

Attention and Awareness in  
Human Learning and Decision Making

Balazs Aczel

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Department of Experimental Psychology  
Emmanuel College

University of Cambridge  
Cambridge  
United Kingdom

## PREFACE

The following work was carried out at the Department of Experimental Psychology, University of Cambridge, under the supervision of Prof Ian McLaren, Prof Nicholas Mackintosh and Dr Michael Aitken.

I hereby declare that this dissertation has not been submitted, in whole or in part, for any other degree, diploma or qualification at any other University.

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

The length of this dissertation is 211 pages.

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## AUTHOR'S NOTE

*Collaborations*

The data collection at the Eötvös Loránd University, Budapest, Hungary was done with the assistance of three undergraduate students: Csongor Cserép (Chapter III), Judit Komlós and Bence Lukács (Chapters IV and V). Their assistance was restricted to recruitment and testing of participants, and did not extend to data analysis, interpretation or any other theoretical contribution of the present thesis.

*Statistical Standards*

Data analysis was performed using SPSS v16 software. Effect sizes were reported as estimates of Cohen's  $d$  for differences, and partial eta-squared  $\eta^2_p$  for higher  $df$  ANOVA effects, the significance of which were always assessed using standard sphericity corrections where appropriate (Cardinal & M. R. F. Aitken, 2006). Significance tests were all assessed at the  $\alpha = 5\%$  level, and directional tests with two-tailed probabilities, except where explicitly stated otherwise.

Reaction time (RT) data were trimmed to discard individual RTs of extreme leverage (more than  $3 \times$  IQR beyond a quartile boundary; see Howell, 2007) from the data of an individual participant. All analyses were repeated on untrimmed data, which did not result in a change in the ordinal pattern of means, or conclusions of significance (Howell, 2007).

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## SUMMARY

This dissertation presents an investigation of the modifying role of *attention* and *awareness* in human learning and decision making. A series of experiments showed that performance in a range of tests of unconscious cognition can be better explained as resulting from conscious attention rather than from implicit processes.

The first three experiments utilised a modification of the Serial Reaction Time task in order to measure the interaction of implicit and explicit learning processes. The results did not show evidence for an interaction, but did exhibit an effect of explicit knowledge of the underlying rules of the task.

Subsequent studies examined the role of selective attention in learning. The investigation failed to provide evidence that learning inevitably results from the simple presentation of contingent stimuli over repeated trials. Instead, the learning effects appeared to be modulated by explicit attention to the association between stimuli. The following study with a novel test designed to measure the role of selective attention in prediction learning demonstrated that learning is not an obligatory consequence of simultaneous activation of representations of the associated stimuli. Rather, learning occurred only when attention was drawn explicitly to the association between the stimuli.

Finally, the Deliberation without Attention Paradigm was tested in a replication study along with two novel versions of the task. Additional assessment of the conscious status of participants' judgments indicated that explicit deliberation and memory could best explain the effect and that the original test may not be a reliable measure of intuition.

In summary, the data in these studies did not require explanation in terms of unconscious cognition. These results do not preclude the possibility that unconscious processes could occur in these or other designs. However, the present work emphasises the role conscious attention plays in human learning and decision making.

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## LIST OF ABBREVIATIONS

AGL	–	Artificial Grammar Learning task
ANOVA	–	Analysis of Variance
CI, CB	–	Confidence Intervals, Confidence Bound
d	–	Cohen’s d, effect size
DWA	–	Deliberation without Attention paradigm
fMRI	–	functional Magnetic Resonance Imaging
HOT	–	Higher-Order Thought theory
IQR	–	Interquartile range
ISI	–	Interstimulus Interval
M	–	Mean
ms	–	millisecond
MTL	–	Medial Temporal Lobe
n	–	Sample size
OCD	–	Obsessive Compulsive Disorder
PDP	–	Process Dissociation Procedure
PDW	–	Post-Decision Wagering
RSI	–	Response-Stimulus Interval
RT	–	Reaction Time
SALT	–	Selective Attention Learning Task
SD	–	Standard Deviation
SED	–	Standard Error of Differences between means
SEM	–	Standard Error of Mean
SM	–	Subjective measures
SOC	–	Second Order Conditional
SRT	–	Serial Reaction Time test
UTT	–	Unconscious Thought Theory
VST	–	Visual Search Task
$\eta^2_p$	–	eta-squared, effect size

## I. INTRODUCTION

*What is the role of awareness in learning? Is attention to coincident stimuli sufficient for learning an association between them? Do we make better decisions if our attention is diverted, or if we consciously deliberate on our options?* Scientific interest in answering these questions started long ago (e.g., Brunswik, 1956; James, 1890) and the resulting theories have had long-lasting effects on general thinking. Consistent with the basic dichotomous propensity of human thinking, binary descriptions of memory and learning processes (e.g., conscious – unconscious; declarative – procedural; short-term – long-term) became principles of our understanding of human cognition. The crucial question, however, remains as to whether we have sufficient empirical evidence to sustain such distinctions. While recent theories postulate the existence of more than two memory systems (e.g., McDonald, Devan, & Hong, 2004), other researchers argue that the empirical data can be explained in a single-model view (e.g., C. J. Berry, Shanks, & Henson, 2008). Is it reasonable to hypothesise the existence of only one form of human learning or two? Is three unthinkable, maybe four or more? This thesis will take the parsimonious position that a single-process learning viewpoint should be sustained until contradictory empirical evidence emerges or until the explanatory costs of maintaining such a position exceed that of its abandonment.

### *The Implicit–Explicit Distinction*

Empirical support for independent systems emerged in parallel in the fields of learning and memory. Systematic investigations of independent memory systems began with Scoville and Milner’s (1957) discovery that patients with medial temporal lobe (MTL) damage demonstrated intact memory performance in certain tasks, but impairment in other types of learning and memory functions. Further evidence for this independence has come

from priming studies (e.g., Cermak, Talbot, Chandler, & Wolbarst, 1985), in which improved performance has been observed after previous presentation of the stimulus, despite patients with amnesia not remembering that they had ever seen the stimulus. Based predominantly upon these studies, theorists started to propagate the idea of a dual-model memory system. As Tulving said, “...we are tempted to think that [these priming effects] *reflect the operation of some other, as yet little understood, memory system*” (1982, p. 341). This conception of memory as a dichotomous process clearly advocated a view of two memory systems that are independent and control different domains of behaviour. These systems have often been dissociated into distinctions such as declarative versus non-declarative (Squire & Zola-Morgan, 1988), or explicit versus implicit (Graf & Schacter, 1985), relating mainly to the presence or absence of awareness.

Based on the observation of correspondences between brain lesions and specific memory deficits, such dissociations between memory systems have been described on a neuroanatomical level. Distinct, different patterns of deficit have been claimed to be associated with disruptions of distinct regions, including the hippocampus and perirhinal cortex (Gaffan, 1994); the hippocampus and amygdala (R. G. Phillips & LeDoux, 1992); the hippocampus and striatum (Packard, Hirsh, & White, 1989); and the cerebellum and amygdala (Hitchcock & M. Davis, 1986).

However, in more recent studies, difficulty has arisen in interpreting the results of such neuroanatomical studies as providing evidence for dichotomous memory processes, and thus a new taxonomy was needed in which to fit the data. While the original concept of a declarative system was relatively clear, the ‘non-declarative’ expression was used only as an ‘umbrella term’ (Squire & Zola-Morgan, 1988) as it referred to several less well-defined subsystems. The first detailed taxonomy of long-term memory systems based on neuroscientific evidence (Squire, 1987) divided the non-declarative system into four sub-

systems (procedural, priming, classical conditioning, non-associative learning) that “*operate in parallel to support behaviour*” (Squire, 2004, p. 174). An increasing number of behavioural and neurobiological researchers claimed recently, however, that separating brain regions by different memory functions without knowing much about their relations is not sufficient for constructing valid models of these memory substrates (e.g., Hartley & Burgess, 2005; McDonald et al., 2004; Poldrack et al., 2001; Turk-Browne, Yi, & M. M. Chun, 2006), and others have questioned whether observed dissociations in test results necessarily indicate dissociating processing systems (e.g., C. J. Berry, Henson, & Shanks, 2006).

In parallel with the memory research, the systematic exploration of this conscious/nonconscious dissociation in the field of learning started with Arthur Reber’s initial work in the late 1960s, when he coined the term *implicit learning* to describe his findings in an Artificial Grammar Learning (AGL) test (A. S. Reber, 1967). In this test, he first trained participants on letter-strings by asking them to reproduce the strings shortly following their presentation. Unbeknownst to them, the letter strings followed a predetermined artificial grammar. In a subsequent test phase participants were asked to judge whether a novel set of letter-strings were grammatical or not. It was observed that many of the participants could categorise the strings correctly above chance, indicating that learning had occurred. Interestingly, however, they were generally unable to verbalise the rules or the presence of rules. On the basis of these results, Reber concluded that the learning in this task was not conscious.

Since his initial empirical work, Reber (1992) has argued that consciousness is a novel phenomenon evolving after many higher perceptual and cognitive processes. From this standpoint, he reasoned, implicit learning is phylogenetically older than explicit learning. Based on this notion, Reber proposed four hypotheses relating to the capacity of implicit learning: (1) it is robust in relation to psychological and neurological effects; (2) it is

independent of IQ; (3) it is independent of age; and (4) it has little variance between individuals. Derived from this view is a general notion that implicit learning requires little effort, and is often accurate and even, perhaps, more optimal than alternative, explicit learning mechanisms (e.g, Holyoak & Spellman, 1993).

### *Theoretical Definitions of Implicit Learning*

Implicit learning has various descriptions and numerous definitions. Some models explain implicit learning as an associative-based process (e.g., McLaren, Green, & Mackintosh, 1994; Spiegel & McLaren, 2006), others as learning by statistical regularities (e.g., Hunt & Aslin, 2001), or in connectionist models (Cleeremans & Dienes, 2008; Dienes, Altmann, & Gao, 1999; Kinder & Shanks, 2001). Although most definitions of implicit learning address some acquisition of knowledge, in practice this ‘knowledge’ often designates a complex rule or sequence, a relationship more complex than simple associations. Implicit learning does not have a single definition, and for that reason, it is important to see what the general characteristics are of the different conceptualisations. Some typical examples of the many definitions are listed below (emphasis added):

Implicit learning *“is the acquisition of knowledge that takes place largely independently of **conscious** attempts to learn and largely in the absence of explicit knowledge about what was acquired.”* (A. S. Reber, 2003, p. 5)

*“[I]mplicit learning [is a] **nonintentional, automatic** acquisition of knowledge about structural relations between objects or events.”* (Frensch, 1998, p. 48)

“*[I]mplicit learning is taken to be an elementary ability of the cognitive systems to extract the structure existing in the environment, regardless of their **intention** to do so.*” (Jimenez, 2003, p. 6)

“*Traditionally, implicit learning has been defined as learning which takes place **incidentally**, in the absence of deliberate hypothesis-testing strategies, and which yields a knowledge base that is inaccessible to **consciousness**.*” (Shanks, 2003, p. 11)

“*Implicit learning occurs without **intention** to learn and without **awareness** of what has been learned.*” (Williams, 2005, p. 269)

A common feature of these definitions is that, unlike models of implicit memory, they describe the mode of learning rather than the mode of retrieval. Implicit learning is often considered to be *nonintentional/automatic, unconscious or incidental*.

Roughly speaking, learning may be described as *automatic* when it is unavoidable and when it happens without conscious effort or monitoring (Perlman & Tzelgov, 2006). Automaticity is a strong assumption since it would require that performing other tasks does not reduce the capacity for learning, since it does not demand attention (Kahneman & Treisman, 1984). Despite intense interest, evidence for such a strong form of automaticity has been difficult to obtain (D. Berry & Dienes, 1993; Jiang & Leung, 2005; Mitchell, De Houwer, & Lovibond, 2009).

The descriptions of implicit learning as *unconscious, nonconscious, and unaware* have slightly different connotations, but are similar in that they state that the process occurs without consciousness. The term *incidental* refers to the case in which learning occurs without direct instruction. This is perhaps the least controversial attribute of implicit learning

amongst researchers in the area, but does not in and of itself necessitate that performance requires a different type of learning.

In consideration of the various issues above, for the remainder of this thesis, the term ‘implicit learning’ will be used only to refer to knowledge acquisition which does not require conscious attention.

### *Operational Definitions and Measures of Implicit Learning*

Operationally, implicit learning is generally defined by performance on implicit learning tests. A typical example is the Serial Reaction Time task (SRT; Nissen & Bullemer, 1987). In this task, a target appears in one of four possible horizontal locations on a computer screen. Participants are instructed simply to report the location of the stimulus by pressing down one of four corresponding keys. Participants are told to be as fast and as accurate as possible. They are not, however, informed that the location of the asterisk follows a repeating sequence (or a probabilistic rule), such that knowledge of the rule or sequence would allow prediction of the location of the asterisk. Participants have shown that they learn about the rule or sequence, in that irregular probe trials typically produce longer reaction times than do trials on which the location of the asterisk is predictable. Explicit, conscious knowledge about the rule or sequence assessed using post-experimental questionnaires (e.g., Eimer, Goschke, Schlaghecken, & Stürmer, 1996), or Process Dissociation Procedures (e.g., Destrebecqz & Cleeremans, 2001) often found that the participants exhibited learning without showing explicit knowledge about the sequences. The sequences used in SRT designs are often constructed as second order conditional sequences where a given pair of consecutive items determines the location of the next item (Reed & P. Johnson, 1994). Learning in the SRT task has also been demonstrated using complex (Remillard, 2008) as well as probabilistic

sequences (Schvaneveldt & Gomez, 1998; Vandenberghe, Schmidt, Féry, & Cleeremans, 2006).

Support for distinct implicit and explicit learning processes has also come from clinical studies (e.g., Nissen & Bullemer, 1987), studies with event-related brain potentials (e.g., Rüsseler & Rösler, 2000) and brain imaging works (e.g., Poldrack et al., 2001). Neuroimaging data have shown different brain activation patterns in implicit versus explicit learning conditions. For example, Rauch and colleagues (1995) found that in an implicit learning condition the right ventral premotor cortex, the right ventral caudate/nucleus accumbens, the right thalamus and the bilateral Area 19 were involved. By contrast, in an explicit learning condition the primary visual and inferior parietal cortex were activated, areas which are usually involved in visual and language processes. Moreover, functional neuroimaging studies have suggested that the MTL activity, which correlated with explicit learning, was independent of the processing of implicit learning (Curran, 1998). Bilateral MTL lesion patients were also reported to be selectively impaired in explicit, but not implicit learning tasks (e.g., Gagnon, Foster, Turcotte, & Jongenelis, 2004). Despite some contradictory findings that demonstrated the involvement of the MTL in implicit as well as explicit learning processes (e.g., Rose, Haider, Weiller, & Buchel, 2004; Schendan, Searl, Melrose, & Stern, 2003), the neuroimaging literature is relatively consistent in interpreting the data according to a model in which the human brain supports multiple learning mechanisms.

As has been described, seemingly compelling arguments for the existence of a nonconscious version of learning have been made based on conceptual considerations, as well as behavioural and neuroscientific research. To assess the validity of these arguments it is essential to consider the (often tacit) preliminary assumptions upon which they are based. In a typical implicit learning study, such as SRT, the presence of relationships between the

stimuli remains hidden from the participants. After the experiment, tests of awareness explore whether any of the hidden rules describing the relationships are available to consciousness as a result of the learning that produced above-chance performance. The absence of conscious knowledge of the rule in conjunction with above-chance performance is often interpreted as a consequence of unconscious learning. For example, Remillard (2008) makes the argument overtly that “*Sequence learning that is explicit [...] would presumably lead to an awareness of the sequence of target locations. Thus, a lack of awareness of the sequence of target locations would suggest that sequence learning was implicit*” (2008, p. 400). Note that, although implicit learning is defined by the learning process, within this approach it is measured by its product. In a practical sense, therefore, the operational definition of implicit learning becomes “*the capacity to learn without awareness of the product of learning.*” (Frensch & Runger, 2003, p. 14).

### *The Smart Unconscious*

Another area of human cognition where the dual-model descriptions are prevalent is decision making. Everyday situations require numerous judgments and decisions where the components of the situations are often very complex and the outcomes of the decisions are rather uncertain. How is the human cognitive resource capable of dealing with these demanding tasks? Brunswik (1956) suggested that the decision-makers utilise their knowledge about the various cues of the environment by way of statistical processing. Brunswik (1955) advocated that humans are better regarded as ‘intuitive statisticians’ since this processing occurs involuntarily. Since then, various dual-models of decision making describe a separate source or process as heuristic (Tversky & Kahneman, 1974), associative (Sloman, 1996), or experiential (Epstein, 1994) distinct from the conscious domain. Stanovich and West (2001) have proposed the term System 1 for a counterpart of deliberate

thinking with older origins. This system is often attributed with labels such as automatic, unconscious, rapid, powerful, associative and pragmatic (Evans, 2007). Attention plays a central role in intuition, as it is often considered to be a thought without attention (e.g., Dijksterhuis & Nordgren, 2006).

For most of the theorists of unconscious cognition, intuition is a conscious feeling about an unconscious knowledge (e.g., Dienes, 2008). In this sense, the intuitive decision is based on knowledge gathered in the past that is currently not available for consciousness (Polanyi, 1967). In another interpretation, however, intuition is a process that can deliberate on the decisions without thinking. The Unconscious Thought Theory (UTT, Dijksterhuis & Nordgren, 2006) claims that in complex situations this unconscious thought, which weighs the various aspects of the decisions in a distributed way, is able to suggest more optimal decisions than conscious thought. This approach ascribes certain intelligence to the ‘unconscious’ and based on its empirical findings it advises us to rely on our intuitions in complex decisions. The validity of this wisdom, however, is debated in the field. Without finer-grained investigation it remains undecided whether intuition is truly a powerful unconscious process, or whether conscious attention is inevitably necessary for consequential thinking.

### *Overview of the Thesis*

This chapter has provided only an introductory overview of theoretical and experimental issues relating to unconscious learning and decision making. However, many of these issues are specific to particular experimental paradigms, and thus will be considered, along with those issues outlined here, in the introductions to the relevant experimental chapters.

This thesis explores the role of awareness and attention in human learning and decision making. In the first empirical chapter, Chapter II, the interaction of implicit and explicit learning processes are investigated based on the idea that if separate learning processes exist, then they could be independently modulated and their effects observed through their interaction. For this reason, preliminary phases were added to the SRT to facilitate the two processes separately and in combination.

The following chapter, Chapter III, asks the following two questions: (1) Does predictive learning occur incidentally without focused spatial attention on the stimuli? (2) Do the different tests of awareness measure the phenomenon in concordance? To explore this question, a new test was designed where peripheral stimuli are used as predictive cues of target locations, thus creating an incidental learning environment. To measure the concordance of the tests of awareness, a combination of forced choice tasks, subjective measures and verbal reports were employed.

