned that if you go to the first interview, you will be late for the second.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

☐ Don't say anything about the other interview to this interviewer and just go through the interview as you ordinarily would; you will have to miss the second one, but the second company will probably understand.

☐ Make your displeasure known to the late interviewer and demand an explanation.

☐ Call the second interviewer and ask if you can reschedule your appointment, so that you can go ahead and do the first interview.

☐ Go through the whole first interview, and at the end tell the interviewer that they better hire you because you have sacrificed your other possible job for this one.

☐ Go through as much of the interview as you can, and then abruptly excuse yourself and leave.

☐ Politely explain to the interviewer that you are afraid you will have to reschedule as you do not now have enough time to go through the interview.

☐ Tell the interviewer that you do not want to work for such a disorganized company and then leave.

☐ Go through the first interview without saying anything about the second interview but give short, curt answers to all of the questions so that the interviewer will realize that you are in a hurry.

13

You've been given more work than you can possibly do in the time you have.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

☐ Think about how often this has happened to you in the past.

☐ Decide that you will ask several of your coworkers to do whatever you will not have time to finish.

☐ Play computer games for an hour to vent some of your frustration before you begin work.

☐ Decide to write a letter, before starting the work, about how it is impossible to complete so much work in one day.

☐ Decide to do the work very slowly so that your boss will get the idea that you are being given too much work.

☐ Decide to take a poll of your fellow workers and see if they are being as overworked as you are.

☐ Take a deep breath and try to relax before you start working.

☐ Decide to prioritize the different assignments yourself and do the most important ones first, as you will not be able to get through all of them.

14

You are assigned to oversee a big project. You know you need to break the project down into a series of concrete tasks.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- [ ] Calculate how long the project will take.
- [ ] Figure out what is most interesting about the project.
- [ ] Figure out how many workers it will take to do the project.
- [ ] Ask one of your coworkers how she would organize the project.
- [ ] Figure out which individual tasks need to be done in order for the whole project to come together in the end.
- [ ] Assemble a committee of coworkers and ask them to decide how to organize the project.
- [ ] Thoroughly analyze the benefits of this project for your employer.
- [ ] Figure out how this project compares with others you have done in the past.

15

The coworker who works next to you is a slob and his workstation is always a mess. He frequently borrows supplies from you because he cannot find his own, and he often makes distracting noises and statements when he cannot find his own things.
Given the present situation, rate the quality of each of the following reactions on this 1-to-7 scale.

1	2	3	4	5	6	7
Extremely Bad	Very Bad	Somewhat Bad	Neither Bad Nor Good	Somewhat Good	Very Good	Extremely Good

- [ ] Ask a mutual friend who works elsewhere in the building to talk to the messy worker.
- [ ] Raise your voice to the coworker the next time he asks for something, so that he will realize how annoyed you are.
- [ ] Ask the coworker politely if he would consider cleaning up his workstation so that the work environment would be better for everyone.
- [ ] Politely offer to help the coworker learn how to organize his workstation.
- [ ] Don't say anything to the coworker, but sneak in after hours and clean up his workstation.
- [ ] Don't say anything to the coworker but slam things around whenever he asks to borrow something.
- [ ] Make your own work station messy for a week and try to borrow the coworker's things, so that he will realize how bothersome his way of functioning is to you.
- [ ] Explain the problem to as many of your coworkers as possible so that eventually word will get back to the messy coworker.

Appendix B: Additional Analyses

1. Invariant Feature Learning task Analysis from Study II

Learning was measured using the percentage of test phase number strings that had been correctly selected above the 50 % chance level. An answer that identified the string containing the invariant feature was deemed correct. Overall, the participants performed near chance and consistent with this, a one-sample *t*-test provided no evidence of learning (M = 0.51 %, SEM = 1.15 %, $t(51) = 0.44$, $p = .66$, $d = 0.06$). Both groups performed near chance and there was no evidence of a significant difference between them (TD: M = 2.69 %; ASC: M = -1.67 %; SED = 2.25 %; $t(51) = 1.94$, $p = .06$, $d = 0.54$). Although, the difference was not significant, there was a trend towards a larger score in the TD group. This trend difference might have masked a learning effect in the TD group. However, when considering just the TD-group, there was still no evidence of learning from a one-sample *t*-test ($t(25) = 1.77$, $p = .09$, $d = 0.35$). Thus, there was no evidence of learning on the IFL task.

2. Full Equivalence Analyses of Learning Indices from Study II

Equivalence analysis (Rogers, et al., 1993; Stegner, et al., 1996) necessitates the *a priori* specification of an equivalence threshold; this was specified as random within-subject variability in TD group. This threshold was chosen using the logic that an interesting between-group difference should be at least as large as the estimated random within-subject variability. To elaborate on the notion of random within-subject variability: if a test measures what it purports to measure perfectly, then the two split-half scores of that test would correlate perfectly with one another. Yet, in spite of no conceptual difference between two split-halves – they are randomly derived halves of the same test – usually such scores do not correlate perfectly. Consequently, the variability in one split half-score that cannot be explained by variability in the other split-half score is determined to be random within-subject variability. Therefore, the equivalence threshold = estimated random within-subject variability = $[(1- r^2) * Var_x * (n - 1) / (n - 2)]^{0.5}$; Var_x = variance on one split-half, r = correlation between the split halves. The null hypothesis would then be tested that the difference between the groups is at least as large as the equivalence threshold by conducting two one-tailed *t*-tests. For example, consider the CC equivalence analysis reported below.

CC

$t(50) = [\bar{x}_{TD} - (\ _{ASC} \pm E)] / S_{\ TD - \ \ ASC}$

$_{TD}$ = 2.71 %; $_{ASC}$ = 3.05 %; Equivalence threshold (E) = random within-subject variability = $[(1- 0.25^2 * 26.89 * (52 - 1) / (52 - 2)]^{0.5} = 5.13$ %

$t(50) = [2.71 - (3.05 \pm 5.13)] / [3.97^2 / 26 + 3.76^2 / 26)]^{0.5}$

$t(50) = 4.47$ and $t(50) = -5.10$.

Since an investigator is interested in whether the difference between the groups is at least as large, they just need to consider the *t*-test that yields the largest *p*-value (i.e. just need to test the possibility of finding the smallest difference between the actual difference and the threshold, given the null hypothesis that the difference is at least as large as the equivalence threshold). Therefore, equivalence analysis rejects the hypothesis of non-equivalence (CC: $t(50) = 4.47$, $p <$ .001).[7] The remaining four equivalent analyses are reported below.

SRT

$t(50) = [\ _{TD} - (\ _{ASC} \pm E)] / S_{\ TD - \ \ ASC}$

$_{TD}$ = 4.82 %; $_{ASC}$ = 4.63 %; E = $[(1 - 0.38^2 * 31.05 * (52 - 1) / (52 - 2)]^{0.5} = 5.25$ %

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[7] This analysis used a revised estimate of within-subject variability compared with Brown and colleagues (2010). This revised estimate did not change the pattern of results; however, this means that the exact figures differ somewhat for the CC and SRT analysis. After publication of Brown and colleagues (2010), it was made clear to me that the method used in Brown and colleagues (2010) for calculating the split-half scores for the CC and SRT was too liberal. Specifically, the same baselines were used to calculate the two difference scores for each of the two split-halves. The original rationale was that learning is measured by the decreases in RTs to high-frequency (or probable), trials, and is effectively 'normed' by the use of the baseline (low-frequency or improbable trials). Given the non-split, and thus more reliable, baseline is always available for an SRT, or CC, task of that length, the logic was that the variability for the baseline did not need to be estimated. However, it was realised that the baseline is, of course, not the same between experiments and so when estimating reliability it is necessary to estimate all sources of measurement error. Thus, split-halves were calculated for both high-frequency and low-frequency (and probable and improbable) trials. Each half was randomly paired together with a half of the other trial-type, which were then used to calculate two split-half average proportional increases in RT differences across blocks.

$t(50) = [4.82 - (4.63 \pm 5.25)] / [3.38^2 / 26 + 4.73^2 / 26)]^{0.5}$

$t(50) = 4.76$ and $t(50) = -4.44$, $p < .001$.

AGL

$t(50) = [\bar{x}_{TD} - (\bar{x}_{ASC} \pm E)] / S\bar{x}_{TD} - \bar{x}_{ASC}$

$\bar{x}_{TD} = 3.35$ %; $\bar{x}_{ASC} = 3.20$ %; $E = [(1 - 0.33^2 * 114.07 * (52 - 1) / (52 - 2)]^{0.5} = 10.31$ %

$t(50) = [3.35 - (3.20 \pm 10.31)] / [7.94^2 / 26 + 8.36^2 / 26)]^{0.5}$

$t(50) = 4.63$ and $t(50) = -4.49$, $p < .001$.