In Chapter IV, the claim that learning is an obligatory consequence of selective attention of the stimuli is tested. Towards this aim a novel test, the Selective Attention Learning Test (SALT), was devised. The unique aspect of this test is that it can engender simultaneous selective attention on the stimuli while disguising elements of their predictive relationship. If the assumption is tenable, then the participant's belief about a particular predictive relationship should not be necessary for learning to occur.

The final empirical chapter, Chapter V, investigates the role of attention and awareness in decision making. The Deliberation without Attention paradigm (DWA) was originally designed as a demonstration that, in complex situations, humans make better decisions if they divert their attention from the task for a period of time than they do by making conscious effort to solve it. The theory behind the paradigm states that unconscious

thought leads to a solution by a more optimal, distributed weighting of the experienced information. A replication of one of the original tests and two further adaptations of the paradigm were performed to allow a detailed examination of the empirical support for this claim.

The General Discussion attempts to integrate the results of the 11 experiments reported and to assess their implications for current conceptualisations of the role of attention and awareness in human learning and decision making. This section also proposes some additional speculative thoughts about the development of learning, aiming to foster new empirical questions and hypotheses for further research.

## II. INTERACTION IN IMPLICIT AND EXPLICIT LEARNING

The objective of the experimental approach adopted in this chapter is to analyse the interaction of the two kinds of processes in a single task. In researching the interactions between cognitive systems, it is generally assumed that the behavioural product of the simultaneous use of the systems may be modulated by the different types of interplay between these systems.

The idea of 'system interaction' has already been applied to the field of memory research. In their summary of the existing neurobehavioral research of memory systems, Hirsh and Kraiden (1982) provided theoretical descriptions of the possible interactions between cognitive-, and habit-based memory systems. They proposed that, depending on the occasion, the systems interact by way of either *competition* or *cooperation*. They propose that in the majority of the cases, the two systems process the information in parallel, and it is determined by the requirements of the given situation whether they interact competitively or cooperatively.

To date, studies examining interactions between memory systems relations have indicated competitive (e.g., Mizumori, Yeshenko, Gill, & D. M. Davis, 2004), cooperative (e.g., Hartley & Burgess, 2005) and compensational (e.g., Voermans et al., 2004) relations between proposed memory systems. The basis of these interactions is held to be the shared representations (Turk-Browne et al., 2006) and common access to the same information (McDonald et al., 2004) between the simultaneously processing parallel systems. The independent retrieval hypothesis assumes that the difference between the systems lies not in the encoding, but only in terms of retrieval processes (Turk-Bowne et al., 2006).

The explanations of when and how these systems interact did not go further than the original framework of Hirsh and Kraiden (1982), and it is mostly limited to notions such as

*“in some tasks, cooperation is possible because the parallel systems support compatible behaviours, whereas in other tasks they drive conflicting responses and must therefore compete to control behaviour”* (Hartley & Burgess, 2005, p. 170).

#### *Evidence for Independent Learning Systems*

Not all subscribers to the multiple memory system view suggested a similar interplay between learning processes. Squire and his colleagues (e.g., P. J. Reber & Squire, 1994; Squire, 1992) advocate that implicit and explicit learning proceed independently, generating knowledge within each system, which, in turn, can have a joint influence on behaviour. Similarly, in his control-based learning theory (COBALT), Willingham (1998) presents a dual mode model of motor skill learning, which applies to SRT. This proposes a Dual Mode Principle which states that the conscious mode is attention-demanding, but accurate, whereas the unconscious mode is not attention-demanding, but also not as accurate. The actor can switch between the two modes weighing the accuracy and attentional demands of the situation. The two modes operate independently, in the sense that one mode may operate without the other. The two systems can interact unidirectionally only; the conscious mode can overrule the unconscious mode. In some cases the conscious mode can be detrimental to the performance (e.g., the choking under pressure effect, Baumeister, 1984), while at other times it can be beneficial. According to the model, easier tasks are not susceptible to the detrimental effect of conscious mode, but for skilled performers on more difficult tasks the unconscious pathway may guide performance more effectively. Therefore, the overriding of the conscious mode can lead to poorer performance.

Further support for the notion of parallel learning systems came from studies of brain impairment. Some of these motor learning studies reported that focused impairment of one system had no effect (N. J. Cohen & Squire, 1980), or led to impaired learning in the other

system (Curran, 1997a). In a behavioural study, Willingham and Goedert-Eschmann (1999) trained participants either on an implicit or an explicit SRT task using a 12-element repeating sequence. The final probe block consisted of mostly random elements, but occasionally probe elements that followed the trained sequence. The authors assumed that in such a probe block explicit knowledge could not be applied. They found that on trials where the sequence was the same as they were previously trained with, the participants were faster than they were on the random trials. Interestingly, the explicit and the implicit groups did not show difference. However, in a post-experiment free recall test the explicit group showed evidence of explicit knowledge, whereas the implicit group did not. This pattern of results was interpreted in several studies as an indication of parallel processing of implicit and explicit learning, with no competitive interaction between them (e.g., Karni et al., 1995; Willingham, Salidis, & Gabrieli, 2002; Deckersbach et al., 2002).

#### *Evidence for Interactive Learning Systems*

On the basis of non-overlapping brain activation patterns observed during implicit and explicit learning tasks, early researchers argued that these processes are mutually exclusive, and cannot even occur simultaneously (Grafton, Hazeltine, & Ivry, 1995; Hazeltine, Grafton, & Ivry, 1997; Rauch et al., 1995). More recent neuroimaging studies of sequence learning, however, found overlapping activation pattern of brain regions in implicit and explicit learning. Willingham, Salidis and Gabrieli (2002) trained the participants to explicitly learn and detect the locations of red circles, which were presented along with black circles. Unbeknownst to the participants, the to-be-ignored black circles followed a different repeating sequence. During the fMRI scanning, participants were presented with either the first (red) sequence, of which they had been aware (explicit condition), or with the second (black) sequence, of which they had not been aware (implicit condition). A crucial third

group received the first sequence, but in black instead of red (explicit-covert condition). The authors expected that this latter group would believe that the sequence is random. However, they had motor knowledge about the sequence, thus creating a “direct comparison” of the presence or absence of awareness about the same sequence. Willingham and his colleagues found overlapping cerebral network activations in these conditions.

Other studies also found overlapping (Schendan et al., 2003) or partially overlapping caudate, prefrontal, and MTL activations (Destrebecqz et al., 2005; Aizenstein et al., 2004) in functional imaging explorations of explicit and implicit learning. In these studies activation of the dorsolateral prefrontal cortex and medio-temporal regions correlated with processing in the implicit learning task (see also McIntosh, Rajah, & Lobaugh, 1999), regions that are primarily associated with the declarative memory system (Squire & Zola, 1996).

Studies of probabilistic classification learning have indicated competitive interaction between implicit and explicit learning systems, which are described as systems constantly engaged in optimising learning (Foerde, Knowlton, & Poldrack, 2006; Poldrack & Rodriguez, 2004). Poldrack and his colleagues (Poldrack et al., 2001) found a reciprocal relationship between the caudate nucleus and the MTL in a probabilistic classification learning task. After some initial activity in the MTL, the caudate became active and MTL activity subsided. The authors claimed that the activity in these regions is indicative of competing implicit and explicit systems. They argued from an evolutionary standpoint that different learning systems have developed, specialised for the different learning situations, which compete for processing in a learning situation (Poldrack & Rodriguez, 2004).

In general, explicit knowledge is often reported to develop far more slowly than implicit learning. Participants could provide usable verbal knowledge only after implicit learning was already measured (Bowers, Regehr, Balthazard, & Parker, 1990; A. S. Reber &

S. Lewis, 1977; Stanley, Mathews, Buss, & Kotler-Cope, 1989). These results were interpreted as explicit knowledge having been “extracted” from implicit knowledge (Seger, 1994; Sun, Zhang, Slusarz, & Mathews, 2007).

The Unexpected-Event Hypothesis (Frensch et al., 2003) introduced another means of interaction between the systems. It posited that implicit learning precedes explicit learning and, furthermore, that explicit learning is triggered by the consequences of implicit learning. The observation of the unexpected events, caused by incidental learning, triggers the conscious system to search for a cause and, consequently, leads to the discovery of regularities. Slower and more error-prone responses on random or irregular trials become unexpected events and can trigger explicit search or interpretation (Rünger & Frensch, 2008). Haider and Frensch (2005) provide an example of an experiment giving empirical support to this hypothesis. In this experiment, the researcher attempted to manipulate of the level of declarative (explicit) learning, whilst keeping the non-declarative (implicit) learning constant. A significant change in verbal reports was detected, but no significant difference in the RTs. The authors interpreted this pattern of results as “*clear evidence in favour of the multiple-systems account*” (p. 399), thus seemingly taking the lack of evidence of difference in RT as conclusive evidence of no difference in implicit learning.

A number of studies trying to promote learning by explicit instruction resulted in slight or no performance improvement for implicit learning tasks (Ingram et al., 2000; Mazzoni & Krakauer, 2006; Watanabe, Ikeda, & Hikosaka, 2006). Many other studies, however, have claimed to demonstrate that explicit processes can influence implicit learning. Explicit knowledge can be provided to participants in a variety of ways. Improved performance has been demonstrated in groups given preliminary explicit training relative to an untrained control group (Curran & Keele, 1993). General information being provided to participants before the test can also have a beneficial effect on the SRT performance (Curran,

1997b; Frensch & Miner, 1994; Buchner, Steffens, Erdfelder, & Rothkegel, 1997). Concurrent verbalisation (Ahlum-Heath & Di Vesta, 1986; Stanley et al., 1989); explicit instructions (D. C. Berry & Broadbent, 1984), or a synergy of the two (Sun, Slusarz, & Terry, 2005; Sun, Merrill, & Peterson, 2001a) have also been shown to lead to improved performance in different implicit learning tasks.

Explicit knowledge is often associated with the acquisition of plan-based control and, consequently, with better performance (Tubau & Lopez-Moliner, 2004). Jiménez, Méndez and Cleeremans (1996) suggested that the benefit of explicit knowledge upon implicit learning tasks may depend on the structural complexity of the stimuli. They found that providing explicit information helped the performance on deterministic sequence learning, but not probabilistic sequence learning. This pattern of results was replicated by Stefaniak, Willems, Adam, and Meulemans (2008). The effect of explicit training was reported to disappear in dual-task conditions, interpreted as support for the existence of two learning mechanisms (Keele, Ivry, Mayr, Hazeltine, & Heuer, 2003). The beneficial effect of explicit knowledge and the measured correlation between SRT performance and post-task explicit knowledge (e.g., Hartman, Knopman, & Nissen, 1989; Buchner et al., 1997; Curran, 1997b; Frensch & Miner, 1994) was not interpreted in these studies as evidence against the implicit nature of the learning task, but rather as an interaction of the two systems and a development of explicit knowledge based on an implicit learning experience.

Explicit knowledge has also been reported to hamper performance on implicit tasks (e.g., A. S. Reber, Kassin, Selma Lewis, & Cantor, 1980). Shea, Wulf, Whitacrem and Park (2001) ascribed their finding of a negative effect of explicit instruction on SRT performance to the processing limitations of the explicit system, saying that in tasks of high demand the implicit processing can be more efficient. However, the explicit information can be sometimes misleading, as Perruchet, Chambaron and Ferrel-Chapus (2003) argued had

happened in Shea and colleagues' case. Masters (1992) argued that highly skilled, but anxious, individuals try to explicitly monitor their behaviour, which in turn interferes with their automatic task processing, resulting in an impaired performance in motor skill tasks. Also, the participants receiving implicit practice conditions are less likely to fail under pressure than if they learned the skill explicitly (Rathus, A. S. Reber, Manza, & Kushner, 1994).

Imaging studies have shown interference of explicit knowledge upon implicit learning tasks using complex sequences, but not for simple deterministic sequences (Fletcher et al., 2005). Also, a behavioural study showed that these explicit processes did not interfere with AGL for young individuals, but they did interfere for elderly ones (D. V. Howard & J. H. Howard, 2001). The varying pattern of results was ascribed to methodological differences in the tasks, such as the ways stimuli were presented (A. S. Reber et al., 1980), or whether the instructions promoted only rule search (Schooler, Ohlsson, & Brooks, 1993) or provided 'how-to' information (Stanley et al., 1989).

Also, decreasing the response-stimulus interval (RSI) in the SRT task was shown to selectively impair explicit, but not implicit learning (Destrebecqz & Cleeremans, 2001, 2003). This finding was interpreted as longer RSIs providing an opportunity to develop conscious expectation about the location of the stimuli, although later studies have repeatedly shown that explicit sequence learning is possible in the 0 ms RSI condition (e.g., Norman, Price, & Duff, 2006; Wilkinson & Shanks, 2004).

### *Integrated Models of Implicit Learning*

More recently, researchers started to argue against models proposing independent or mutually exclusive systems, claiming that it is highly implausible to assume that any form of learning could be "process pure" since awareness cannot be "turned off" (Perruchet,

Cleeremans, & Destrebecqz, 2006; Destrebecqz, 2004; Destrebecqz & Peigneux, 2006). This approach suggests a model with simultaneous involvement of the different processes with varying contribution from each (Sun, Merrill, & Peterson, 2001b; Sun et al., 2005; Cleeremans & Jimenez, 1998). Instead of aiming for studying these processes in isolation, the integrated approach tries to escape the controversies of identifying which process is involved in a task by taking into account both learning processes. As an example, in a study of skill learning, Sun and his colleagues (Sun et al., 2001a) constructed CLARION, a hybrid connectionist model for the continuous interaction of declarative and procedural knowledge. This model combined the contribution of top-down learning to a bottom-up development of knowledge. For the skill-learning (Sun et al., 2001a) and process-control (Sun et al., 2007) tasks under investigation, the model provided a good fit for the human data.

Other evidence for a form of ‘compensatory interaction’ comes from studies involving patients with Obsessive-Compulsive Disorder (OCD). Neuroimaging studies (Rauch et al., 1997, 2001) found that those patients with a dysfunction in the frontal-striatal network (a region that is associated with implicit learning) showed normal implicit learning, but failed to show striatal activation. Instead, these patients had activation in the hippocampal-parahippocampal regions (medial temporal regions), brain regions normally associated with explicit learning. This finding was interpreted as representing compensatory interaction between the two learning systems. The hypothesis has been supported by another experiment, where the SRT task was combined with a dual task to engage the explicit system of the OCD group (Deckersbach et al., 2002). As a result of this manipulation, the OCD group did not show implicit learning, supporting the idea that the original pattern indicated that the two systems are in compensatory interaction.

*The Present Study*

Despite the repeated criticism of the multiple systems approach (e.g., Dulany, 1997; Kinder & Shanks, 2001; Shanks & St. John, 1994; Lovibond & Shanks, 2002; Perruchet & Vinter, 2002) and the failure to replicate implicit sequence learning in Destrebecqz and Cleeremans' (2001, 2003) critical no-RSI group (Shanks, Wilkinson, & Channon, 2003), measuring only explicit learning in further repetitions (Wilkinson & Shanks, 2004), the question of implicit-explicit duality is still unsettled.

The aim of the present study was to further investigate the topic of interactive learning systems. To separate implicit, explicit and interactive conditions is a challenging task in the implicit learning paradigm. As reported in several of the above mentioned studies, previous training in sequence learning tasks have led to (at least partial) explicit knowledge about the sequence. To manipulate the degree to which the (putative) implicit and explicit processes contribute to sequence learning, a novel SRT methodology was used, adapted from the field of judgment and decision making.

Ferreira and his colleagues (Ferreira, Garcia-Marques, Sherman, & Garrido, 2006) compared the involvement of automatic and controlled components in reasoning tasks. To facilitate the processing of heuristic reasoning or rule-based reasoning, they used 'preliminary priming'. The notion behind their design was that a particular type of processing of a stimulus facilitates the same processing of new stimuli (Smith, 1994). Hence, the priming of either automatic or controlled processing was expected to facilitate the subsequent use of one type of processing, leaving the other unaffected. Applying this preliminary process facilitation to the learning paradigm, the expectation is that implicit and explicit processing of sequences would enhance the same processes in subsequent, novel sequences. Using this logic, the interaction between learning processes may be open to analysis.

### Experiment 1.1: SRT Study 1

The basic assumption behind this study was that if separate learning processes exist then their effects could be observed separately, or in interaction. One way to attempt such research would be to measure the contributions of each process to task performance separately, and then to compare these contributions with those when both processes are involved. Even if separate implicit and explicit systems exist it is highly unlikely that any experimental task could be constructed in such a way that it would clearly depend only and entirely on one system. Thus the only practicable aim of an investigation such as this is to set and manipulate the task properties so that they are more or less likely to rely on a particular kind of processing.

A suitable task is one which can be solved both explicitly and implicitly and for which the two strategies are not antagonistic, in the sense that outputs of any explicit process would not mask any implicit processes. Rather, the task should be of a kind where the implicit processes could act in conjunction with any explicit process such as the deliberate application of rules. A suitable candidate may be a reaction time task where motor sequence control is expected to be facilitated by automatic resources based upon associative learning (Spiegel & McLaren, 2006, 2003), in addition to any separate explicit knowledge concerning the sequence.

Given that a task may use either type of process, to investigate the contribution of each requires the ability to construct situations where one of the processes is preferentially involved. One possibility is to use a priming logic, where prior activity may lead to facilitation of one domain of processing. According to previous studies (Ferreira et al., 2006; Smith, 1994) processing a particular stimulus in a given way facilitates the subsequent repetition of the same processing with new stimuli. Recent evidence suggests that such

priming may be domain specific (Ferreira et al., 2006). Rule-governed formal activity prior to the task may encourage the use of explicit (rule-based) processes, while leaving the implicit processes unaffected. Similarly, activity which may involve implicit processing may facilitate the use of highly similar processes during the task, without influencing the proposed rule-based system.

Following this logic, a standard SRT task was utilised, preceded by preliminary process facilitation to manipulate the involvement of the two processing systems. A dual-system model predicts that experimental groups solving the same test would do so differently, depending on the type of facilitation they received. Furthermore, if the two systems are truly interactive, the facilitation due to each type of priming may be ‘additive’ or ‘subtractive’. To investigate this possibility a group which receives both kinds of preliminary facilitation was included.

In summary, the aim of this study is to extend the SRT paradigm by an attempt to ‘prime’ processing of implicit and explicit types both independently and in combination.

## Methods

### *Participants*

66 undergraduate students (38 females and 28 males; age  $M = 19.97$  years;  $SD = 1.22$  years) of the Department of Experimental Psychology at the University of Cambridge participated in the study. The task was included in a teaching session as an illustration of the SRT paradigm. The participants were informed about the nature of the paradigm only after the practical session. The participants were divided into four groups: Implicit Group (I) ( $N = 16$ ); Explicit Group (E) ( $N = 24$ ); Random Group (R) ( $N = 10$ ); and Combined Implicit-Explicit Group (IE) ( $N = 16$ ).

### *Materials and Procedure*

The testing was conducted in group sessions in the same classroom at separate computers. The participants were seated approximately 60 cm from the computer monitor and were presented with the instructions on the screen. The task program was written in *REALbasic 2006 Standard Edition, Academic Version* software. The test application was run under *Mac OS X* operating system on a set of identical *iMac G3* personal computers of *Apple Inc.*. Responses were collected via the keyboard.

The test consisted of three phases: a Preliminary Facilitation phase, a learning phase (Main Task) and a Process Dissociation Procedure (PDP) phase. The sequence knowledge of the participants was assessed by a paper questionnaire after the experiment (Appendix A).

*Main Task Phase.* All of the participants from the four groups were presented with an SRT task (Nissen & Bullemer, 1987) based on a design used by Destrebecqz and Cleeremans (2001). The task consisted of 10 training blocks during which participants were exposed to a serial four-choice RT task. Each block consisted of 96 trials, giving a total of 960 trials. On each trial, a stimulus (asterisk) appeared at one of four possible screen locations (Figure 1). Participants were instructed to respond as fast and as accurately as possible by pressing on the corresponding key. The participants were not informed that the majority of blocks contained repetitions of a sequence. Reaction times were recorded via the computer program, incorrect and timed-out responses were signalled to the participant.



Figure 1. SRT test presented on computer. The letter string above represents an example of hidden order of the appearance of the four stimuli. The corresponding keys were Y, C, B, and M.

After the associated key was pressed the target was immediately removed from the screen and the next stimulus appeared with no latency<sup>1</sup>. A short break was programmed between each 96-trial block where the participants could restart the test whenever they felt ready.

The sequences were 12 items long, and created from ‘second order conditional’ transitions (SOC, Reed & P. Johnson, 1994), where two elements always determine the location of the next stimulus and no consecutive repetition of a location is permitted. Following this rule, the four elements make 12 possible pairings and since two elements always determine the location of the next stimulus, the sequence is a composition of chunks of three elements (Table 1). Following this procedure, each task sequence was consequently counterbalanced for stimulus location and transition frequency.

Table 1

<sup>1</sup> The zero latency condition was used as a longer, 250ms interval resulted in evidence of explicit knowledge in Destrebecqz & Cleeremans, 2001.

*The Construction of SRT Sequences*

SOC chunks:	1	2	4										
		2	4	3									
			4	3	1								
				3	1	3							
					1	3	2						
						3	2	1					
							2	1	4				
								1	4	2			
									4	2	3		
										2	3	4	
sequence:	1	2	4	3	1	3	2	1	4	2	3	4	

*Note.* Table 1 demonstrates the construction of a single 12-element SOC sequence. Since two elements always determine the location of the next stimulus, the sequence is a composition of chunks of three elements. The numbers represent the screen locations from left to right.

All the 10 blocks included 96 trials in 8 sub-blocks of 12-element SOC sequences generated as shown in Table 1. Seven of the eight sub-blocks were the same sequence which shall be termed SOC1 (e.g., 124313214234, where the numbers represent the screen locations). In addition, each block contained a single sub-block of a different sequence termed SOC2. A different sequence was used as SOC2 in each block, which occurred between the third and the seventh sub-block of the block randomly. The RT difference between the SOC2 sub-block and the equivalent regular, SOC1 sub-blocks thus is one measure of the acquired SOC knowledge.

The last but one 96-trial block (Block 11) was used as an irregular probe block. This block consisted of eight previously unseen sequences without repetition. All the participants received different sequences. The last block returned to the original design and sequence. The comparison of the RT measures of Block 11 to the regular blocks serves as another measure of sequence learning, and is typically reported in SRT tasks.

A third way to analyse the effect of learning is to compare the proportion of errors in the detection of the asterisk locations during the test. It is plausible to assume that the sequence knowledge could lead the participants to mispredict and consequently respond incorrectly to the location of the stimulus in the case of irregular trials. It is also possible that knowledge about the sequences that arises from different learning conditions (instructed/uninstructed during to the preliminary phase) could result in different patterns of error.

*Preliminary Facilitation phase.* The I (Implicit) group received two 96-trial blocks of SRT training prior to the Main Task. These blocks were of the same format as the ten blocks of the main task, except that all eight SOC sequences were identical. These 192 trials were expected to prime<sup>2</sup> implicit processing for the succeeding task.

The E (Explicit) group received 2 blocks of explicit SRT training prior to the main Sequence Learning phase. In the explicit SRT the participants were instructed to watch two blocks of a self-moving SOC sequence on the screen and attempt to memorise it and notice any sequences present without pressing down any keys. These 192 memorising trials were expected to facilitate explicit processing of new sequences during the subsequent Main Task phase (Table 2).

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<sup>2</sup> The term priming in this study is not used in the sense that presentation of a stimulus influences response to a later stimulus, but rather a mechanism whereby a particular mode of stimulus processing facilitates the subsequent processing other stimuli in the same mode (see Ferreira et al., 2006).

Table 2

## General Comparison of the Implicit and Explicit Preliminary Tasks

	<b>Implicit group</b>	<b>Explicit group</b>
<b>Task set</b>	- sequence learning task	- sequence learning task
<b>Instruction</b>	- attend to the moving stimuli and press the corresponding key	- attend to the moving stimuli and memorise the sequence
<b>How information is learned</b>	- without instruction - unintentionally - by practice	- with instruction - intentionally - by explicit memorisation
<b>What is learned</b>	- presented sequence	- presented sequence
<b>Facilitated system</b>	-mainly the implicit	- mainly the explicit

The IE (Implicit-Explicit) group received two blocks of training on a SOC sequence in the same manner as the I group, during which they were also instructed to notice any sequences occurring.. This task was expected to prime both implicit and explicit processing for the main Sequence Learning task. Before the start of the next phase the explicit knowledge of the E and IE groups was assessed in a 12-trial test where they were asked to regenerate the previously presented sequence.

The control R (Random) group received the same instructions as the I group. However, no sequences were repeated for this group (all blocks, both during pretraining and the main task, were constructed in the same way as block 11 for participants in other groups). There was, therefore, nothing to learn for this group, and so the performance of this group was planned as a control to the performance of the experiment groups

All the four pre-training conditions were followed by a pause and the instructions for the next phase.. The design is summarised in Table 3.

Table 3

## Structure of the Experiment

	Preliminary facilitation task	Main task	PDP
Implicit group	2 blocks of imp SRT	10 blocks of SRT	Inclusion + Exclusion
Explicit group	2 blocks of exp SRT	10 blocks of SRT	Inclusion + Exclusion
I-E group	2 blocks of imp & exp. SRT	10 blocks of SRT	Inclusion + Exclusion
Random group	2 blocks of rSRT	10 blocks of rSRT	—

*Process Dissociation Procedure task*<sup>3</sup>. After the Main Task, the participants were informed that the asterisks on the screen have followed a 12-element sequence. In the Inclusion phase of the PDP the participants were presented with a single asterisk in a random location and they were asked to freely generate a series of 96 trials that resemble the training sequence as much as possible. They were also told that they should rely on their intuition when feeling unable to recollect the location of the next stimulus. In the Exclusion phase of this task the participants were asked to type another series of 96 trials, but this time they had to try to avoid reproducing any sequential regularities of the training sequence. By pressing the keys the asterisk moved to the corresponding locations. In both phases the participants were told not to repeat any response, i.e., no responses of the form 11 or 22 or 33 or 44.

When the computer test was terminated, the participants were asked to fill out a one-page paper questionnaire assessing their sequence knowledge and awareness (Appendix A).

<sup>3</sup> A discussion of the Process Dissociation Procedure is in Chapter III.

## Results

Reaction time data are the primary measure for analysis in this experiment. For groups I, E and IE, mean reaction times were obtained from each of the experimental blocks for the trained sequence (Regular) subblocks and the probe sequence (Irregular) subblocks.

The two blocks of the Preliminary Facilitation phase were analysed separately. Blocks 3 - 10 were analysed as the Main Task; Block 11 as the probe block, and Block 12 was the return to the trained sequence.

### *Preliminary Facilitation*

Data from the preliminary facilitation stage are shown in Figure 2 for the I, IE and R groups (there are no RTs data for the E group in these blocks). A mixed ANOVA with Block as within-subjects factor and Group as between-subjects factor compared the mean RT values during these two blocks. This showed a strong main effect of Block,  $F(1,39) = 86.90$ ,  $p < .001$ ,  $\eta^2_p = .69$ , confirming that responding became more rapid across these two blocks. A significant group effect was observed,  $F(2,39) = 8.35$ ,  $p = .001$ ,  $\eta^2_p = .30$ , and further comparison showed that this Group effect was the result of the longer mean RTs of the IE group compared to the I group,  $F(1,30) = 13.26$ ,  $p = .001$ ,  $\eta^2_p = .30$ ; and to the R group,  $F(1,24) = 5.63$ ,  $p = .026$ ,  $\eta^2_p = .19$ . There was no reliable evidence for a difference between the I and the R groups,  $F(1,24) = 1.24$ ,  $p = .275$ ,  $\eta^2_p = .05$ . Thus, the task instructions for the IE group seem to have had a detrimental effect on the RT performance. A Group  $\times$  Block interaction,  $F(2,39) = 8.09$ ,  $p = .001$ ,  $\eta^2_p = .29$ , suggests that this effect was reduced by the second block.

An assessment of explicit knowledge about the sequence showed that the participants regenerated more chunks of the presented sequence than they would have done by chance in

the E group,  $t(23) = 4.29$ ,  $p < .001$ ,  $d = .88$ ; and in the IE group,  $t(15) = 3.57$ ,  $p = .003$ ,  $d = .89$ . These data indicated that the two groups instructed to memorise the sequence followed the instructions.

### *Main Task*

RT data for all the groups in Block 3-12 are shown in Figure 2. A mixed ANOVA with Block as within-subjects factor and Group as between-subjects factor applied to the mean RT values of Block 3-12 of the task showed a significant effect of Block,  $F(4.26, 263.80) = 5.99$ ,  $p < .001$ ,  $\eta_p^2 = .09$ , suggesting that responding became more rapid across blocks. Whilst this is consistent with the patterns of sequence learning, such speeding could also arise from mere practice with the task stimuli. Sequence knowledge would be revealed by a difference between those groups with a repeated sequence (I, E and IE) improving more across blocks than did the control group, R. Whilst the main effect of Group did not approach significance,  $F(3, 62) < 1$ , the predicted pattern of differential improvement across blocks is apparent from (Figure 2), and confirmed by a significant Group  $\times$  Block interaction as well,  $F(12.77, 263.80) = 2.04$ ,  $p = .019$ ,  $\eta_p^2 = .09$ .

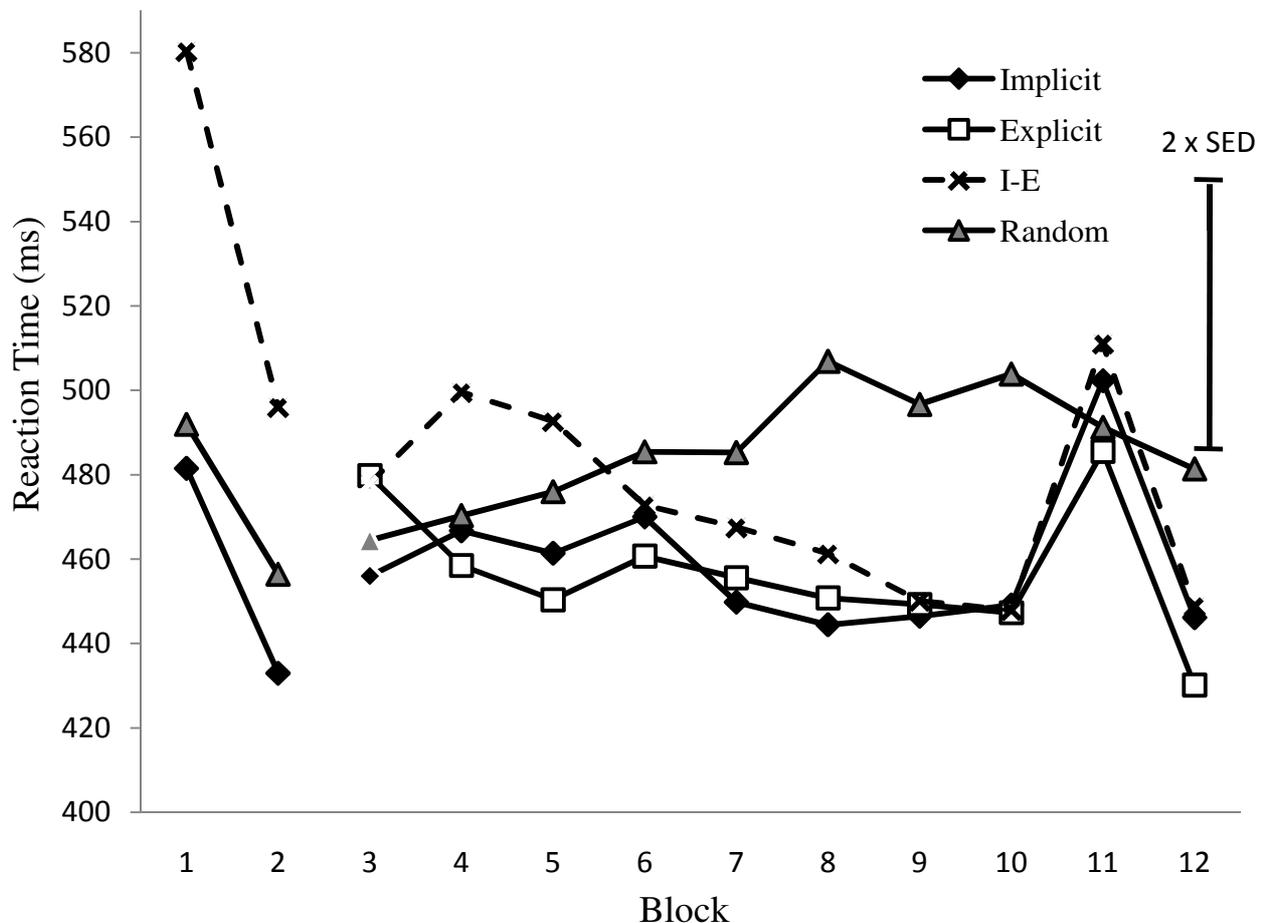


Figure 2. The mean RTs of the four groups in the 12 blocks of the test. Block 1 and 2 are the Preliminary Facilitation phase, Block 11 is the random probe block of the Main Test.

The role of sequence-specific knowledge in the RT improvement was demonstrated by comparing the impaired performance on Block 11 (which contained novel SOC sub blocks only) with the other blocks. Mixed (2 blocks  $\times$  4 groups) ANOVAs revealed that the Block 11 RTs were significantly longer than the RTs on the block before,  $F(1, 62) = 17.19, p < .001, \eta_p^2 = .22$ , and longer than those on the final block,  $F(1, 62) = 41.26, p < .001, \eta_p^2 = .40$ . This pattern is restricted to the groups with repeated sequence (I, E, IE) as Block 11 is the same as the adjacent blocks for Group R, confirmed by a Group  $\times$  Block interaction in an ANOVA comparing the three final blocks,  $F(5.53, 114.25) = 2.24, p = .049, \eta_p^2 = .10$ . Taken together, the comparisons between the sequential groups and the control group, R, indicated

that participants were able to use sequence knowledge to respond faster when the task contained a repeated SOC sub-blocks.

Further evidence for sequence knowledge comes from the analysis of the differences between the RTs from the Irregular and Regular sub-blocks in the groups. The degree of facilitation due to sequence regularity was calculated by subtracting the mean regular RT values of the sub-blocks 3-7 from the mean RTs of the irregular SOC sequences (which was always a sub-block appearing randomly in the sub-blocks 3-7 during the training) in each block. These data are shown in Figure 3.

A mixed ANOVA compared the mean RT on each trial type across Blocks 3-10 with Block as a within-subject factor and Group (I, E, and IE; the Random group received no regular trials) as a between-subject factor. The mean difference scores were above zero on Blocks 3-10 for each of the experimental groups: I group 95 % CI = 10.35 - 48.98; E group CI = 26.96 – 57.87; IE group CI = 55.18 – 93.03; indicating more rapid responding on regular trials for each group. This difference appears to represent gradual learning of sequence knowledge: the advantage for regular trials increased across blocks, as reflected in a within-subjects linear contrast along Block 3-10,  $F(1, 53) = 30.95, p < .001, \eta^2_p = .37$ , giving a significant effect of Block,  $F(6.58, 348.60) = 7.48, p < .001, \eta^2_p = .12$ . In Block 11, where all groups received a novel set of SOC sub-blocks, there was no evidence for such effects,  $F(2, 53) < 1$ .