PCL

$t(50) = [\bar{x}_{TD} - (\bar{x}_{ASC} \pm E)] / S\bar{x}_{TD} - \bar{x}_{ASC}$

$\bar{x}_{TD} = 4.95$ %; $\bar{x}_{ASC} = 8.74$ %; $E = [(1 - 0.30^2 * 173.66 * (52 - 1) / (52 - 2)]^{0.5} = 12.85$ %

$t(50) = [4.95 - (8.74 \pm 12.85)] / [7.01^2 / 26 + 11.75^2 / 26)]^{0.5}$

$t(50) = 3.37$ $p < .001$ and $t(50) = -6.20$.

PAL

$t(50) = [\bar{x}_{TD} - (\bar{x}_{ASC} \pm E)] / S\bar{x}_{TD} - \bar{x}_{ASC}$

$\bar{x}_{TD} = 46.03$ %; $\bar{x}_{ASC} = 39.74$ %; $E = [(1- 0.87^2 * 431.39 * (52 - 1) / (52 - 2)]^{0.5} = 10.48$ %

$t(50) = [46.03 - (39.74 \pm 10.48)] / [15.07^2 / 26 + 23.64^2 / 26)]^{0.5}$

$t(50) = 3.05$ and $t(50) = -0.76$ $p = .22$.

3. PCL Strategy Analysis from Study II

The full details of this analysis were not presented in the main body of the thesis because it was not an express aim of Study II to provide such in depth analysis of each individual implicit learning task performance. Study II had been designed to investigate the generality of any implicit learning deficit in ASC, and to determine whether any intact performance could be attributed to other factors such as explicit-IQ related compensation. The study provided evidence of intact implicit learning on a range of tasks, which could not be accounted for by compensatory explicit strategies. However, in discussions about the study, it was suggested that although the overall ASC performances had been implicit and equivalent to the TD group, perhaps there were *general* differences between the groups in *how* they achieved those equivalent, implicit performances. Although this possibility was considered unlikely, such differences might be theoretically interesting for a functional analysis of differences in implicit learning and potentially useful to ASC research. Thus, a review was conducted into what analyses might reveal such differences in how the groups achieved their equivalent overall performances. Given the particular designs used for each of the tasks, it was concluded that a strategy analysis of the PCL dataset was most suited to such investigation (Gluck, et al., 2002).

The two groups achieved equivalent overall performance on the PCL task, as reported in Study II. Gluck and colleagues (2002) have identified a number of different ‘strategies’ that participants tend to use during the PCL task (see also Lagnado, Newell, Kahan, & Shanks, 2006; Meeter, Myers, Shohamy, Hopkins, & Gluck, 2006; Price, 2009). Therefore, in order to determine whether the equivalent overall performance between the groups was achieved using similar learning strategies, a strategy analysis was conducted on the PCL data from both groups. Following the established method (e.g., Gluck, et al., 2002), response profiles were constructed that would be expected if a participant were reliably following a particular strategy and compared individually with each participant’s data. Gluck and colleagues’ (2002) Least Means Square procedure was used to determine the extent to which each strategy provided a fit for each participant’s dataset. A participant was classified as having utilised the strategy that provided the best fit for their data. In order to reflect the possibility that participants switched strategies, this process was conducted separately for each of the learning and test blocks. The different strategies that were modelled are described below and relate to the stimuli (A, B, C etc.) detailed in Table 17 (reproduced from Study III).

Table 17. *The Stimuli and Probability Structure of the PCL Task*

Stimulus	Cue 1	Cue 2	Cue 3	Cue 4	*P* (stimulus)	*P* (vanilla|stimulus)
A	0	0	0	1	.136	.143
B	0	0	1	0	.079	.375
C	0	0	1	1	.089	.111
D	0	1	0	0	.079	.625
E	0	1	0	1	.061	.167
F	0	1	1	0	.061	.667
G	0	1	1	1	.042	.250
H	1	0	0	0	.136	.857
I	1	0	0	1	.061	.333
J	1	0	1	0	.061	.833
K	1	0	1	1	.033	.333
L	1	1	0	0	.089	.889
M	1	1	0	1	.033	.667
N	1	1	1	0	.042	.750

Note: *Cue 1 = brown moustache, cue 2 = red hat, cue 3 = blue glasses, cue 4 = bow tie. Each cue could be present (1) or absent (0) for each stimulus. The all-present (1111) and all-absent (0000) stimuli were never used. On any trial during the learning phase, there was a given probability of each of the 14 stimuli appearing (P(stimulus)), and a dynamic stimulus-outcome probability for each of these 14 stimuli. During the test phase, when feedback is removed, the stimulus-outcome probability is static (P(vanilla|stimulus)). All stimuli appeared equally often during the test phase. The overall probability of the vanilla outcome across all stimuli is 50 %.*

In addition to the stimulus-outcome probabilities detailed in Table 17, the constituent cues of the stimuli necessarily had a probabilistic relationship with the outcomes. Specifically, the final cue-outcome probabilities can be calculated from the table: *P*(vanilla|cue 1) = .733; *P*(vanilla|cue 2) = .600; *P*(vanilla|cue 3) = .450; *P*(vanilla|cue 4) = .222.

3.1. Strategy Models

Singleton strategies. These strategies modelled participants who only learnt about stimuli that were composed of only one of the four possible cues. In particular, one model assumed participants learnt about all four singleton stimuli (A, B, D and H), while the second assumed participants only learnt about the two singleton stimuli with the strongest probability of an outcome (A &H). In both cases, it is assumed that participants guessed on the remaining trials.

Single-Cue strategies. These strategies modelled participants who learnt about only one cue, and used that cue's presence or absence to determine responding to all stimuli, regardless of the presence or absence of any of the other cues. This produced four models: one for each of the four cues.

Intermediate strategies. These strategies modelled participants who learnt about and responded to stimuli on the basis of more than one cue, but in contrast to the integrative strategies described below, these participants did not learn about the relative likelihood of outcomes for cues, instead they learnt only about the direction of the outcome. Specifically, the singleton-prototype model assumed participants learnt the optimal response pattern for all four singleton stimuli, and generalised this responding to include the two stimuli with two singleton cues that were associated with the same outcome (C & L). The singleton-2vs1 model extended the prototype model and assumed responding was also generalised to stimuli where 3 singleton cues are present (G, K, M & N), with responding determined by the outcome associated with 2 of the 3 singleton cues present.

Integrative strategies. These strategies modelled participants that learnt about and responded to stimuli on the basis of more than one cue and had to keep track of the relative strengths of associations of cues and/or stimuli. The optimal singleton model extended the 2vs1 model such that responding was also generalised to stimuli where 2 singleton cues were present and each were associated with the opposite outcome but one more strongly than the other (E, J). The all-but-two-strong model was the same as the optimal singleton model except that it predicted guessing on the stimuli with 3 cues present including two cues strongly associated with opposite outcomes (M &K). The summing-all-single-cues model departed from the singleton assumption that participants learnt only about singleton stimuli, and instead assumed participants learnt the number of times each cue was associated with an outcome, and summed this probability for each of the 14 stimuli. The summing-two-strong-single-cues was the same as summing-all-single-cues except that it assumed participants only learnt about the two cues most strongly associated with an outcome, and therefore guessed on stimuli in which both cues were absent (B, D & F). The multi-cue model assumed that participants distinguished each of the 14 stimuli, and learnt about each of the 14 stimuli's association with an outcome. The multi-strong model assumed that participants distinguished the stimuli holistically but only learnt about the 8 stimuli that were associated strongly with one outcome (A, C, E, G, H, J, L, & N).

Incorrect strategies. Participants that responded in a consistent but incorrect manner were modelled by incorrect strategies (Price, 2009). Three types of incorrect strategies were considered: (1) incorrect singleton strategies modelled participants that responded on singleton stimuli with the opposite response expected and then guessed on the remainder of stimuli; (2) incorrect one-cue strategies modelled participants that provided a response depending on the presence or absence of just one-cue but that the response was in opposition to the cue's outcome-association; (3) incorrect multi-cue strategies modelled participants that distinguished the 14 stimuli but provided responses in opposition to each stimulus's outcome-association.

Random strategy. This strategy modelled participants that responded with the two outcomes equally often for each of the stimuli.