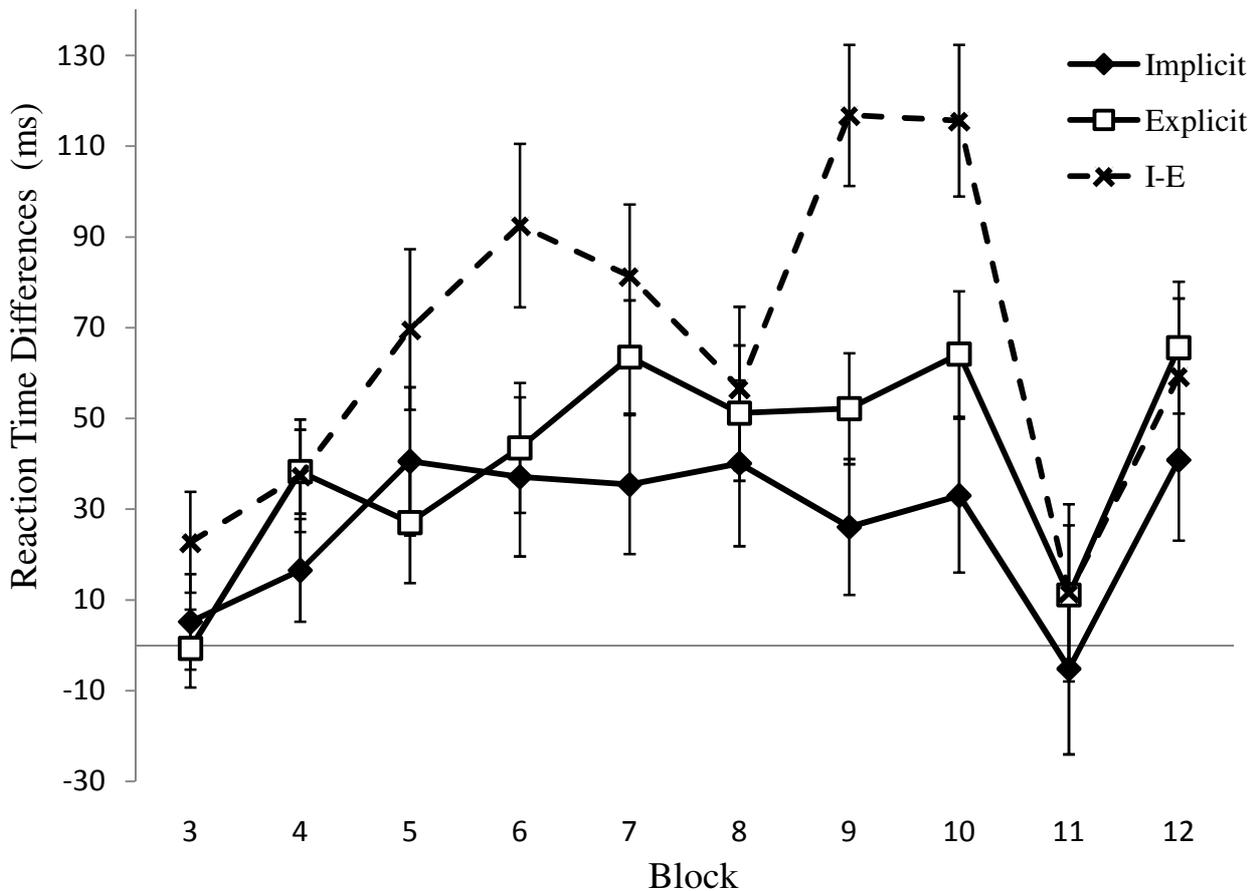


Figure 3. Reaction times differences of the irregular and regular sequence means of the three groups in Block 3-12 of the Main Task. The error bars depict the SEMs.

Crucially, these learning effects were not equal for all three groups, as shown by a main effect of Group,  $F(2, 53) = 6.06$ ,  $p = .004$ ,  $\eta^2_p = .19$ . This provides evidence that different forms of preliminary training influenced learning on this task differently. Differences between the three groups were investigated using Fisher's LSD procedure, which showed that the difference scores were greater for the IE group than either the I or E group (larger  $p = .012$ ), with no evidence that these latter groups were different from each other,  $p = .285$ .

Figure 4 shows the mean error rates for each type of trial, which were analysed using a mixed ANOVA with Regular-Irregular Error as within-subjects factor and Group as between-subjects factor. This analysis revealed that regular trials produced lower error rates

overall,  $F(1, 53) = 7.14, p = .010, \eta^2_p = .12$ , an effect which interacted significantly with Group,  $F(2, 53) = 10.79, p < .001, \eta^2_p = .29$ . Figure 4 suggests that the regularity effect is restricted to Group I. Paired  $t$  tests confirmed that error rates were lower on the regular than on the irregular trials in this group,  $t(15) = 3.88, p = .002, d = 1.03$ , with no evidence of a difference in the other groups,  $ts < 1$ .

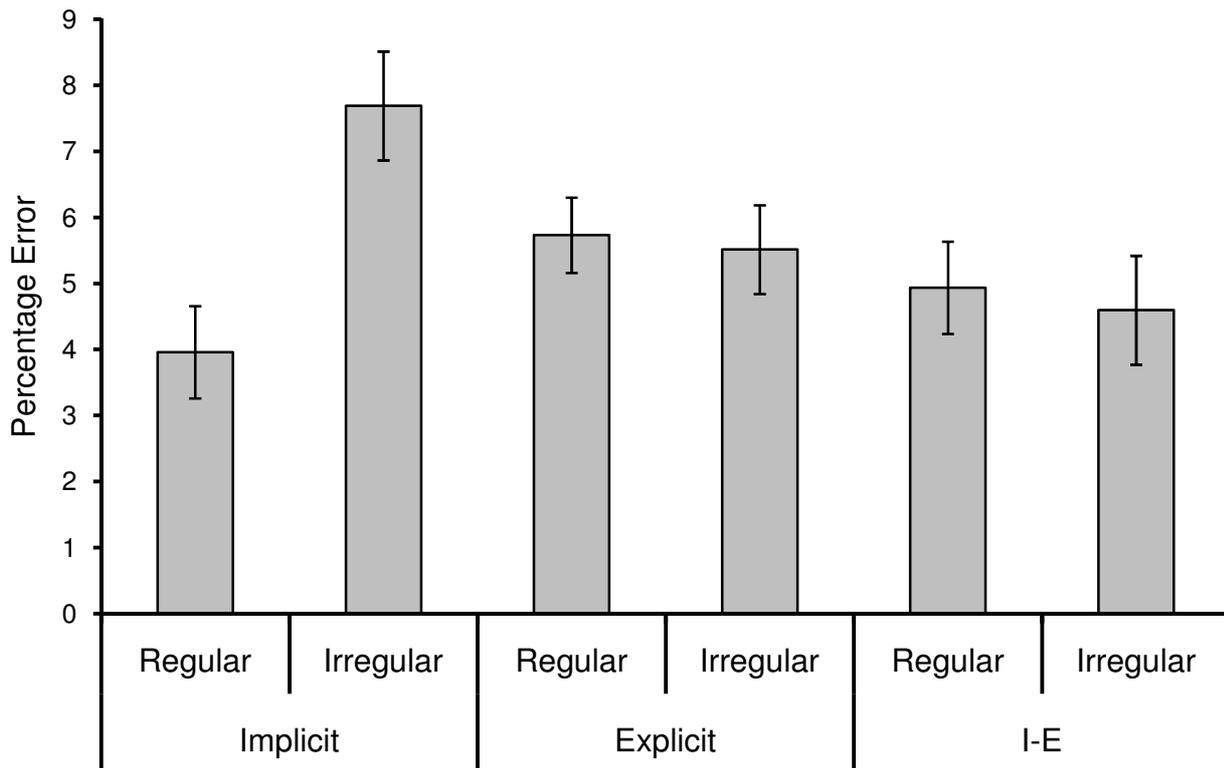


Figure 4. The percentage of the errors made in the detection of the asterisk in the regular and irregular trials in the three experimental groups. The error bars represent the SEMs.

Overall, error rate data gave a slightly different impression to the RT data, in that those groups who were encouraged to seek explicit knowledge (E, IE) did not differ in their error rates between the regular and irregular trials, whereas the group primed to take an ‘implicit’ approach (I) showed less accuracy on the irregular than the regular trials.

### *Process Dissociation Procedure*

After the SRT test the sequence knowledge of the participants was assessed by the PDP test. The performance in each condition was evaluated by the number of 3-item long chunks from the regular sequence (Figure 5). Since the participants were asked not to repeat any key press on subsequent trials in both conditions of the PDP, they could have chosen one of the three locations on each trial. After any non-repeating pair of responses, exactly one response was correct according to the original SOC sequence. Therefore, the chance level of their performance for a randomly generated valid set of response would be 33.33%.

As described earlier, above-chance performance in the Inclusion part indicates sequence knowledge, which could be a result of both explicit recollection and implicit influence. In the Exclusion part, however, above-chance performance (that a higher degree of correct chunks, in violation of instructions) may be regarded as the sign of pure implicit knowledge: such a pattern would result from automatic generation without knowledge that the response violated the instructions. In the absence of above-chance performance in the Exclusion part the presence of implicit knowledge cannot be claimed unambiguously (Wilkinson & Shanks, 2004).

A mixed ANOVA with Condition (Inclusion, Exclusion) as a within-subjects factor and Group as a between-subjects factor showed a significant effect of Group,  $F(1, 54) = 4.61$ ,  $p = .014$ ,  $\eta^2_p = .15$ , indicating that the type of preliminary training influenced the overall probability of reproducing the sequences. In addition, a significant effect of Condition,  $F(1, 54) = 15.70$ ,  $p < .001$ ,  $\eta^2_p = .23$ , shows that, overall, participants were able to strategically control at least some of the knowledge that they had acquired. The Group  $\times$  Condition interaction was not significant,  $F(1, 54) = 2.38$ ,  $p < .103$ ,  $\eta^2_p = .08$ , thus there was no evidence that groups possessed knowledge that was different in flexibility.

The criterion for demonstrating ‘pure’ implicit learning (above-chance performance in an Exclusion condition) was not met. Performance was not above chance in any of the exclusion conditions, in fact only the Inclusion performance of the IE group differed reliably from the chance level, it was higher,  $t(16) = 4.06, p < .001, d = .99$  (Figure 5).

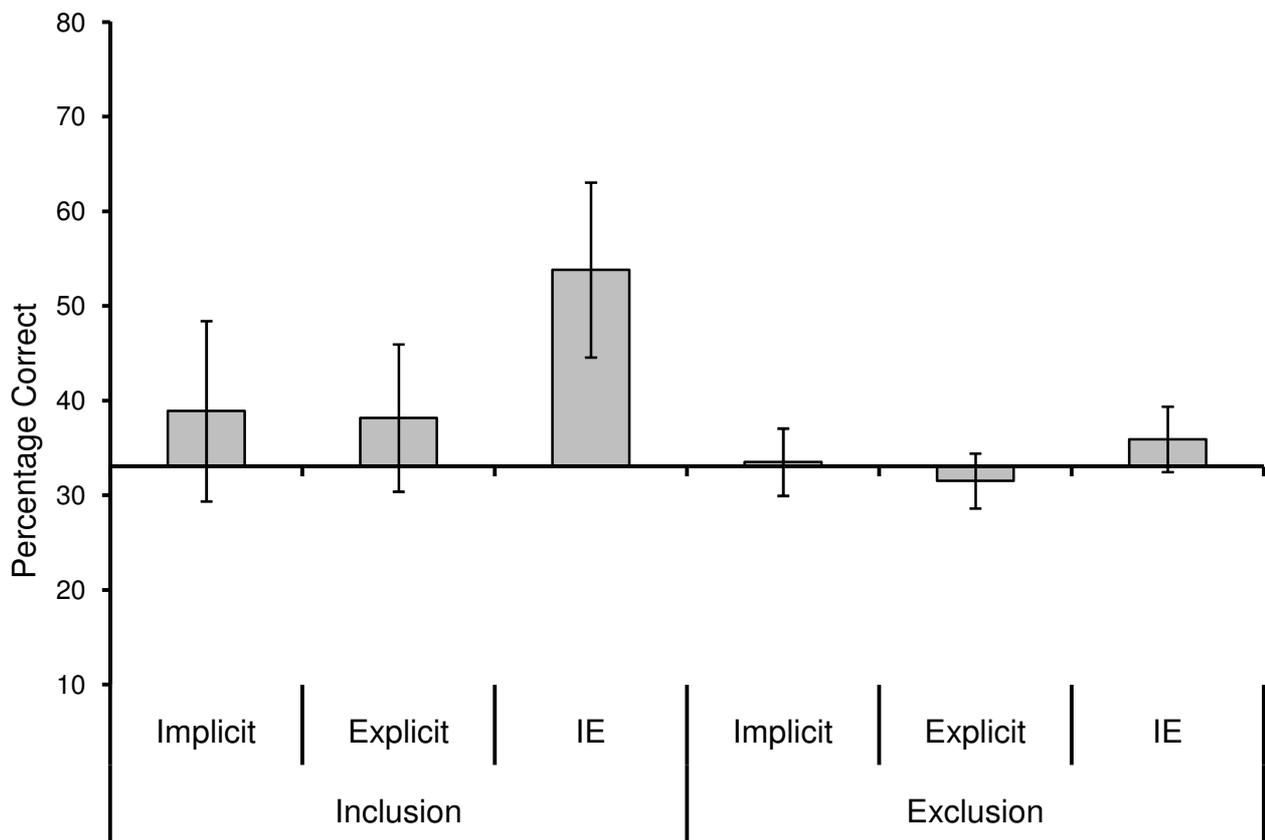


Figure 5. The Inclusion and Exclusion conditions of the PDP for the three experimental groups. The error bars represent the 95% confidence intervals.

The PDP results suggest that the IE group acquired the greatest overall sequence knowledge from the three experimental groups. The exclusion instruction had significant effect on the behaviour of this group, the participants generated fewer chunks of the sequence than in the Inclusion condition,  $t(16) = 3.45, p = .003, d = 1.16$ . This result suggest that the IE group had controllable knowledge about the sequences, even if this knowledge was not enough to avoid producing sequence fragments below chance-level during the exclusion condition,  $t(16) = 1.58, p = .133, d = .38$ .

### Questionnaire Assessment

The answers of the questions in the paper questionnaire indicated participants had acquired explicit knowledge about the regularity in the test and the presence of a sequence. On average the length of the sequence that they believed to be present was  $M = 9.25$  items,  $SD = 3.02$  items for the experimental groups, the true length being 12 items, while the random group (which one never saw the sequence) believed that they had experienced much shorter ones,  $M = 6.31$ ,  $SD = 1.06$ , (Figure 6). Dunnett Post-Hoc pairwise comparisons showed that, for the combined IE group, the mean reported length was greater than for the control (Random) group,  $p = .029$ .

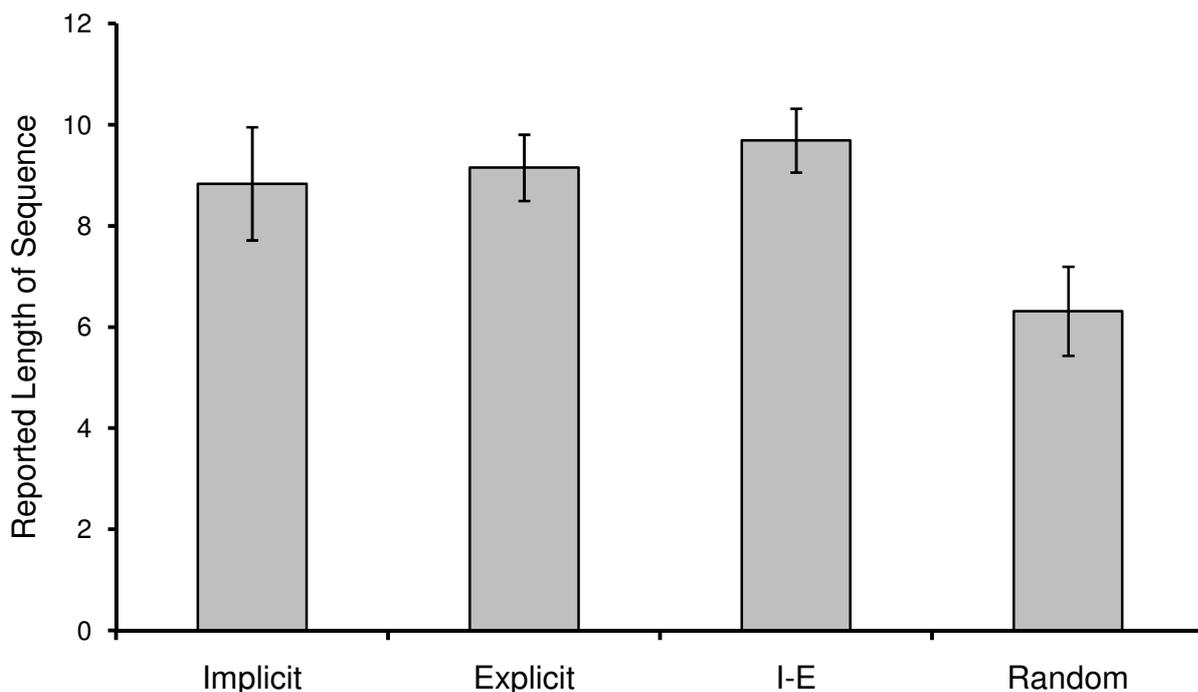


Figure 6. The length of sequence as reported by the four groups. The true length was 12 items for the experimental groups.

The four groups differed in their answers to the question “*To what extent did you feel that the asterisk followed a random or predictable sequence of locations?*” in a scale of 1-5 where 1 represented “*totally random*” and 5 was “*totally predictable*”. The average of the

three experimental groups was above the half predictable scale point (3),  $M = 3.39$ ,  $SD = .71$ , while the Random group found the test mostly unpredictable  $M = 2.67$ ,  $SD = 1.00$ ). An ANOVA confirmed that the groups differed on average rating,  $F(3, 48) = 3.41$ ,  $p = .026$ ,  $\eta^2_p = .19$ , (Figure 7). A Dunnett Post Hoc test indicated that the only significant difference from the report of the R group was of the IE group,  $t(24) = 3.13$ ,  $p = .005$ ,  $d = .30$ . The average of these IE group ratings was largest (closest to the label of “mostly predictable”)  $M = 3.65$ ,  $SD = .61$ . The questionnaire assessment thus revealed that participants acquired some explicit knowledge of sequence regularity, and that this knowledge was the highest for the IE group.

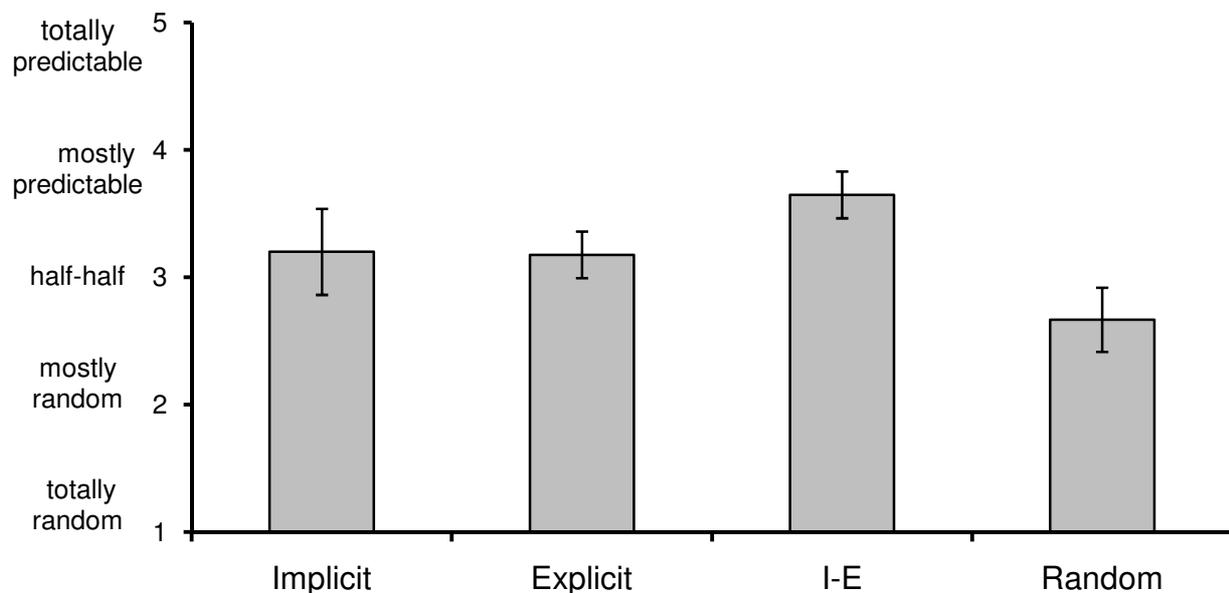


Figure 7. Predictability in the test as the participants reported it in the paper questionnaire in the different groups.

## Discussion

In this experiment, the various behavioural measures all showed that the three experimental groups acquired effective knowledge about the sequence of stimulus locations. The evidence suggested that, according to each measure, the groups learned different

amounts, the overall pattern indicating more learning for the combined IE than for the I and E groups.

Was this effect in the IE group a result of some summation of facilitation for both implicit and explicit processes? One possible interpretation could be that the two learning or memory systems interacted in a cooperative fashion and their joint activation led to the beneficial performance.

This hypothesis can be supported by the finding of the error rate analysis, which explored a qualitative difference between the I and E groups suggesting distinct processing systems. However, an alternative, single-system explanation would simply suggest that the combined group improved as a result of both previous practice and the information provided, while the other groups benefited at most from either one or the other. The single system account is somewhat supported by the absence of any evidence for implicit knowledge in the PDP and the presence of explicit knowledge in the verbal reports. In addition, it is possible that, lacking practice at responding during the Preliminary facilitation phase, the Explicit group regarded the Main Task as a different task to the extent that they did not transfer any useful knowledge (about sequence presence, structure or length) to the second task. These open questions were explored in the following experiment by replicating the study with additional conditions in which the possible effect of practice, explicit knowledge, and transfer were disentangled.

### Experiment 1.2: SRT Study 2

This experiment was designed to explore the possible contributing factors to the 'IE effect' found in the previous study. It is possible that practice, explicit knowledge and

instructions could be causes of this effect as well as any combined facilitation of the processing systems. In this study, each experimental group received different preliminary treatments to allow an examination of the effect of practice, explicit knowledge and information separately. The role of attention was also investigated in an additional manipulation which separated the visual attention to the sequence and the requirement to learn the sequence.

## Methods

### *Participants*

61 undergraduate students (43 females and 20 males;  $M = 19.60$  years;  $SD = .92$  years) of the Department of Experimental Psychology at the University of Cambridge participated in the study as part of their practical course. Each participant was randomly allocated into one of the seven groups described below.

### *Materials and Procedure*

The materials and procedure of the present experiment were unchanged after *Experiment 1.1* in the Main Task. The procedures of the Preliminary Facilitation phase for each of the seven groups were as follows:

(1) Implicit Group (I) ( $N = 7$ ): This group was the same as in *Experiment 1.1*: two blocks of SRT training (192 trials) using a different sequence to the main task, with no irregular sub-blocks.

(2) Explicit Informed Group (E-Inf) ( $N = 10$ ): This group received the same training as the E group of *Experiment 1.1*: two blocks of a self-moving sequence with instructions to memorise it and notice any sequences, then to report the learned sequence. After completion of this training (and unlike the previous study) the participants were

explicitly informed before the Main Task that “*The asterisk will follow a repeating sequence of locations, thinking of this may help you to be faster with pressing the keys*”.

(3) Informed Group (Inf) ( $N = 11$ ): This Inf group received no pre-training. Instead, they were explicitly informed about the presence of a sequence in the same way as the E-Inf group.

(4) Implicit-Explicit Group (IE) ( $N = 10$ ): This group received the same training as the IE group of *Experiment 1.1*: two blocks of SRT like those for the I group, with additional instructions to notice any sequences occurring.

(5) Implicit Informed Group (I-Inf) ( $N = 9$ ): This group received the same implicit training as the I group, followed by information about presence of a sequence in the same way as the Inf and E-Inf groups.

(6) Perceptual Group (P) ( $N = 10$ ): The P group received similar SRT pretraining to that for the E-Inf group, with a different instruction. The colour of each asterisk stimulus was selected at random from four different colours (white, red, yellow and purple). The task was merely to signal if two consecutive stimuli had the same colour by pressing key ‘M’, otherwise the instruction was to push another key (‘X’). The aim of this design was to divert the attention from the underlying sequence of locations while still requiring attention on the stimuli.

(7) Random Control Group (R) ( $N = 6$ ): This group received the same training as the R group of *Experiment 1.1*: two blocks of SRT with no repeating sequences (a randomly generated series of individual SOC sequences).

Table 4

## Structure of Experiment 1.2

	Preliminary Facilitation	Info.	Main task	PDP
Group I	2 blocks of imp SRT	-	10 blocks of SRT	Inclusion + Exclusion
Group E-Inf	2 blocks of exp SRT	+	10 blocks of SRT	Inclusion + Exclusion
Group I-Inf	2 blocks of imp SRT	+	10 blocks of SRT	Inclusion + Exclusion
Group Inf	-	+	10 blocks of SRT	Inclusion + Exclusion
Group IE	2 blocks of imp-exp SRT	-	10 blocks of SRT	Inclusion + Exclusion
Group P	2 blocks of explicit SRT with a concurrent task	-	10 blocks of SRT	Inclusion + Exclusion
Group R	2 blocks of random SRT	-	10 blocks of rSRT	-

*Note.* I = Implicit, E-Inf = Explicit-Informed, I-Inf Implicit-Informed, IE = Implicit-Explicit, P = Perceptual, R = Random, rSRT = random sequence.

After the Preliminary Facilitation phase all groups were presented with the Main Task, the PDP test (for all except group R), and the paper questionnaire (Appendix A), as described in *Experiment 1.1*.

## Results

### *Preliminary Facilitation*

A mixed ANOVA with Block (1, 2) as within-subjects factor and Group (I, I-Inf, IE, R)<sup>4</sup> as between-subjects factor applied to the mean values of the first two blocks of the experiment showed only a main effect of Block,  $F(1,28) = 46.29$ ,  $p < .001$ ,  $\eta^2_p = .62$ . There was no Group  $\times$  Block interaction,  $F(3, 28) = 2.58$ ,  $p = .073$ ,  $\eta^2_p = .22$ , nor any effect of Group,  $F(3, 28) = 2.513$ ,  $p = .079$ ,  $\eta^2_p = .21$ . These results indicated that practice on the SRT task caused a reduced mean RT on the second block, but no evidence that this effect differed

<sup>4</sup> From the remaining groups no RTs were recorded in this part of the task.

between the groups. The IE group, which in *Experiment 1.1* was significantly slower than the other groups, was once again numerically the slowest here, (Figure 8).

### Main Task

A mixed ANOVA, with Block (3-12) as a within-subjects factor and Group as a between-subjects factor contrasting all seven groups, was applied to the mean RT data. This revealed a significant effect of Block,  $F(4.51, 252.78) = 10.09, p < .001, \eta^2_p = .15$ . Whilst the Group effect was not significant,  $F(6, 56) < 1$ , the significant Group  $\times$  Block interaction,  $F(27.08, 263.80) = 1.81, p = .010, \eta^2_p = .16$ , suggests learning, as the RT change across blocks was not equal in all groups, (Figure 8).

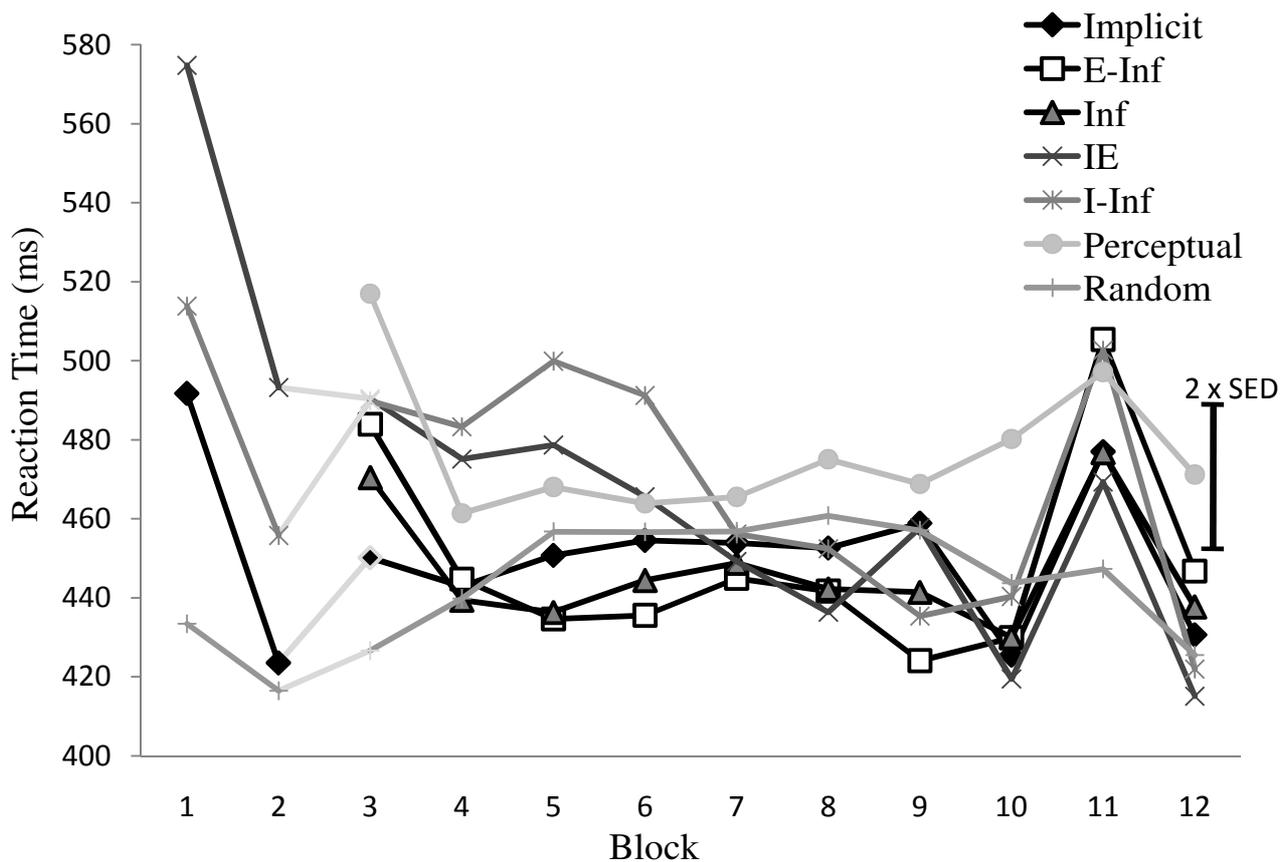


Figure 8. The mean RTs of all the groups in the 12 blocks of the test. Block 1 and 2 are the Preliminary Facilitation phase, Block11 is the random probe block of the Main Test.

Sequence knowledge was also observed, in that the RTs of the control Block 11 were significantly longer than the RTs of the blocks before,  $F(1, 56) = 34.14, p < .001, \eta^2_p = .38$ ; and after it,  $F(1, 56) = 50.82, p < .001, \eta^2_p = .48$ ; with no evidence of a difference between the groups on this block,  $F(6, 56) < 1$ .

Analysing the differences of the Irregular and Regular RTs in a mixed ANOVA with Block (3-10) as a within-subjects factor and Group (all except the Random group that received no regular trials) as a between-subjects factor showed a significant effect of Block,  $F(6.86, 349.73) = 6.33, p < .001, \eta^2_p = .11$ , and a difference between regular and irregular RTs that linearly increased along Block 3-10,  $F(1, 51) = 20.82, p < .001, \eta^2_p = .29$ , suggesting that the sequence knowledge gradually developed in the test, (Figure 9). There was no overall effect of Group,  $F(5, 51) = 1.84, p = .121, \eta^2_p = .15$ , or Group  $\times$  Block interaction,  $F(32.30, 329.48) = 1.12, p = .308, \eta^2_p = .099$ , and the mean regularity effects were above zero on Block 3-10 for each group, (in ms): I group 95 % CI = 15.06 – 63.47; E-Inf group CI = 40.14 – 80.64; Inf group CI = 18.92 – 57.54; IE group CI = 49.07 – 90.57; I-Inf group CI = 35.14 – 77.83; P group CI = 16.13 – 56.63; indicating a facilitatory effect of learning in all these groups.

A planned comparison of the two purely explicit groups (E-inf, Inf) did not show evidence for a difference between them in this measure,  $F(1, 19) = 2.29, p = .147, \eta^2_p = .11$ , nor was there any evidence for a difference between the IE and I-Inf groups,  $F(1, 17) = 1.21, p = .286, \eta^2_p = .07$ . The Perceptual group did not differ from any of the other groups,  $ps \geq .157$ . Finally, the data did not provide a replication of the finding of *Experiment 1.1*, here the IE group did not show reliably greater learning than the Implicit and Explicit groups,  $F(2, 24) = 2.09, p = .146, \eta^2_p = .15$ .

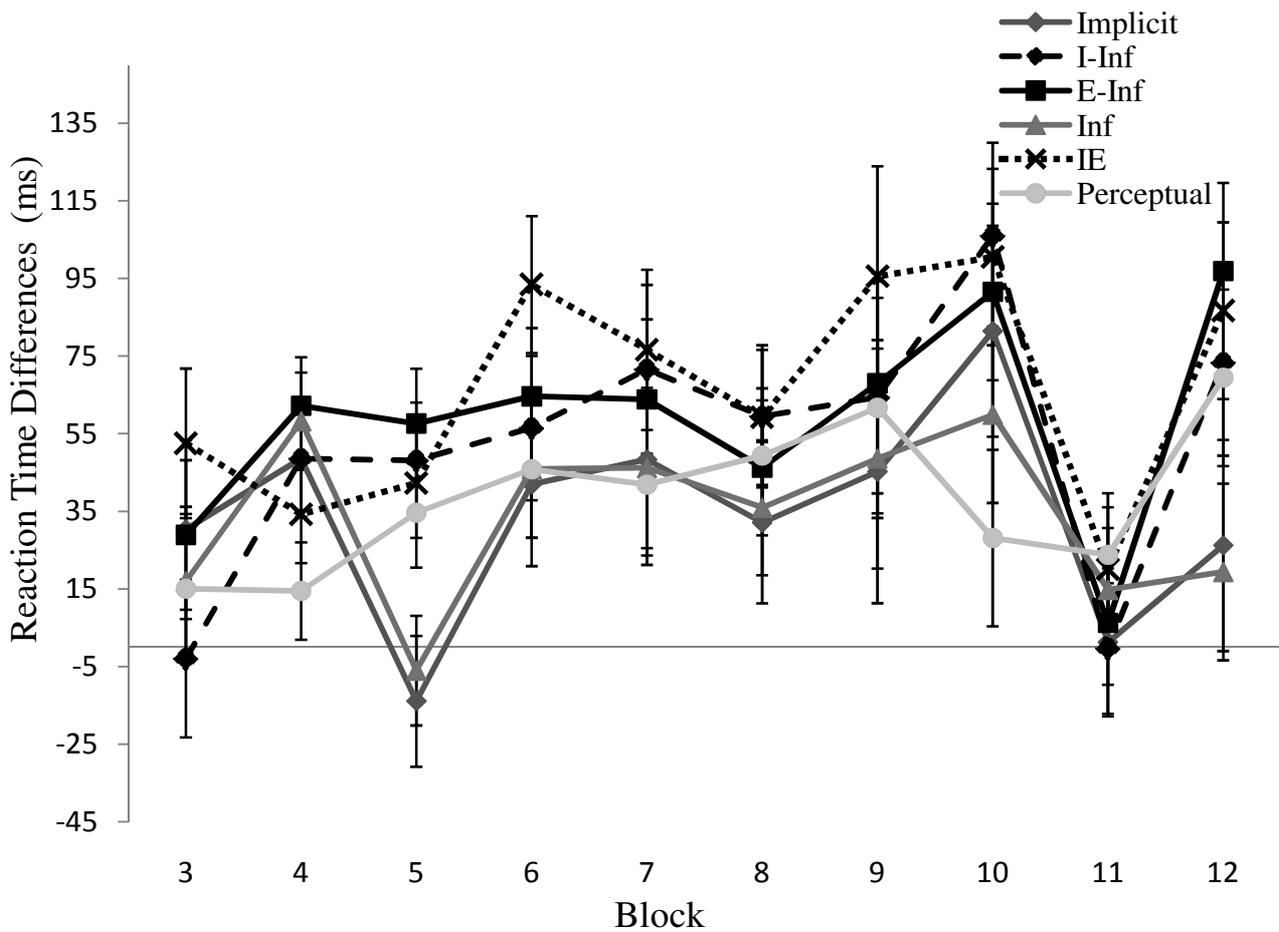


Figure 9. Reaction time differences of the irregular and regular sequence means of the groups in Block 3-10. The error bars depict the SEDs of the Dunnett comparison.

The error rates in these groups across Blocks 3-12 are shown in Figure 10. A mixed model ANOVA with regular and irregular error rates as within-subjects factor and Group as between-subjects factor showed that there was a reliable difference between the regular and irregular error rates,  $F(1, 51) = 48.32$ ,  $p = .006$ ,  $\eta^2_p = .14$ , and an interaction between Regularity and Group,  $F(5, 51) = 5.31$ ,  $p = .001$ ,  $\eta^2_p = .34$ . Investigation of the interaction reveals that the regularity effect (more errors on irregular than on the regular trials) is the largest, and significant, in two groups: the I group,  $t(6) = 3.28$ ,  $p = .017$ ,  $d = 1.34$ ; and the I-Inf group,  $t(8) = 3.09$ ,  $p = .015$ ,  $d = 1.14$ . Interestingly, these two groups received the same kind of uninformed preliminary facilitation SRT task.