In addition to the introduction of four novel strategies (described above as summing-all-single-cues, summing-two-strong-singles-cues, multi-strong and incorrect multi-cue), three general improvements were applied to the modelling of all these strategies:

1) The impact of the dynamic probabilities experienced throughout the task was modelled. The dynamic nature of the probabilities experienced by participants has been acknowledged previously, and addressed using other techniques such as rolling regression (e.g., Kelley & Friedman, 2002; Lagnado, et al., 2006; Speekenbrink & Shanks, 2009); however, it has not been previously addressed within a strategy analysis framework. In this strategy analysis, the impact of dynamic probabilities was modelled by generating response profiles for each block according to the outcomes a participant had cumulatively experienced up until that learning block. In contrast, previous strategy analyses appeared to use the same probabilities to model response profiles for each of the four learning blocks; probabilities that were only correct after the fourth learning block. Furthermore, Study II utilised a test block with feedback removed, and thereby provided responses that could be modelled according to static probabilities.

2) Both maximising and matching behaviour were modelled for all strategies. Once a participant has learnt an outcome probability according to a given strategy, they might always select the more probable outcome (maximising) or they might distribute their responses in order to match the probability of the outcomes (matching). Lagnado and colleagues (2006) noted this distinction and implemented alternative profiles for the multi-cue model according to both maximising and matching. Lagnado and colleagues (2006) found that the multi-matching model seemed to provide the best-fit of all the strategies. Surprisingly, however, matching behaviour was not applied to all the other possible strategies. In Study II, two sets of response profiles were generated for all of the strategies based on either maximising or matching behaviour. The maximising models were retained, in spite of the finding by Lagnado and colleagues (2006) that a matching model provided the best-fit, because the literature is divided: other researchers have reported the prominence of maximising behaviour (e.g., White & Koehler, 2007).

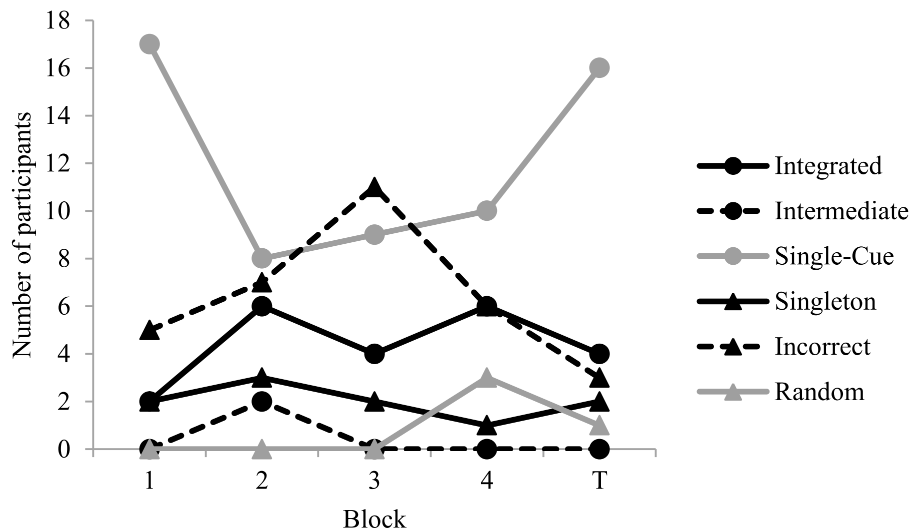
3) The possibility of forgetting or disregarding old information was modelled for all strategies. Finally, another possibility relating to the dynamic experience of learning was acknowledged: participants may have utilised their strategies according to the most recent outcomes that they experienced, disregarding or forgetting earlier experiences. Therefore, two sets of response profiles were generated for all the strategies based on either a cumulative or recent use of information. The recent use of information assumed participants only used outcomes experienced within the current block.

Together, these improvements combat some of the key criticisms aimed at previous strategy analyses, including the unrealistic assumptions of global, static probabilities (e.g., Lagnado, et al., 2006). In light of such improvement, strategy analysis is preferable to an alternative rolling regression analysis (e.g., Kelley & Friedman, 2002; Lagnado, et al., 2006; Speekenbrink & Shanks, 2008). Strategy analysis is preferable because it allows an assessment of a wide range of strategies, which is particularly important when analysing TD and ASC participants who may have attended to different aspects of the stimuli. In contrast, rolling regression analysis only assesses the strength with which individual cue weights were learnt, and thereby assumes that all participants learn only about the individual cue weights. This assumption does not allow for participants who learnt more holistically about the stimuli, which was particularly inappropriate presently because the MrPotatoHead stimuli used in Study II were expressly designed to be evaluated as integrated customers rather than a set of individual cues. Additionally, a great benefit of rolling regression analysis was not applicable in Study II. Specifically, a rolling regression analysis analyses a participant's responses and predicts what cue-weights would produce those responses (under the assumption that the learner was learning and responding only on the basis of cue-weights), and thereby quantitatively estimates the cue-weights of the learner. The great benefit arises from a comparison of those weights with the participant's ratings of the cue weights/cue usage, which thereby reveals whether their performance reflected their explicit judgement. However, such ongoing assessment was not included in this task in case its inclusion encouraged explicit processes (e.g., Gebauer & Mackintosh, 2007).[8]

3.2. Strategy Use

Figure 13 depicted the number of participants using each category of strategy between the two groups across the different phases of the PCL task. This figure demonstrated that the distribution of strategies was similar between the two groups. Accordingly, chi-square contingency table analyses provided no evidence that Group impacted upon the distribution of strategies in any of the blocks (for all blocks: $\chi^2 \leq 5.53$, $ps \geq .27$ and $\Phi^2 \leq .11$). There were no obvious trends in the use of individual strategies, and further analyses of all six categories were inappropriate given the small number of participants in several of the categories.

[8] Lagnado and colleagues (2006) found that the inclusion of ratings did not make the performance more explicit on their task. However, this may have resulted from the performance already being explicit prior to their inclusion of the ratings. Thus, there was still a risk associated with including ratings in Study II, and the ratings were omitted. The risk seemed particularly relevant given there is reason to suspect that the version of the PCL task used by Lagnado and colleagues encouraged explicit performance. Specifically, the stimuli in their Weather Prediction task are composed of particularly discrete cues (symbols on a Tarot Card), which is known to encourage explicit learning (Maddox & Ashby, 2004). Additionally, the PCL procedure used in Study II was designed to encourage implicit performance. Study II used holistic MrPotatoHead stimuli. Also, the feedback conditions were selected to minimise explicit learning: feedback was displayed immediately after the response and feedback processing time was minimised by allowing only 600ms between first receiving the feedback and beginning the next trial (Maddox & Ashby, 2004). The equivalent procedural details were not reported by Lagnado and colleagues (2006).



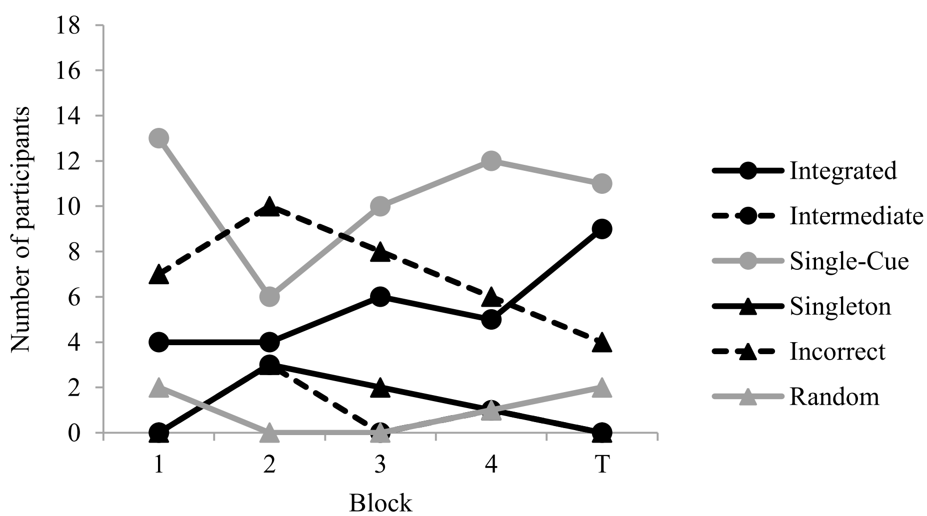


Figure 13. *There was a similar distribution of strategy use between the TD (top panel) and the ASC group (bottom panel). Depicted are the numbers of participants selecting a particular strategy across the different stages of the PCL task for both groups.*

In line with Price (2009) and Shohamy and colleagues (2004), important comparisons were considered more sensitively by collapsing across some of the categories. Therefore, the categories of strategies were classified as either 'incorrect' or 'correct' (all strategies except incorrect strategies), and 'integrated' or 'non-integrated' (all strategies except integrated strategies). The number of incorrect and correct strategies appeared similar between the groups, see Figure 14. Chi-square contingency table analyses provided no evidence that Group impacted upon the distribution of correct and incorrect strategies in any of the blocks (for all blocks: $\chi^2 \leq$

1.56, *ps* $\geq$ .35 and $\Phi^2 \leq .03$). It was also evident from Figure 14 that the total number of participants using a correct or incorrect strategy appeared stable over the course of the task, and that the two groups were similar in this stability. In line with this interpretation, a Wilcoxon matched-pairs, signed ranks test provided no evidence of an increased use of correct strategies in the Test block relative to Block 1 ($z = .69$, $p = .65$, $d = .09$), and a Mann-Whitney U-test gave no evidence of a difference between the groups in this change across the blocks ($z = .27$, $p = .72$, $d = .06$).

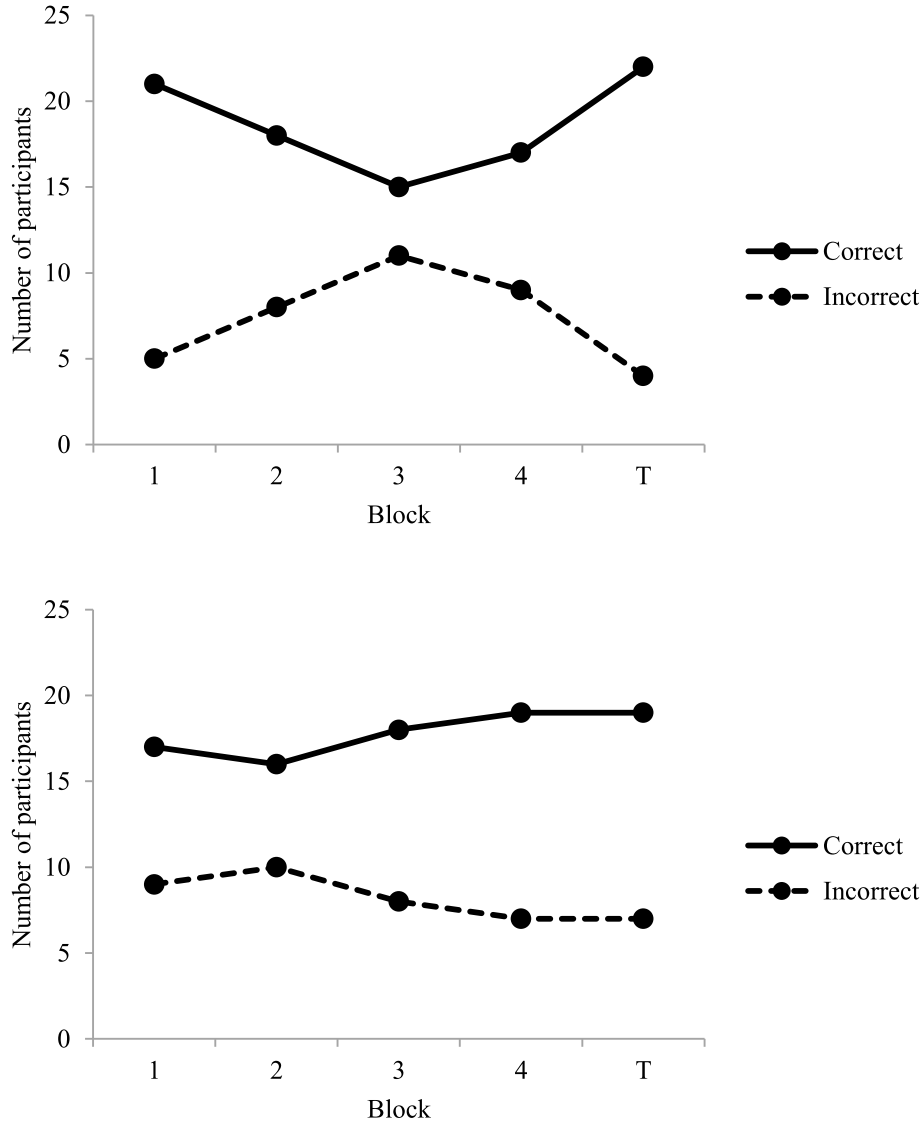


Figure 14. *There was a similar distribution in the use of correct and incorrect strategies between the TD (top panel) and the ASC group (bottom panel). Depicted are the numbers of participants selecting a correct or incorrect strategy across the different stages of the PCL task for both groups.*

The number of participants using integrated strategies appeared similar between the two groups, see Figure 15. Consistent with this interpretation, there was no evidence that Group affected the distribution of integrated and non-integrated strategy use from chi-square contingency table analyses (for all blocks: $\chi^2 \leq 2.56$, $ps \geq .20$ and $\Phi^2 \leq .05$). Figure 15 also indicated that the total number of participants using an integrated or non-integrated strategy remained stable over the course of the task, and that this was true for both groups. In line with this interpretation, a Wilcoxon matched-pairs, signed ranks tests provided no evidence of an increased use of integrated strategies in the Test block relative to Block 1 (z = 1.81, p = .12, d = .26), while a Mann-Whitney U-test supplied no evidence of a difference between the groups (z = 0.83, p = .41, d = .22).

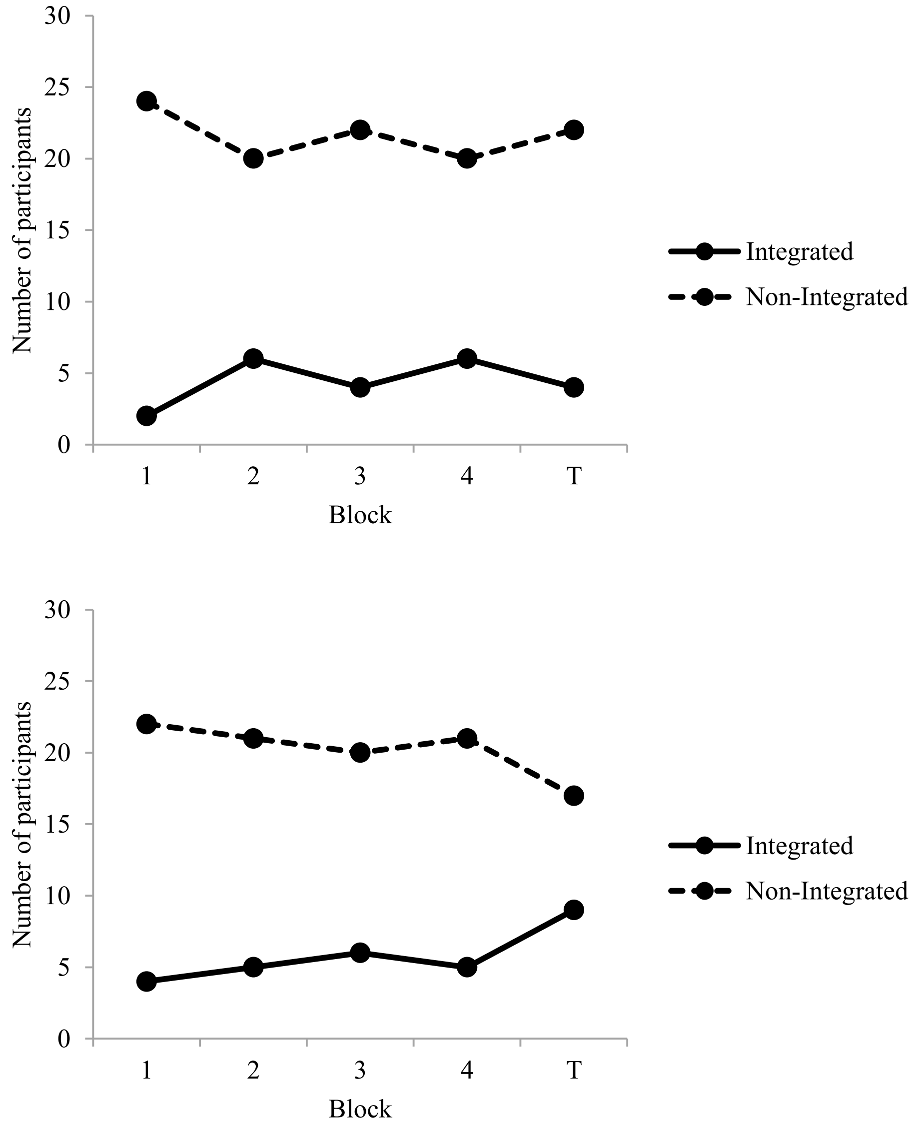


Figure 15. *There was a similar distribution in the use of integrated and non-integrated strategies between the TD (top panel) and the ASC group (bottom panel). Depicted are the numbers of participants selecting integrated or non-integrated strategies across the different stages of the PCL task for both groups.*

3.3. Consistency of Strategy Use

The general consistency of individual participants' strategy use was considered using two novel indices. First, for each individual, the frequency with which each strategy fitted their responses across the 5 blocks of the PCL was calculated (0-5 was possible for any strategy). The strategy that fitted an individual most frequently was used as the individual's score (1-5 was possible for each individual), and the mean score was calculated for each group. Both groups seemed to use their most-frequently-fit strategy relatively regularly across the blocks with the TD group using the same strategy 2.88 times (SD = 0.43), and the ASC group 2.76 times (SD = 0.81). There was no evidence of a difference between the groups ($t(38) = 0.64$, $p = .53$, $d = .18$).