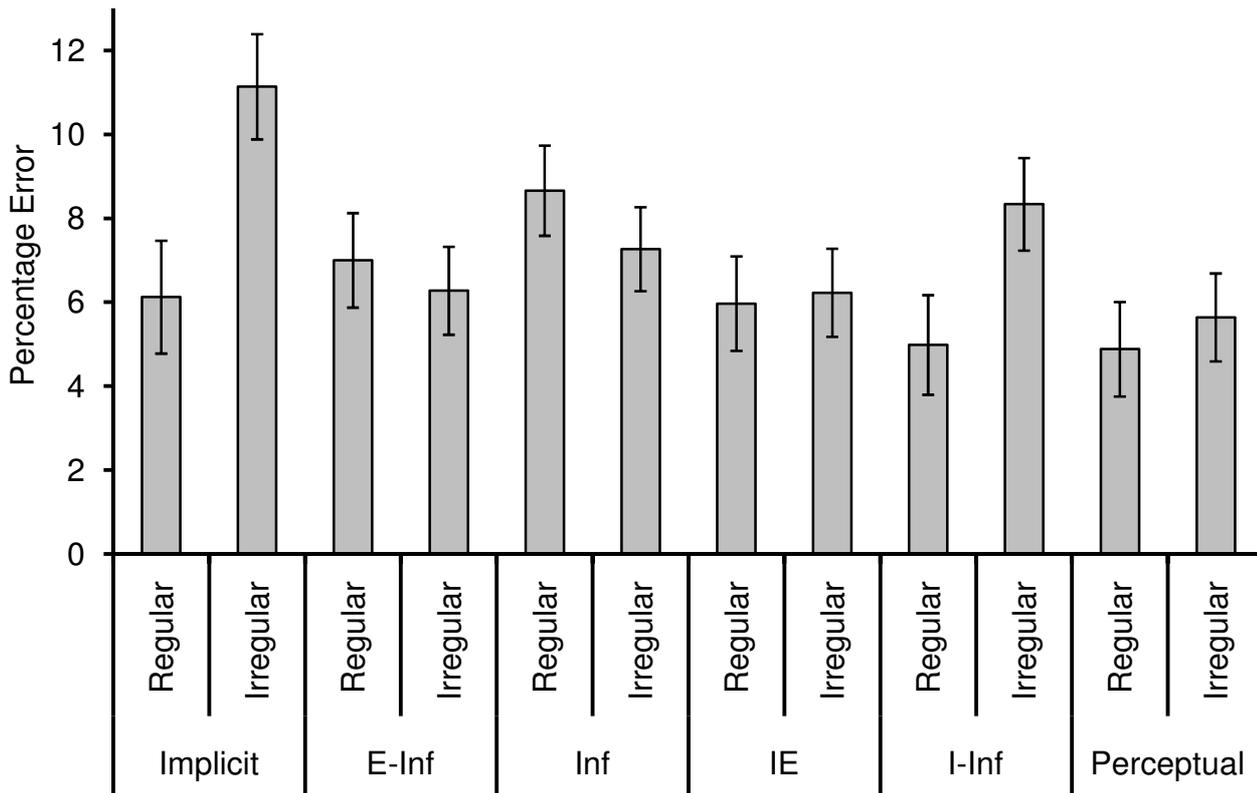


Figure 10. The percentage of the errors made in the detection of the asterisk in the regular and irregular trials in all of the groups. The error bars represent the SEMs.

### *Process Dissociation Procedure*

After the SRT test the sequence knowledge of the participants was assessed by the PDP test. A mixed ANOVA with Condition (Inclusion, Exclusion) as within-subjects factor and Group as between-subjects factor showed a significant effect of Condition,  $F(1, 51) = 30.69$ ,  $p < .001$ ,  $\eta^2_p = .38$ , indicating acquisition of flexible knowledge, and an effect of Group,  $F(5, 51) = 4.00$ ,  $p = .004$ ,  $\eta^2_p = .28$ , but no interaction of Group  $\times$  Condition,  $F(5, 51) < 1$ . One sample  $t$ -tests revealed that only the inclusion performance of the E-Inf group,  $t(9) = 2.64$ ,  $p = .027$ ,  $d = .84$ ; and the inclusion performance of the IE group,  $t(9) = 3.26$ ,  $p = .01$ ,  $d = 1.03$ , were higher than chance-level; and that the exclusion performance of the Inf group,

$t(10) = -5.62, p < .001, d = 1.7$ , was significantly lower than chance-level (33.33%) (Figure 11).

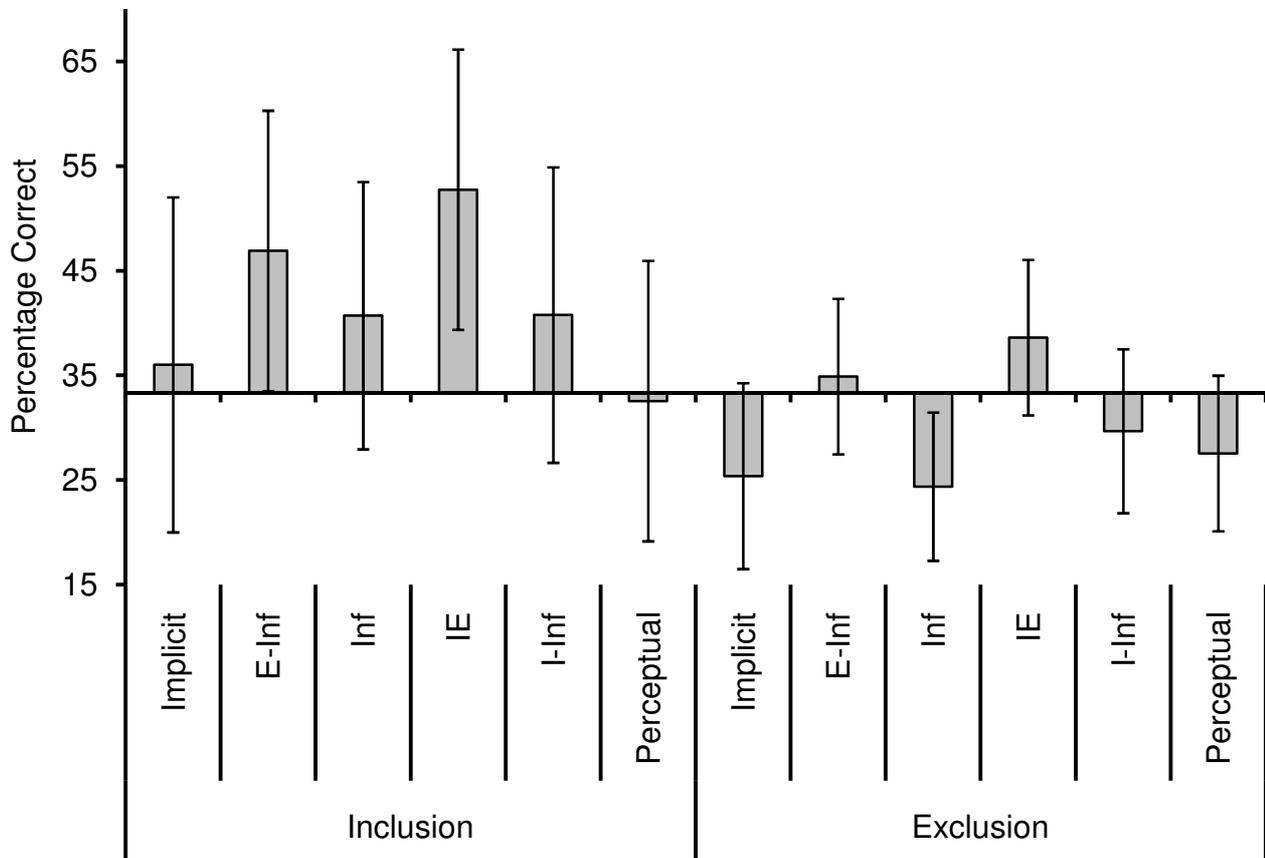


Figure 11. The Inclusion and Exclusion conditions of the PDP for the three experimental groups. The error bars represent the confidence intervals with corrected  $\alpha$ .

The lack of a significant interaction implies that there is no evidence of a difference between groups in terms of the amount of flexible sequence knowledge; however, as in the previous study, the IE group showed (numerically) the greatest sequence knowledge of the experimental groups. Once again, there was no tendency for the exclusion conditions to be above chance level, providing no evidence for implicit knowledge.

### Questionnaire Assessment

There were group differences in the answers of the regularity question in the paper questionnaire (Q2 in Appendix A),  $F(6, 56) = 4.00, p = .025, \eta_p^2 = .22$ . Reporting the

observed regularity in the task, the means of the E-Inf, IE, I-Inf groups were closer to the predictable than the random end of the scale (Figure 12).

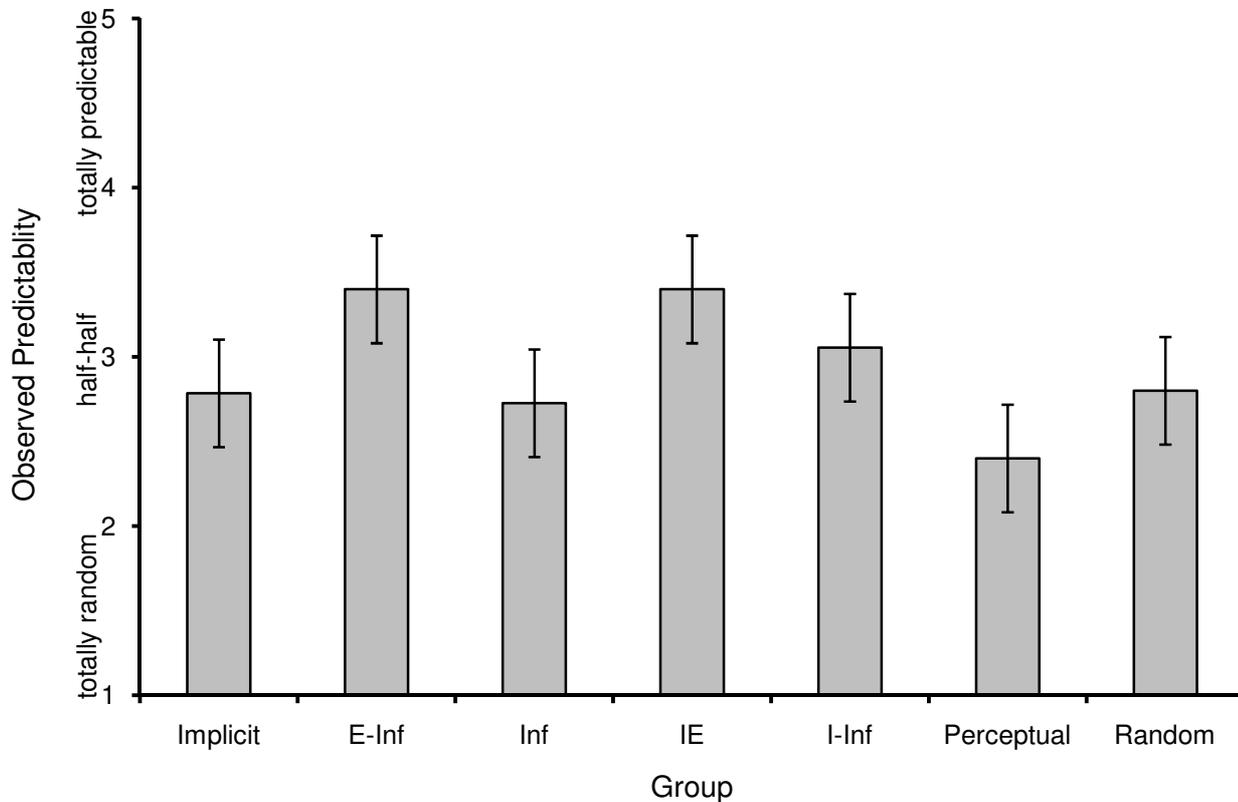


Figure 12. The means of the reported observed predictability in the task by groups. The error bars depict the SEDs.

The same groups gave (numerically) the nearest estimation of the length of the repeating sequence as well (Figure 13). The IE group gave the closest estimation ( $M = 9.40$ ,  $SD = 2.79$ ), and the only that was significantly different from the estimation of the R group ( $M = 4$ ,  $SD = 06$ ),  $t(14) = 3.21$ ,  $p = .006$ ,  $d = 1.24$ .

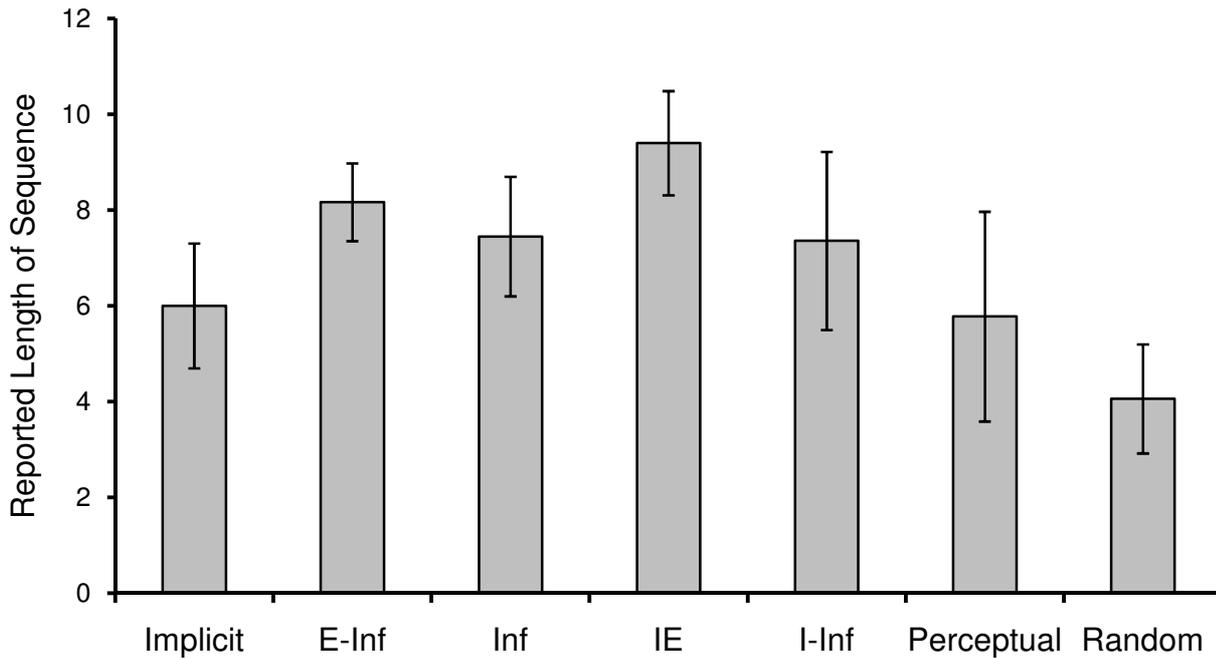


Figure 13. The length of sequence as reported by the four groups. The true length was 12 items for the experimental groups.

### Discussion

The RT measure showed sequence knowledge in all the sequence groups, but did not differentiate between the effects of the various group treatments. In contrast to the previous experiment, the overall regularity effect in the combined IE group was not appreciably larger than the I or the E groups. The PDP, however, suggested that the clearest evidence for acquired knowledge emerged within the IE group. There was no evidence, however, that the knowledge of the IE group was based on increased implicit processes; the PDP and the paper questionnaire reports suggested the opposite. In fact, the PDP did not provide evidence for implicit knowledge in any of the groups.

The analysis of the error rates showed, however, an interesting pattern: only the two groups which received the uninformed preliminary facilitation SRT showed the clear effect of regularity (more errors on irregular than on the regular trials) that was observed for the I group in *Experiment 1.1*. One interpretation could be again, that these groups processed the

sequence knowledge implicitly, and this automatic behaviour was detrimental when the location of the stimulus followed an irregular sequence. However, since no other data indicate the presence of implicit knowledge, it cannot be excluded that these groups had knowledge about the sequence that was less controllable, leading to commission errors on irregular trials.

Interestingly, the P group that received a decoy task in the preliminary facilitation phase showed a weak performance over all the measures. The RTs of this group were (numerically) the slowest in all the blocks and their perception of predictability in the task was (numerically) lower than the Random group. It is possible that the previous experience with the sequence at a perceptual level and with the task in a different setting prevented the participants from exploring and finding the hidden sequences in the Main Task, or that they continued to attend to the (unchanging) colour information during this task. In this case, a prior belief may have interfered with the sequence learning.

In summary, this experiment failed to provide any clear replication of the previous combined effect of implicit and explicit facilitation. Overall, the performance of the groups seems to be best explained by suggesting they acquired explicit knowledge. The absence of significant group differences in RT measures and lack of a systematic pattern of differences in other measures in this study trigger the question of whether the preliminary training had any effect on learning processes. It is plausible that the providing of explicit information is solely responsible for the group differences in learning observed in the two studies.

### Experiment 1.3: SRT Study 3

The aim of this experiment was to replicate the original groups of *Experiment 1.1* and contrast them with a group with no preliminary facilitation or explicit knowledge. This contrast should answer the question of whether the training in the design really primed different processing. The Perceptual group was also replicated to test whether the previously observed tendency reflected an effect of the manipulation.

#### Methods

##### *Participants*

73 undergraduate students (46 females and 27 males;  $M = 20.89$  years;  $SD = 5.53$  years) of the Department of Experimental Psychology at the University of Cambridge participated in the study as part of their practical course. The participants were divided into five groups: Implicit (I) Group ( $n = 16$ ); Explicit (E) Group ( $n = 12$ ); Combined Implicit-Explicit (IE) Group ( $n = 16$ ); No Pre-training (NP) Group ( $n = 15$ ); Perceptual (P) group ( $n = 14$ ).

##### *Materials and Procedure*

The materials and procedure of most conditions were precisely as described above for *Experiment 1.1* (Groups I, E and IE) and *Experiment 2.2* (Group P), for facilitation phase, main task and final questionnaire. Group NP was different from the other conditions in that it received no preliminary facilitation, nor any explicit instruction about a sequence. The experiment for this group started with the Main Task.

## Results

*Main Task*

A mixed ANOVA model (Block as within-subjects factor, Group as between-subjects factor) applied to the mean RT on Blocks 3-12 of the task revealed a Block effect,  $F(3.80, 257.57) = 16.60, p < .001, \eta^2_p = .20$ . However, there was no significant difference between the five groups,  $F(4, 68) < 1$ , nor a Group  $\times$  Block interaction,  $F(14.21, 241.34) < 1$ , thus there was no evidence of the facilitation phase differences between groups influencing performance. Overall, none of the experimental groups differed from the control NP group in Dunnett's Multiple Comparison,  $ps \geq .203$  (Figure 14).