Second, for each individual, the 4 transitions from each block of the PCL were scored: if the same strategy was used consecutively, the transition scored 1, if a different strategy was used, the transition scored 0 (0-4 was possible for each individual). The TD group used a strategy consecutively a mean number of 1.38 times (SD = 0.90), while the ASC group was 1.46 times (SD = 0.95), with no evidence of a difference between the groups ($t(50) = 0.30$, $p = .77$, $d = .08$). Insofar that both groups scored above 0, there was some consistency in their use of strategy. However, participants were clearly not completely consistent: on average, the most frequent strategy was used approximately 3 times during the task, but the consecutive strategy score was below 3. Thus, this difference between most-frequent and consecutive scores implied that individuals did *not* persist with their most-frequent strategy once it was identified. Instead, participants continued to show strategy-exploration, probably returning to their most-used strategy upon finding the new strategy inappropriate. Such individual behaviour was consistent with the earlier conclusion from the Group level analyses that there were no coherent trends towards the use of particular strategies over the course of the task.

The consistency of an individual's strategy use was further analysed by collapsing across categories to consider the most interesting comparisons with greater power. The mean frequency with which a correct or incorrect strategy was used (out of 5) was 4.00 times (SD = 0.89) for the TD group and 3.92 times (SD = 0.80) for the ASC group ($t(50) = 0.33$, $p = .75$, $d = .08$), while the mean frequency of either correct or incorrect consecutive strategy use (out of 4) was 2.65 times (SD = 1.20) for the TD group and 2.62 times (SD = 1.17) for the ASC group ($t(50) = 0.12$, $p = .91$, $d = .03$). These analyses implied that the use of correct or incorrect strategies was consistent. Again, such individual consistency fitted with the earlier finding that there were no trends towards using correct strategies over the blocks at the Group-level.

The mean frequency with which an integrated or non-integrated strategy was used (out of 5) was 4.23 times (SD = 0.82) for the TD group and 4.12 times (SD = 0.86) for the ASC group ($t(50) = 0.50$, $p = .62$, $d = .14$), while the frequency of either integrated or non-integrated consecutive strategy use (out of 4) was 3.08 times (SD = 0.98) for the TD group and 3.19 times (SD = 0.80) for the ASC group ($t(50) = 0.47$, $p = .64$, $d = .13$). These analyses implied individual consistency in the use of integrated or non-integrated strategies, and were therefore coherent with the earlier conclusion that there were no Group-level trends towards the use integrated strategies across the blocks.

3.4. Impact of Strategy on Performance

In order to assess the impact of strategy use on performance, and in particular differences between the groups in their capacity to utilise different strategies, percentage correct during the PCL was compared between different categories of strategies. It was not possible to conduct analyses using all six categories because the data was not sufficiently distributed among those categories. Therefore, the integrated-non-integrated and correct-incorrect categorisations were analysed. An inspection of Figure 16 showed that the use of correct strategies resulted in superior task performance. ANOVAs with two between-subject factors Categorisation (Correct vs. Incorrect) and Group (TD vs. ASC) were conducted separately within each level of block, and revealed that the use of correct strategies led to superior task performance in every block (all $Fs \geq 9.00$, $ps \leq .01$ and $\eta^2_p \geq .16$). There was no evidence of any group differences or interactions (all $Fs \leq 1.20$, $ps \geq .28$ and $\eta^2_p \leq .02$).

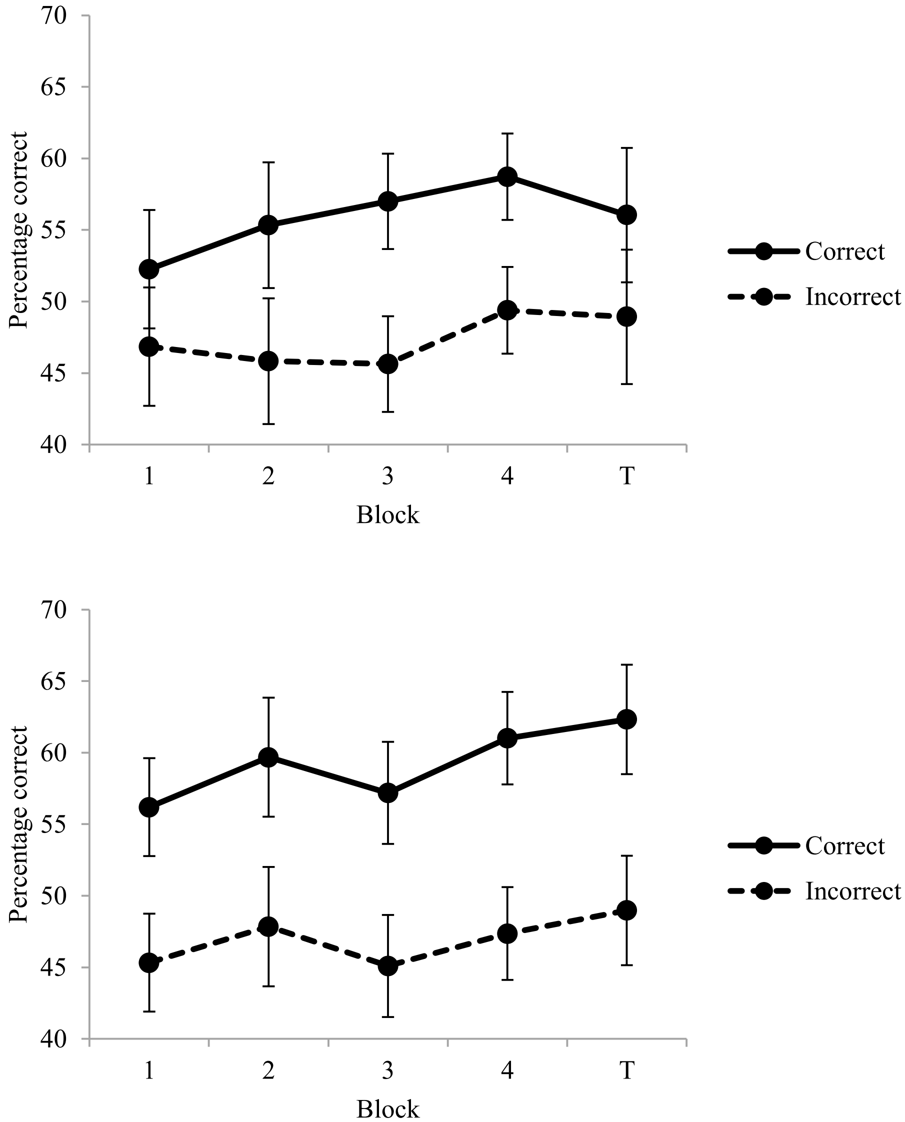


Figure 16. *In both the TD (top panel) and the ASC group (bottom panel), there was a similarly superior performance by participants using correct rather than incorrect strategies. Depicted are the mean accuracies of participants selecting correct or incorrect strategies across the different stages of the PCL task for both groups. The error bars show twice the standard error of differences between categorisation means separately for each of the two groups.*

Figure 17 demonstrated that the use of integrated strategies resulted in superior task performance. ANOVAs with two between-subject factors Categorisation (Integrated vs. Non-Integrated) and Group (TD vs. ASC) were conducted separately within each level of block, and revealed that the use of integrated strategies led to superior task performance in every block except the first (Block 1: ($F(1, 48) = 2.38$, $p = .13$, $\eta^2_p = .05$; for all other blocks: $Fs \geq 19.07$, $ps \leq$

.001 and $\eta^2_p \geq .28$). While there was a numerical trend for the ASC group to have utilised integrated strategies to achieve better PCL performance, there was no statistical evidence of such interactions (all $Fs \leq 3.81$, $ps \geq .06$ and $\eta^2_p \leq .07$). There was no evidence of overall Group differences (all $Fs \leq 2.96$, $ps \geq .09$ and $\eta^2_p \leq .06$).

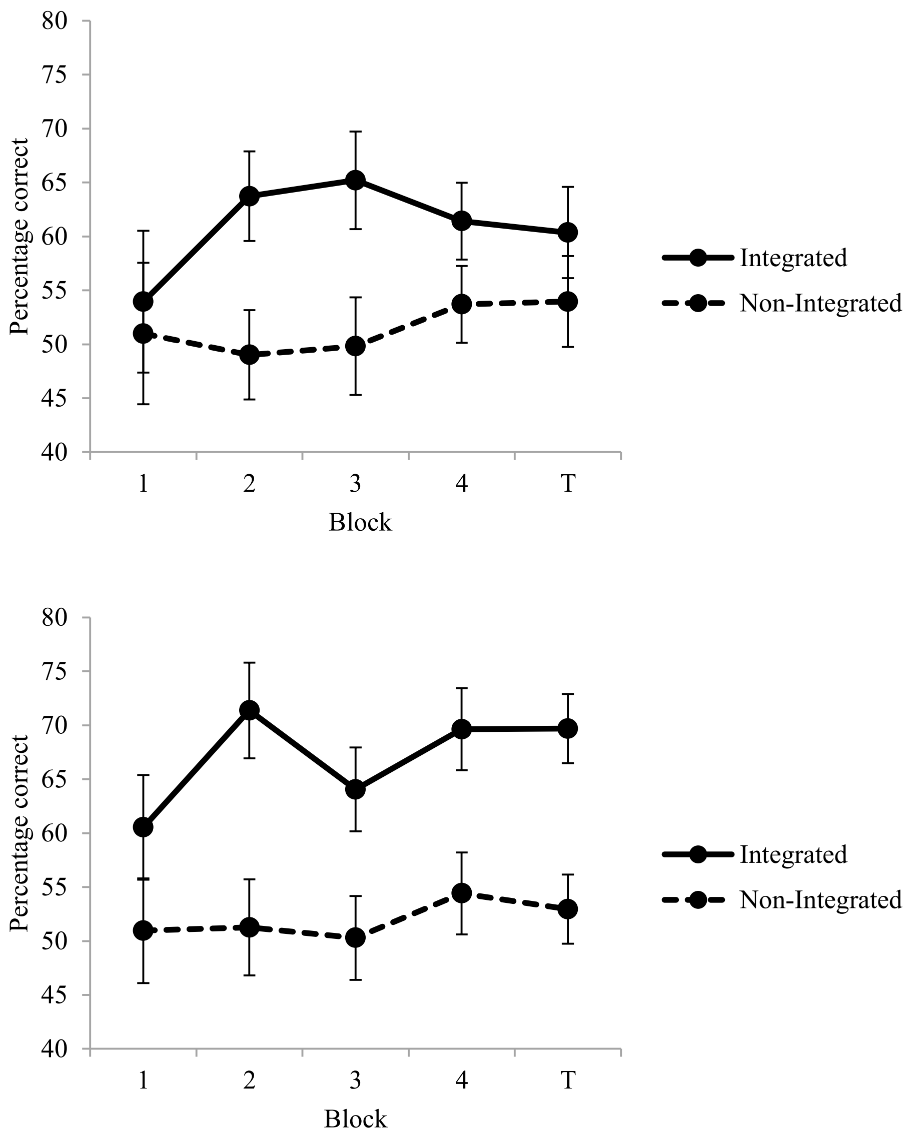


Figure 17. *In both the TD (top panel) and the ASC group (bottom panel), there was a similarly superior performance by participants using integrated rather than non-integrated strategies. Depicted are mean accuracies of participants selecting integrated or non-integrated strategies across the different stages of the PCL task for both groups. The error bars show twice the standard error of differences between categorisation means separately for each of the two groups.*

3.5. Implicitness of Strategies

There is debate as to whether strategies reflect implicit or explicit learning (e.g., Lagnado, et al., 2006; Meeter, Radics, Myers, Gluck, & Hopkins, 2008; Price, 2009; cf, Gluck, et al., 2002; Shohamy, Myers, Kalanithi, & Gluck, 2008). For example, in two studies researchers have found correspondence between the estimates of cue weights and actual cue weights (Lagnado, et al., 2006; Price, 2009). However, Gluck and colleagues have found no correspondence between reported strategies and best-fit strategies (e.g., Gluck, et al., 2002). Therefore, it seems possible that whether strategies are used explicitly will depend upon the particulars of the task. The PCL task procedure used in Study II was designed to minimise explicit learning by following the recommendations of previous research, which has detailed the factors affecting the explicit contributions to categorisation performance. Therefore, Study II used configural, holistic stimuli, rather than stimuli with particularly discrete cues (Maddox & Ashby, 2004). Additionally, Study II used feedback conditions found to minimise explicit processing: feedback was displayed immediately after a response and feedback processing time was minimised by allowing only 600 ms between first receiving the feedback and beginning the next trial (Maddox & Ashby, 2004).

Accordingly, there was evidence from the explicit interviews that implied the task procedures had been successful in minimising explicit processing. In particular, the verbal reports were blindly evaluated in order to determine which strategy each report resembled. Each report was classified as most-resembling either integrated/ intermediate (these two strategy categories could not be distinguished from the reports); single-cue; singleton; incorrect; or random. The number of times a reported strategy matched the best-fit strategy was calculated. This calculation was only carried out for the Test Block because participants were only asked about their final strategies. The number of participants who provided strategies that corresponded to their best-fit strategy was small (n = 14), and a two-tailed binomial test demonstrated that the number was not significantly above the chance level of 20 % (p = .28; a chance level of 20 % was used because 5 category classifications were possible). The number of matches was similar for both the TD (n = 6) and ASC groups (n = 8), and a chi-square contingency table analysis did not provide any evidence of an association between the number of matches and Group ($\chi^2 = 0.39$, $p = .76$, $\Phi^2 = .01$).

Additionally, the verbal reports were blindly evaluated and rated on a 3-point scale of 'explicitness' (1 = reported no knowledge of the relationships in the task; 2 = reported knowledge about the existence of relationships in the task but provided no details as to what they were and/or expressed doubt about their existence; 3 = reported knowledge about at least one relationship they believed to be present in the task). The reports received a variety of ratings (1-rating, n =13; 2-rating, n =14; 3-rating, n =25), and while more participants appeared to have provided 3-ratings than anything else, a chi-square goodness-of-fit test failed to reject the null hypothesis that all ratings were chosen equally often ($\chi^2 = 5.12$, $p = .08$, w = .31). A chi-square contingency table analysis failed to provide any evidence of an association between Group and the Explicitness rating (TD: 1-rating, n =4; 2-rating, n = 8; 3-rating, n =14; ASC: 1-rating, n = 9; 2-rating, n = 6; 3-rating, n = 11; $\chi^2 = 2.57$, $p = .30$, $\Phi^2 = .05$). More important than this analysis of the distribution of the absolute ratings was whether the insight was related to performance. Therefore, the relationship between explicitness and performance was examined. If performance had been mediated explicitly, then those participants who were able to report explicitly the most information should have also performed the best. However, Figure 18 and a two-way ANOVA, with two between-subject factors of Group and Explicitness-rating, provided no evidence of an effect of Explicitness-rating on performance ($F(2, 46) = 0.17$, $p = .85$, $\eta^2_p = .01$), nor of an interaction between Group and Explicitness-rating ($F(2, 46) = 0.31$, $p = .74$, $\eta^2_p = .01$). This same pattern of results remained even after excluding the 12 participants who provided at least one incorrect piece of information about the relationships in the task (Explicitness-rating: $F(2, 34) = 0.39$, $p = .68$, $\eta^2_p = .02$; Group and Explicitness-rating $F(2, 34) = 0.03$, $p = .97$, $\eta^2_p > .01$).