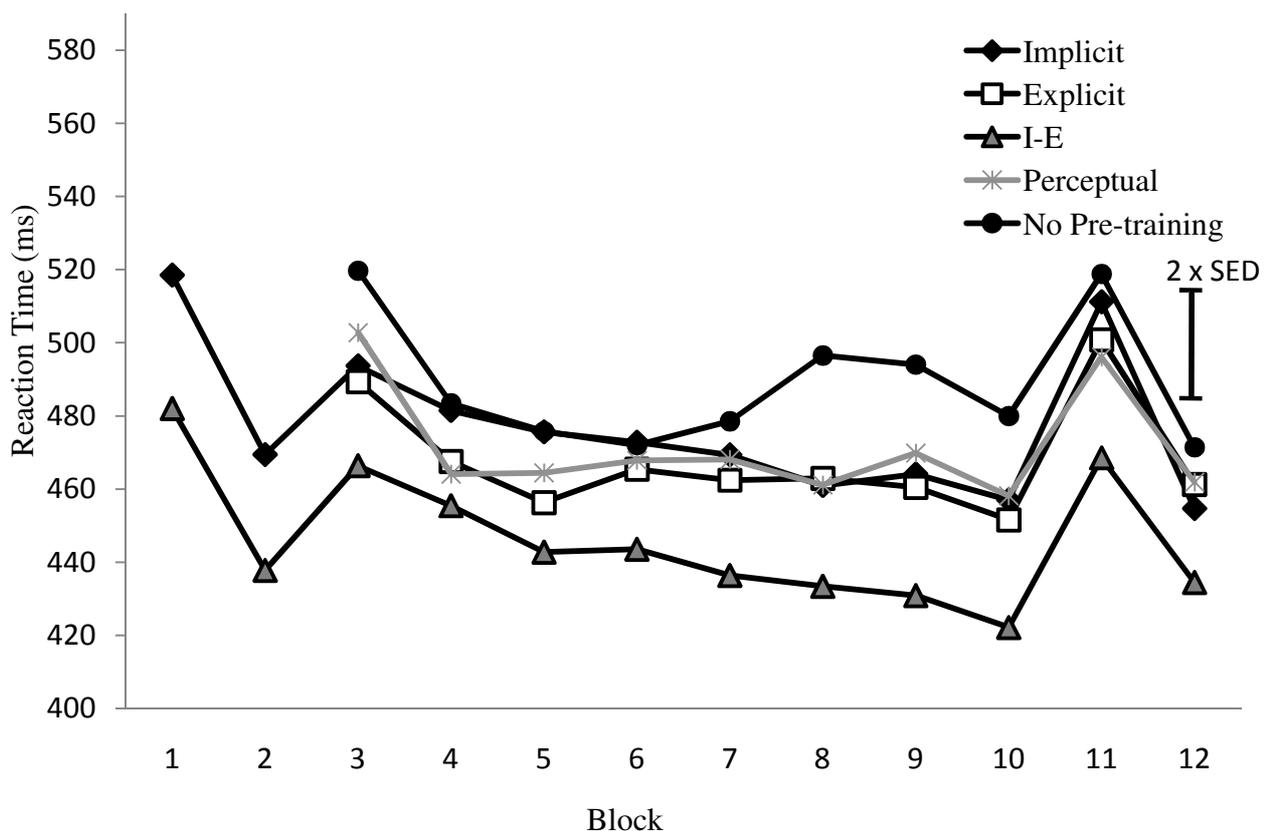


Figure 14. The mean RTs of the four groups in the 12 blocks of the test. Block 1 and 2 are the Preliminary Facilitation phase, Block 11 is the random probe block of the Main Test. The error bar represent the SED of the interaction.

As in the previous studies, learning was shown in terms of a longer mean RT in the probe Block 11 compared to Block 10,  $F(1, 68) = 40.54, p < .001, \eta^2_p = .37$ ; and a RT decrease on Block 12 compared to Block 11,  $F(1, 68) = 47.87, p < .001, \eta^2_p = .41$ ; with no evidence of a reliable group difference on Block 11,  $F_s(4, 68) = 1.03, p = .396, \eta^2_p = .06$ . These results confirm that learning happened in each group, although, the magnitude of learning was not reliably different across the groups.

Analysing the differences between the Irregular and Regular RTs in a mixed ANOVA with Block (3-10) as within-subjects factor and Group as between-subjects factor showed a significant effect of Block,  $F(6.58, 447.95) = 10.38, p < .001, \eta^2_p = .13$ ; but there was no evidence for a difference between the groups,  $F(4, 68) < 1$ , nor any reliable Group  $\times$  Block interaction,  $F(26.52, 450.81) < 1$ . The mean RT difference scores were above zero on Block 3-10 for each group: I group 95 % CI = 19.13 – 57.46; E group CI = 15.01 – 59.28; IE group CI = 28.12 – 66.46; P group CI = 14.89 – 55.87; NP group CI = 24.26 – 63.85, and a linear contrast confirmed that the difference between the Regular and Irregular RTs gradually increased along the blocks (3-10),  $F(1, 68) = 542.52, p < .001, \eta^2_p = .39$  (Figure 15). Thus the data again indicated that learning occurred in all of these groups.

These findings are in agreement with the previous results: aside from a reliable effect of learning there was no difference between the groups. None of the groups differed from the No Pre-training group,  $ps \geq .932$ , providing no evidence that learning is reliably affected by the preliminary facilitation per se. Finally, a planned comparison of the three experimental groups of *Experiment 1.1* (I, E, IE) once again did not provide a reliable replication of the group differences within that experiment  $F(2, 41) < 1$ .

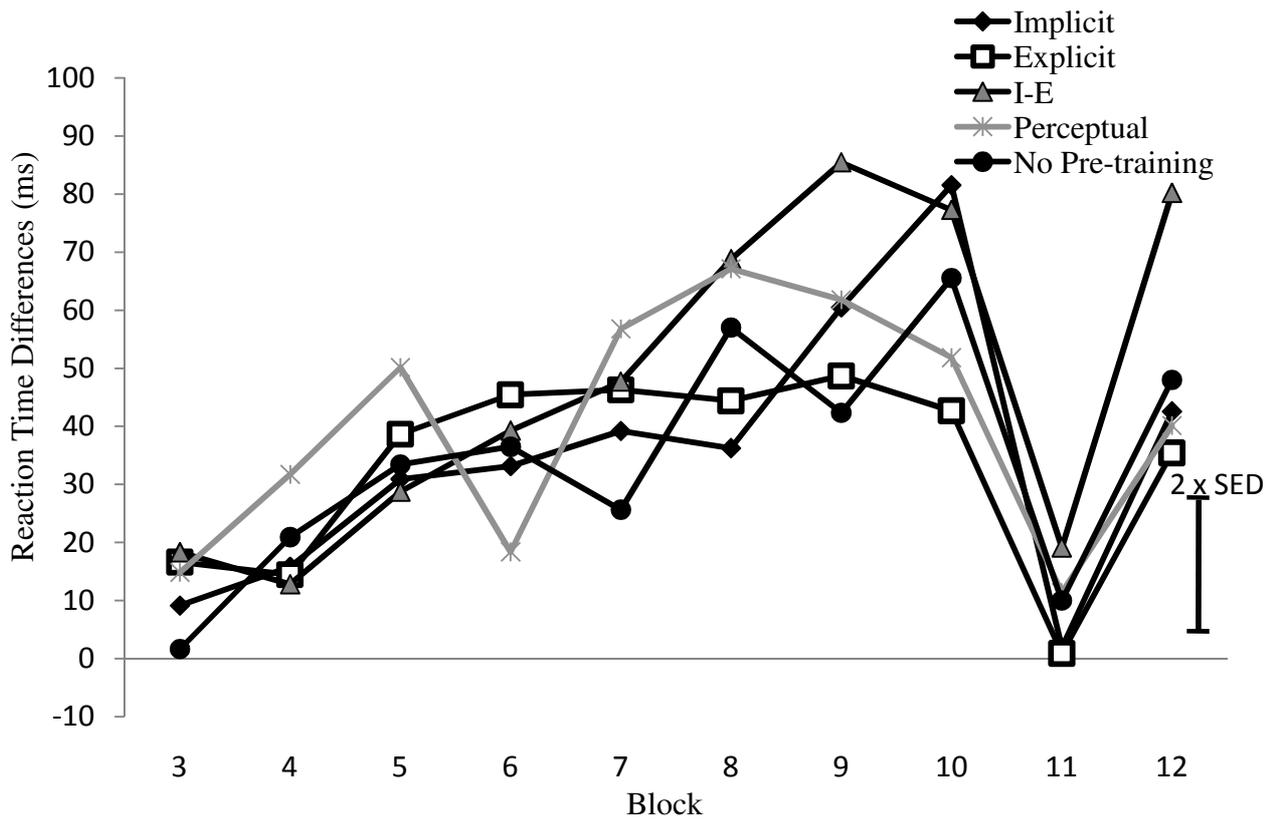


Figure 15. Reaction time differences of the regular sequence means of the groups in Block 3-12. The error bars depict the SED of the interaction.

Paired Sample comparisons showed that the participants made significantly fewer errors on the Regular vs. the Irregular trials in the I,  $t(15) = 3.67, p = .002, d = .85$ ; and P groups,  $t(13) = 4.55, p = .001, d = 1.19$ , (Figure 16). For no other groups was there evidence of a difference in error rates between Regular and Irregular trials,  $t_s < 1$ . The overall pattern of error rates is, once again, interesting: the groups with explicit sequence instruction (E, IE) seem to make more mistakes on the regular trials whereas those ‘more implicit’ groups, without the explicit sequence instructions, (I, P, NP) make relatively fewer errors in their detections.

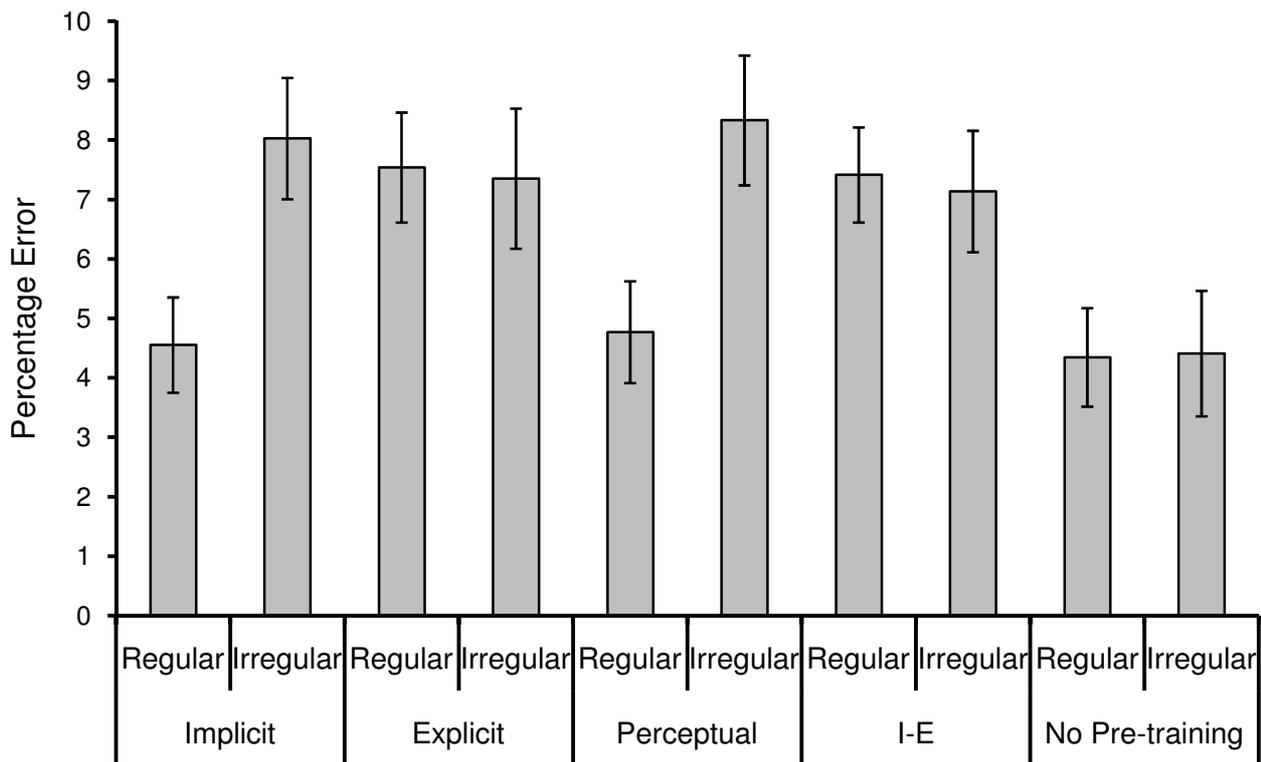


Figure 16. The percentage of the errors made in the detection of the asterisk in the Regular and Irregular trials in the five groups. The error bars represent the SEMs.

Overall, the analysis of the RT measures did not indicate that the preliminary facilitation had any reliable effect on the performance of the groups. The error measures indicated some group differences, in that the groups with more implicit pre-training made more errors on irregular than regular trials, providing some evidence of an influence of the preliminary training.

#### *Process Dissociation Procedure*

A mixed ANOVA with Condition (Inclusion, Exclusion) as within-subjects factor and Group as between-subject factor showed a significant effect of Condition,  $F(1, 63) = 6.45$ ,  $p = .014$ ,  $\eta^2_p = .09$ , reflecting flexible knowledge; and an effect of Group,  $F(4, 63) = 2.90$ ,  $p = .029$ ,  $\eta^2_p = .16$ , but no Group  $\times$  Condition interaction  $F(4, 63) < 1$ , and thus no evidence for a difference between the groups in terms of their level of explicit, flexible knowledge.

One sample t-tests revealed that only the inclusion performance of the I group,  $t(13) = 2.24$ ,  $p = .043$ ,  $d = .60$ ; the inclusion performance of the IE, one-tailed  $t(15) = 1.91$ ,  $p = .038$ ,  $d = .48$ , were higher than chance-level; and the exclusion performance of the E group,  $t(11) = -2.92$ ,  $p = .014$ ,  $d = .84$ , was significantly lower than chance level (33.33%) (Figure 17).

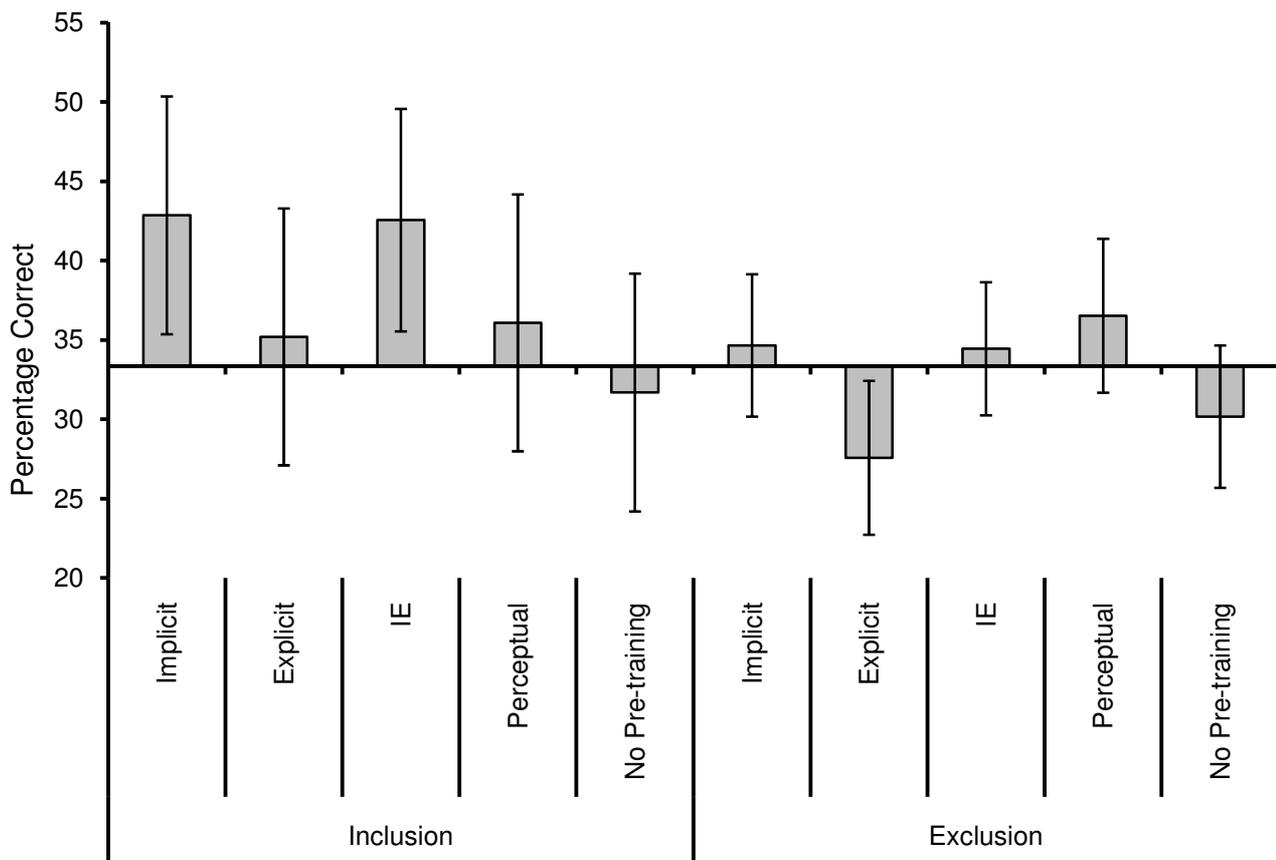


Figure 17. The Inclusion and Exclusion conditions of the PDP for the three experimental groups. The error bars represent the 95% confidence intervals.

### Questionnaire Assessment

There were no reliable group differences between the reported measures of observed regularity in the test as assessed by the post-test questionnaire,  $F(1, 67) < 1$ . All groups, on average, reported the predictability of the movements of the asterisk as close to the label “half

and half”, *i.e.* halfway between random and predictable. Nor was there any evidence for a difference between the groups in the estimation of the length of the sequence either,  $F(4, 66) = 1.36, p = .257, \eta^2_p = .08$ . The mean estimations of the real length of the sequence were as follows: Explicit (M = 7.25, SD = 4.59), Implicit (M = 6.57, SD = 5.12), IE (M = 6.31, SD = 3.84), P (M = 4.93, SD = 3.50) and NP (M = 4.07, SD = 3.02); the true length of the sequence was 12 items.

## Discussion

This experiment replicated aspects of *Experiment 1.1* and *1.2*, exploring the possible interactions between the proposed implicit and explicit learning mechanisms. The effects of facilitatory pretraining conditions from the first experiment, along with the perceptual pretraining condition from the second, were compared with a group that received no preliminary facilitation.

As in *Experiment 1.2*, the RT results failed to show reliable group differences in learning, including comparisons with the group that did not receive any pretraining. Whilst the NP group responded the slowest overall and the most accurately, these data offer no support for the notion that the preliminary facilitation stage influences the amount learned during the SRT main task.

The analysis of the error rates provided some support for the pattern from *Experiment 1.2* in that the uninformed groups generally made more errors on the irregular trials than the regular trials. Whilst this could be assumed to provide evidence that these groups had learned in a different, perhaps more ‘implicit’ way, the data from the knowledge tests do not indicate that these groups possessed any implicit knowledge.

It is possible that these groups, whose attention was previously not drawn to the sequential structure, used their knowledge in a different, less controllable way during responding on the SRT. Whilst it is possible that a different ‘use of knowledge’ may be responsible for the particular pattern of error rates, there is no reason to take the difference as indicating *unconscious* learning and memory processes.

The performance of the Perceptual group did not differ from that of the other groups, and so the previous conjecture that the preliminary facilitation had an inhibitory effect on the performance was not supported. The analysis of the accuracy measures showed great similarity between the I and the P groups, which provides support for the notion that the key difference lies in whether the attention of participants was drawn to the presence of the hidden sequences.