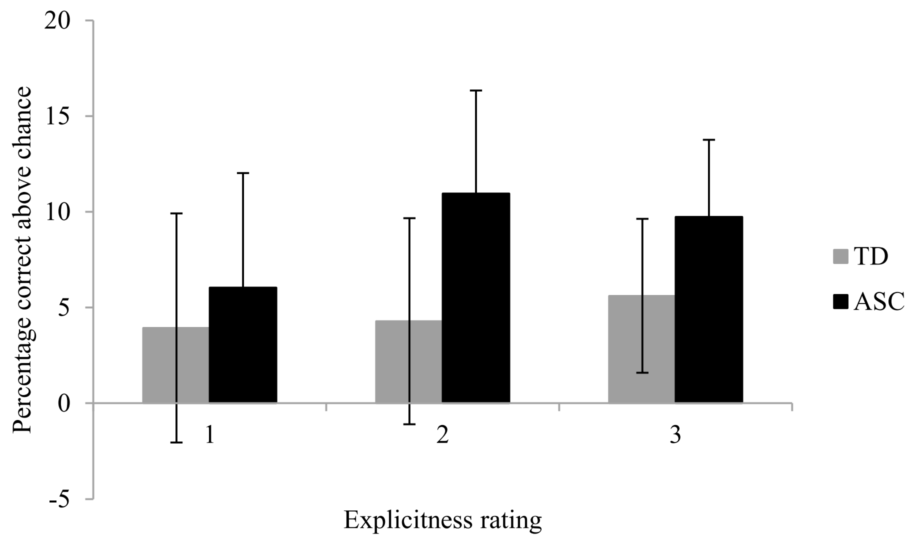


Figure 18. *In both groups, PCL performance was not determined by the explicit knowledge participants had gained about the task. Presented are mean percentage of correct guesses that were provided above chance on the PCL test phase. This score is presented for the two groups depending upon the „explicitness' rating given to the post-task interviews. The error bars show twice the standard error of differences between group means at different levels of explicitness ratings.*

3.6. Modelling Improvements

3.6.1. Modelling Maximising and Matching Behaviour

Figure 19 demonstrated the importance of modelling probability-matching behaviour: maximising models rarely provided a better fit for the data when in competition with matching models. This seemed equally true for both groups and appeared to have remained stable across the blocks. Statistical analyses were not appropriate since the maximising category was always below 5.

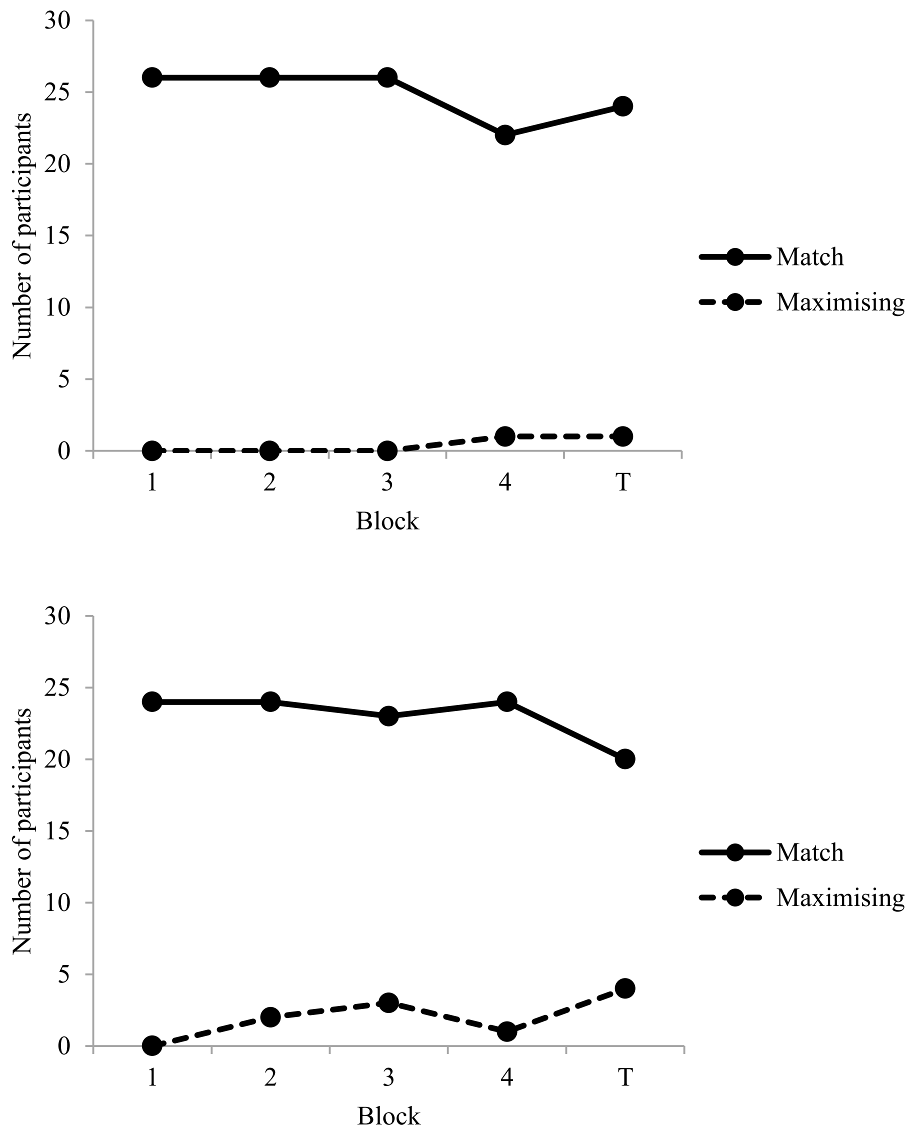
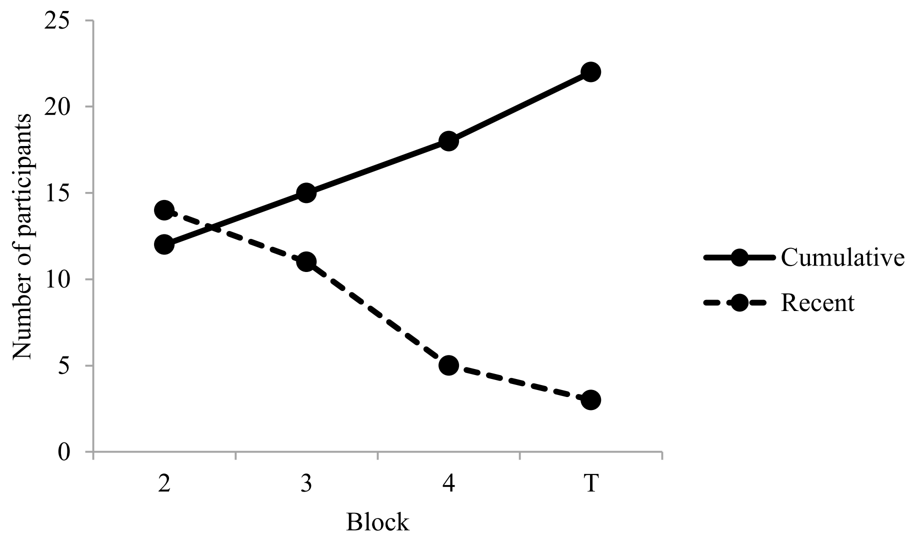


Figure 19. *In both the TD (top panel) and the ASC group (bottom panel), matching models provided a better fit for most participants. Depicted are the numbers of participants best modelled by matching or maximising choices across the different stages of the PCL task for both groups.*

3.6.2. Cumulative and Recent Use of Information

Figure 20 depicted the number of participants best modelled by the recent or cumulative use of information models. The figure demonstrated that there were several instances in which the recent use of information models provided a better fit than the standard cumulative models. Thus, the analysis had been improved by including the recent use of information models.

Additionally, Figure 20 illustrated the similarity of the two groups in their use of cumulative and recent information. Chi-square contingency table analyses comparing the proportion of each group better modelled by recent or cumulative information in each block were consistent with this interpretation (for all blocks: $\chi^2 \leq 1.24$, $ps \geq .40$ and $\Phi^2 \leq .02$). Figure 20 also showed that fewer participants relied on recent information as the task progressed. A Wilcoxon matched-pairs, signed ranks test was consistent with the decreased use of recent information in the Test block relative to Block 2 ($z = 2.94$, $p < .01$, $d = .50$). It was also evident from Figure 20 that the decrease across the blocks in the use of recent information was similar in both groups. A Mann-Whitney U-test was consistent with this interpretation, insofar that it provided no evidence of group differences in the number of participants changing to cumulative strategies in the Test block relative to Block 2 ($z = 1.28$, $p = .24$, $d = .35$).



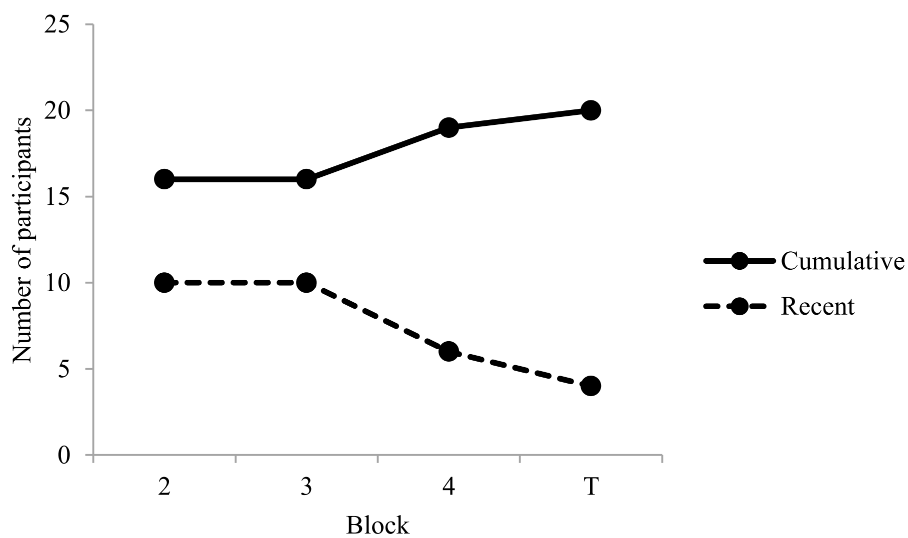


Figure 20. *In both the TD (top panel) and the ASC group (bottom panel), the recent use of information models provided a better fit for some participants. Depicted are numbers of participants best modelled by the recent or cumulative use of information across the different stages of the PCL task for both groups. There were no results for Block 1 because the two models made the same predictions and thus the models were indistinguishable.*

3.7. Discussion

In Study II, analyses had indicated that the TD and ASC groups were equivalent in their overall performance on the PCL task. However, there was a possibility that the overall equivalence was achieved using notably different strategies. Overall, the analyses presented in this appendix emphasised the similarity between the TD and ASC groups in their use of implicit learning strategies on the PCL task. Specifically, there was no evidence of differences between the groups using fine-grained analyses, which considered nuanced variations in strategy, such as which strategies were used, the consistency with which strategies were used and the success with which strategies were used. Additionally, there was evidence that the strategies were largely implicit: strategy insight appeared unrelated to both the strategies that the participants actually used and how successfully the participants performed. Thus, this strategy analysis has demonstrated that the equivalent overall PCL performance was underpinned by a similarity in the implicit learning strategies used by the groups. Additionally, this similarity on the PCL task implies that there cannot be *general* differences between the groups in *how* they achieve equivalent performances on implicit learning tasks.

More generally, this analysis described and demonstrated the benefits of two improvements to strategy analysis, specifically the inclusion of models to reflect both participants who preferred maximising to matching behaviour, and participants who preferred the recent use of information to the cumulative use. Additionally, it is proposed that the strategy analysis was improved both by the inclusion of new analyses, such as the analysis of the consistency with which strategies were used, and the avoidance of the unrealistic assumption that static probabilities were experienced by participants throughout the task.

4. Accuracy Analysis of SRT from Studies III and IV

4.1. Study III

4.1.1. Training: Block 1-10

Unlike RTs, accuracy did not appear to improve as a consequence of training. For example, mean accuracy between the first five and last five blocks was similar, and this appeared equally true of both groups (TD: Mean difference (*M*) = 0.07 %; ASC: *M* = - 0.71 %; *SED* = 0.87 %). Consistent with this interpretation, a mixed analysis of variance with factors of Group and Block revealed no significant effect of Block ($F(5, 137) = 1.22$, $p = .30$, $\eta^2_p = .04$) nor interaction with Group ($F(5, 137) = 1.63$, $p = .16$, $\eta^2_p = .05$). There was also no evidence of an overall effect of Group ($F(1, 30) = 0.15$, $p = .70$, $\eta^2_p = .01$). The failure of accuracy to index learning during the training stage of the task was a consequence of a ceiling effect – accuracy was high from the beginning. This was consistent with findings from Study II: Study II demonstrated that accuracy indexes learning by measuring the deterioration of performance on relatively unexpected (irregular) trials rather than improvement on the sequenced trials. The deterministic version of the SRT used in this study had no unexpected trials until the test block.

4.1.2. Test: Block 10-12

The introduction of the control sequence during the test block made the task more difficult to the extent that accuracy became an index of learning. Specifically, accuracy was worse on the control sequences in block 11 as compared with the training sequences averaged between blocks 10 and 12, and this decrease was similar between the groups (TD: Mean difference (*M*) = 9.08 %; ASC: *M* = 9.52 %; *SED* = 2.68 %). A mixed ANOVA with factors of Group and Block (Control Sequences Block 11 vs. Block 10&12) produced a pattern of results equivalent to the RT analysis: there was an effect of Block indicative of sequence learning ($F(1, 30) = 48.12$, $p < .001$, $\eta^2_p = .62$) but no interaction with Group ($F(1, 30) = 0.03$ $p = .87$, $\eta^2_p < .01$). There was no overall difference between the groups in accuracy ($F(1, 30) = 0.01$ $p = .91$, $\eta^2_p < .01$).

4.1.3. Sequence validity: Block 10-12

As an indirect measure of whether the application of the sequence was explicit, mean accuracy on training sequences in test block 11 (during which the global validity of the sequence was disrupted) were compared with mean accuracy on training sequences in neighbouring blocks 10 & 12. Both groups were more inaccurate on the training sequence in Block 11 than in Block 10 and 12 (TD: Mean difference (*M*) = 4.09 %; ASC: *M* = 0.85 %; *SED* = 1.96 %). A mixed ANOVA with factors of Group and Block (Training Sequences Block 11 vs. Block 10&12) revealed a main effect of Block ($F(1, 30) = 6.37$, $p = .02$, $\eta^2_p = .18$), which indicated that the sequence learning had been explicit to the extent that performance had been more inaccurate when there had been a global disruption to the validity of the sequence knowledge. There was no significant effect of Group ($F(1, 30) = 0.53$, $p = .47$, $\eta^2_p = .02$) nor interaction between Group and Block ($F(1, 30) = 2.74$, $p = .11$, $\eta^2_p = .08$).

4.2. Study IV

4.2.1. Training: Block 1-2

As in Study III, accuracy did not appear to improve as a consequence of training due to a ceiling effect. In both groups, mean accuracy was similar in the first and second block (TD: *M* = 0.99 %; ASC: *M* = -2.83 %; *SED* = 2.51 %). Consistent with this, a mixed analysis of variance with factors of Group and Block revealed no significant effect of Block ($F(1, 30) = 0.54$, $p = .47$, $\eta^2_p = .02$) nor interaction between Group and Block ($F(1, 30) = 2.32$, $p = .14$, $\eta^2_p = .07$). There was no overall effect of Group ($F(1, 30) = 1.92$, $p = .18$, $\eta^2_p = .06$).

4.2.2. Test: Block 10-12

Once again accuracy became sufficiently sensitive across the test block to index sequence learning. Accuracy was worse on the control sequences in block 11 as compared with the training sequences averaged between blocks 10 and 12, and this decrease was similar between the groups (TD: Mean difference (*M*) = 7.81 %; ASC: *M* = 8.52 %; *SED* = 2.24 %). A mixed ANOVA with factors of Group and Block (Control Sequences Block 11 vs. Block 10&12) produced a pattern of results equivalent to the RT analysis: there was effect of Block that indicated sequence learning ($F(1, 30) = 53.35$, $p < .001$, $\eta^2_p = .64$) but there was no evidence of an interaction with Group ($F(1, 30) = 0.10$ $p = .75$, $\eta^2_p < .01$). There was no overall difference between the groups in accuracy ($F(1, 30) = 1.86$ $p = .18$, $\eta^2_p = .06$).

4.2.3. Sequence validity: Block 10-12

As an indirect measure of whether the application of the sequence was explicit, mean accuracy on training sequences in test block 11 were compared with mean accuracy on training sequences in neighbouring blocks 10 & 12. In both groups, there was a decrease in accuracy on the training sequences in Block 11 compared with Block 10 and 12 (TD: Mean difference (*M*) = 3.48 %; ASC: *M* = 0.53 %; *SED* = 1.86 %). A mixed ANOVA with factors of Group and Block (Training Sequences Block 11 vs. Block 10&12) revealed a main effect of Block ($F(1, 30) = 4.66$, $p = .04$, $\eta^2_p = .13$), which was another indication that the sequence learning was explicit. There was no significant effect of Group ($F(1, 30) = 0.52$, $p = .48$, $\eta^2_p = .02$) nor interaction between Group and Block ($F(1, 30) = 2.53$, $p = .12$, $\eta^2_p = .08$).