In summary, the present data failed to provide support for the original finding that the performance of the IE group represents the result of the summation of two kinds of processes. Furthermore, in none of the tests of knowledge was evidence found for performance based on implicit knowledge.

## Chapter Discussion

The basic assumption behind these studies was that if there are separate learning processes then they could be observed through their interaction. For this, an attempt was made to manipulate, through facilitation, implicit and explicit processes both independently and in combination.

The task of exploring the interaction of learning processes is a real challenge from both theoretical and empirical perspectives. As was described in the introduction of this

chapter, there is no general agreement in the field about either the definitions and the descriptions of these learning processes, nor about the methods of how to differentiate the implicit processes from their explicit counterparts.

The present work approached the question by focusing on interactions. It was reasoned that even if independent processes cannot be easily separated in behavioural tasks, an interaction of effects could serve as an indication of the presence of more than one source of processing. Apart from some works studying the effect of explicit prior knowledge or the computational modelling of interaction in learning, very few systematic methodologies are described for tackling the question of process interaction.

Based on previous studies (Ferreira et al., 2006; Smith, 1994) the idea was followed that processing a particular stimulus in a given way can facilitate the subsequent repetition of the same processing with new stimuli. Specifically, in this design, instructed formal learning prior to the task was applied to encourage the use of explicit processes, while aiming to leave the implicit processes unaffected. Similarly, presenting a test during which implicit processing could be used may be expected to facilitate the use of similar processes during the task, whilst not influencing the proposed explicit system. If the two systems have an interactive relationship then it was expected that the combination of the two processes could lead to cooperative or to interfering influences upon performance.

The results of *Experiment 1.1* allowed for the interpretation that the interaction of the two systems resulted in a summated performance; that is, the preliminary engagement on the two systems with the same task (but different sequences) may have added up in a beneficial way. This interpretation, however, was not supported by any of the tests of awareness, nor was it replicated in the following two experiments. Crucially, none of the experimental groups

turned out to be reliably different from the control group that received no preliminary facilitation.

From these results it can be concluded that despite the occasional group differences in the SRT and accompanying measures, the preliminary facilitation is not an effective method for the exploration of learning processes.

It is possible that the failure to find reliable group differences in the RT data was due to a lack of sensitivity in the test, the test being sensitive to only one type of processing, or that the facilitation did not promote specific processing styles in any way.

A surprising result of the experiments in this study is the similar patterns in accuracy whereby the uninformed groups made more mistakes on the irregular trials compared to the regular trials. Different behavioural characteristics of RT and error rate indices have been reported previously (e.g., Hikosaka et al., 2002; Watanabe et al., 2006). Song and colleagues (Song, J. H. Howard, & D. V. Howard, 2007) ascribe high importance to this dissociation saying that in SRT “*accuracy reflects only implicit learning, whereas reaction time also incorporated aspects of explicit knowledge and strategy.*”(p. 173).

It is difficult to argue the same for the present results. Although the error rates differentiated between the groups primed for ‘implicit’ and ‘explicit’ strategies, the overall analysis of the data concerning the conscious status of knowledge did not suggest that these groups acquired knowledge through different underlying processes. It is plausible that they differed somewhat in how any knowledge was applied during responding on the SRT task, perhaps as a result of differences in attention to the sequence.

The design of the Perceptual group was constructed to investigate a slightly different question. If types of preliminary training are differentially beneficial, do the benefits arise

due to the experience with the motor task, the explicit knowledge about the hidden sequences or simply the engagement of the attentional system in localising stimuli in a repeating order?

Previous perceptual-based implicit sequence learning tasks have led to controversial results. Kelly and Burton (2001), for example, did not find learning after pure observation of the sequence. However, in this experiment the participants were not prompted to pay attention to the stimuli. Others (Deroost & Soetens, 2006a, 2006b; Remillard, 2003) have found evidence for learning with a decoy task where the participants' attention was drawn to the stimuli, but this learning was restricted to very simple sequences and appeared to be limited by attentional capacity. The results of the current study did not provide reliable evidence that the purely perceptual exposure to a repeating sequence was of benefit in the test phase. Instead, this group behaved similarly to a group receiving implicit pre-training that also received no instructions about the presence of a hidden sequence.

In summary, the aim of this study was to extend the SRT paradigm by attempting to 'prime' implicit and explicit processing both independently and in combination. Although the RT results of the first study suggested that the IE group combined facilitation of two processes in a summative way, further attempts to replicate this effect, and tests to probe for different levels of consciousness, failed to support any interpretation based upon implicit knowledge.

Rather, all the groups showed evidence for explicit knowledge, thus a single source of explicit knowledge provides the most parsimonious account of the behavioural results. It appears that learning was facilitated in these experiments primarily when the visual attention of the participants was drawn to the existence of the hidden rule.

The finding that all groups, at least at some stage during experimentation, became aware of the contingencies of the task, leaves open the question of whether learning is

possible in the absence of such awareness. Furthermore, the inability to observe an interaction between implicit and explicit conditions in the IE group in itself cannot rule out the existence of an implicit system, but may simply be the result of ceiling effects of explicit knowledge on performance. The following chapter was dedicated to addressing these issues.

### III. VISUAL ATTENTION AND LEARNING

An inherent hindrance of nonconscious cognition research is that the conscious status of any process can be assessed only indirectly. Generally speaking, research in this area has involved two methodological approaches to provide evidence of nonconscious cognition. One approach is that of using or inducing situations which are believed to restrict or facilitate either conscious or nonconscious cognition; the other approach is to attempt to assess the conscious status of the task-relevant knowledge.

In the field of implicit learning, one example of the first approach is the use of special populations known to have selective deficiencies in the explicit, or in the implicit domains of memory, for example, people with amnesia (Nissen & Bullemer, 1987; Knowlton, Mangels, & Squire, 1996), Huntington's disease (Knowlton, Squire, Paulsen, Swerdlow, & Swenson, 1996; Willingham & Koroshetz, 1993), or Parkinson's disease (Joel et al., 2005; Westwater, McDowall, Siegert, Mossman, & Abernethy, 1998). Performance of these patients may be contrasted with that of patients with striatal dysfunction, such as in Obsessive Compulsive Disorder (Rauch et al., 2001) or Tourette Syndrome (Keri, Szlobodnyik, Benedek, Janka, & Gádoros, 2002), who are thought to display deficiencies in implicit processing.

Restricting explicit processing can be also achieved through test design, typically by means of a procedure where the real aim of the test remains hidden from the participants (incidental learning design, e.g., Marvin M. Chun & Jiang, 1998). Alternatively, the task can be constructed to be so complex in its nature (e.g., Lewicki & Hill, 1987; Schvaneveldt & Gomez, 1998), or to require such rapid reactions (Destrebecqz & Cleeremans, 2001) that it is assumed that learning of the task is beyond the capacity of the explicit system.

Another way to obtain evidence that learning happened without awareness is via *post-experimental evaluation* of awareness. The aim of such evaluation is a post-hoc assessment of

the state of consciousness of the representation of the learned knowledge. These measures of awareness are often divided into *subjective* and *objective* categories. The measures are subjective when they assess the extent to which people believe that they know. The objective measures assess how much people know.

This introduction will discuss the most frequently applied post-experimental assessment tools: verbal report and other subjective measures, along with two measures typically labelled as objective: Post-Decision Wagering (PDW) and the Process Dissociation Procedure (PDP).

### *Verbal Report*

Since consciousness is an essentially first-person experience, verbal report is the most obvious measurement for estimating conscious knowledge. The earliest empirical support for implicit learning came from the discrepancy between behavioural performance on, and verbal reports of, the same task (Nissen & Bullemer, 1987; A. S. Reber, 1967). Participants are often unable to report what knowledge they used in the performance of the implicit learning tests despite their above-chance performance (e.g., Curran & Keele, 1993; Frensch, Buchner, & Lin, 1994; Frensch & Miner, 1994; Willingham, Nissen, & Bullemer, 1989).

Some authors insist that since consciousness is an intimate, first-person experience, only verbal reports can assess it. As Marcel (1988) argued “*There is really only one criterion for phenomenal experience. This is the person’s report, direct or indirect, that they have a sensation of one or another kind, they are or were conscious in one or another way. /.../ [P]rovided that the person is not lying, there is little reason to doubt the validity of a report that there is phenomenal experience*” (p. 131). According to French and Rüniger (2003), verbal reports are the most valid measures of explicit sequence knowledge. Nonconscious knowledge can induce a feeling of ‘rightness’ which can be deployed to the execution of

forced-choice prediction tests, thus confounding other, nonverbal tests of awareness with non-aware knowledge (Norman et al., 2006).

Other authors have suggested applying more rigorous verbal assessment procedures (Brody, 1989) or verbal discrimination tasks (Eriksen, 1958). Yet, a fundamental criticism of verbal report concerns the basic assumptions behind the assessment process. A tacit assumption is the reliability of introspection, that is, the consideration that people reliably monitor their mental states and that they can be trusted to report them accurately to the researchers (Goldman, 2000). Another assumption is that the participants can remember whether they were aware or not of a particular stimulus or rule at the moment of the behaviour.

In an extensive analysis of the research taken as evidence for dissociable implicit and explicit learning systems, Shanks and St John (1994) pointed out that any test of awareness of some knowledge has to satisfy the *information* and *sensitivity* criteria. The *information criterion* requires of the awareness test that the information that it assesses must be the same information that is responsible for the performance change, *i.e.* the information of which learning has been demonstrated. The *sensitivity criterion* requires the experimenter to design a test of awareness that is sensitive to all of the conscious knowledge that could have been relevant in the test.

Verbal reports may fall short in the test of these criteria. To satisfy the first criterion most researchers try to use the very same design in the assessment as in the test, which is a difficult, if not impossible, requirement for verbal reports. The ability to verbalise a conscious state may also be more difficult than it was to experience it.

In summary, verbal reports can constitute strong evidence for presence of conscious knowledge if, say, the person is able to verbally describe the role of the stimuli (e.g., the

sequence in the SRT). It is more troublesome to claim the opposite; that the inability to recall results from the absence of conscious knowledge: it may just as well result from the lack of sensitivity in a questionnaire, a memory failure, or motivational biases.

### *Subjective Measures*

One of the possible reasons why, despite these criticisms, verbal reports are still frequently employed as a test of awareness may be most clearly understood in term of the theoretical considerations of the Higher Order Thought (HOT) theory (Rosenthal, 1997). Rosenthal's conceptual theory of consciousness places constraints on any mental state to be conscious: "*We are conscious of something, on this model, when we have a thought about it. So a mental state will be conscious if it is accompanied by a thought about that state. [...] so the state we are conscious of is a conscious state. Similarly, when no such [higher-order thought] occurs, we are unaware of being in the mental state in question, and the state is then not a conscious state*" (p. 741). In this view, therefore, any evidence for the absence of higher-order thought about a representation would be evidence for the unaware state of that representation. According to this, if a verbal report is assumed to be sensitive enough to measure the relevant higher-order thought then it legitimises the use of subjective reports.

In terms of the content of learning, we can differentiate two kinds of knowledge: *structural knowledge* and *judgment knowledge* (Dienes, 2008). The structural knowledge refers to knowledge that enables performance, such as the actual details of a rule, or the order of elements in a sequence. If the person has to decide whether a string follows a certain rule or if a chunk is part of a sequence, then they may rely on (conscious or unconscious) structural knowledge to come to a certain answer, but the knowledge of this answer is judgment knowledge. The decision of how to respond requires only the judgment knowledge: knowledge of the answer, but not the knowledge of how the answer was obtained. In this

sense the traditional view of unconscious knowledge reflects a situation where one has no conscious judgment knowledge, nor any conscious structural knowledge. On the other hand, when one has conscious judgment knowledge about something, but has no conscious structural knowledge of it, that qualifies as intuition (Dienes, 2008).

Two criteria have been proposed for taking subjective measures as evidence of unconscious knowledge: the *guessing criterion* and the *zero-correlation criterion*. These criteria rely on the premises of the HOT theory (Dienes, Altmann, Kwan, & Goode, 1995; Dienes & D. Berry, 1997). As Dienes argues, “[i]f a person’s knowledge states are conscious, she will know when she knows and when she is just guessing” (2008, p. 57). It follows from this that when people believe (and thus report) that they are guessing, any knowledge that their performance reflects is unconscious knowledge. This is referred to as the *guessing criterion* of nonconscious processing. (Cheesman & Merikle, 1984). However, the criterion for reporting “guess” may differ between individuals, biasing the reliability of such a measure (Eriksen, 1960). One participant may only report as knowledge those beliefs held with high confidence, and report anything below as ‘guess’; others may set a more liberal criterion.

The *zero-correlation criterion* (Dienes et al., 1995), however, escapes this conundrum. It is suggested that higher confidence should correlate with performance if the participant is aware of the knowledge. If the participant’s confidence rating correlates with the measured performance then it must be that some part of the knowledge is conscious. If there is no such correlation then the knowledge is unconscious. In repeated applications of these subjective measures, a dissociation was reported between performance and confidence (e.g., Channon et al., 2002; Dienes & Altmann, 1997). Note that these subjective measures (guessing and zero-correlation criteria) of conscious knowledge do not assume that the presence of one kind of knowledge excludes the presence of the other (Jacoby, 1991). These

criteria allow for simultaneous conscious and unconscious knowledge (e.g., conscious judgment knowledge with unconscious structural knowledge).

It is important to note that the guessing and zero-correlation criteria are not meant to be operational definitions of consciousness (Dienes, 2008), nor is a lack of correlation between performance and confidence a necessary indicator that all knowledge is unconscious. Rather, “[they are] *tools and like any tool must be used with intelligence and sensitivity on each application*” (Dienes, 2008, p. 59).

### *Post-Decision Wagering*

The subjective measures of unconscious knowledge described above rely on the honesty and cooperation of the participant in reporting their subjective knowledge state. Persaud, McLeod and Cowey (2007) planned to overcome the uncertainties associated with such tests by inviting the participants to wager on correctness of their judgments. The rationale behind the procedure is that if someone has subjective confidence about a judgment then the person would use it for contingent monetary gain, even if they may be motivated to report that judgment as a guess. For instance, in an AGL experiment Persaud and colleagues trained the participants on letter-strings which, unbeknownst to them, followed a predetermined grammar. In the test phase, where they were presented with new grammatical and ungrammatical strings, they had to judge whether the presented strings were grammatical or ungrammatical. After each judgment they had to wager £1 or £2 on the correctness of their choice. Each participant could have earned an average of £76 if they wagered high on the correct judgments. The correct classification was 81% on average, however, the amount of high wagering on the correct trials was not significantly higher than chance level, reflecting, as they argued, the lack of awareness. In a subsequent experiment, where the

participants were made aware of the grammar of the strings, their wagering accurately reflected their performance.

Persaud and colleagues argued that while other subjective measures measure introspection, and awareness about awareness, their post-decision wagering (PDW) technique measures awareness directly. This claim is open to criticism, namely that PDW is not a direct measure of awareness since it is a second-order judgment, a judgment of the reliability of a first-order experience (Seth, 2008a). Persaud and his colleagues (Persaud, McLeod, & Cowey, 2008) insist, however, that in contrast to the questions used in subjective measures of awareness, in PDW the participants found wagering intuitive. Also, they found that a blindsight patient showed good performance in another test while not being able to turn that knowledge to optimal wagering. Therefore, they claimed that the PDW might involve metacognition, but it does not measure it.

Nevertheless, other empirical works suggest that since PDW is a decision about confidence, it can be sensitive to metacognitive decision biases, such as risk aversion (Schurger & Sher, 2008). Prospect Theory (Kahneman & Tversky, 1979) summarises decades of empirical evidence that people exhibit greater sensitivity to possible losses than possible wins when making probabilistic decisions. This has also been claimed to be true for PDW bets (Clifford, Arabzadeh, & Harris, 2008a). In summary, PDW differs from the previously mentioned subjective measures of awareness, because it does not directly rely on introspection and, therefore, it is in some sense an objective measure (Seth, 2008b). However, it can be biased by the wagering strategies of the participant (Clifford, Arabzadeh, & Harris, 2008b).

### *Process Dissociation Procedure*

Considering the weaknesses of the subjective measures of awareness, many authors suggested that forced-choice tasks are useful for detecting knowledge that could not be captured by verbal reports (e.g., Perruchet & Amorim, 1992; Willingham et al., 1989). Since reports of consciousness are associated with recollection, most of the forced-choice tasks constituted *generation* or *recognition* tasks (e.g., Dulany, Carlson, & Dewey, 1984; Gomez & Schvaneveldt, 1994; Perruchet & Pacteau, 1990). According to the *exclusiveness assumption* of Reingold and Merikle (1988), an acceptable test of awareness should be sensitive only to the relevant conscious knowledge. It is, however, easy to recognise that the performance of these tasks require the same kind of retrieval processes as the implicit task itself, and hence may be sensitive to unconscious processes as well. Indeed, successful generation can be measured on the same trials where the participants report guessing (Ziori & Dienes, 2008).

What should an optimal test of awareness be like? In order to fulfil Shanks & St John's (1994) information criterion; the design and task should be as close as possible to the original test. To overcome the contamination problem – that all processes can depend on both simultaneously implicit and explicit influences – the two kinds of processes can be set in opposition in a manner similar to Jacoby's (1991) Process Dissociation Procedure (PDP). This procedure was developed in the field of implicit memory research based on the assumption that the conscious and unconscious knowledge may have independent influences on performance. Assuming that the influences differ in 'flexibility' it is possible to decompose them by pitting them against each other.

A PDP task consists of two parts, an inclusion condition and an exclusion condition, which differ in the instructions (as in was used in Chapter II). In the inclusion part (I) the participants have to make a valid response, including if possible the items or rules from the

preceding learning phase; while in the exclusion part (E) they are asked to make valid responses whilst avoiding learned items. For example if in a word learning task the person consciously recalls the word 'dean' then if the inclusion part consists of a word-stem completion task they might regenerate the word when presented with the stem 'de\_\_'. In the exclusion part, however, the person should attempt to complete the stem with a different word, for example 'deer.' In either case, if they are unable to recall a suitable item they can rely on their intuition.

It is assumed that both conscious (recollection) and unconscious (automatic facilitation) processes can be responsible for an item being successfully produced during the inclusion task. In the exclusion part, however, they are asked to avoid any regeneration, thus conscious control should result in lower probability of response, whereas automatic facilitation will still lead to production of the item. According to the logic of PDP, if the researcher still observes above-baseline performance, it can be ascribed exclusively to automatic facilitation based on unconscious knowledge, coupled with the absence of conscious knowledge (Jacoby, 1991).

Assuming independence of the two systems, an algebraic computation of the probabilities of recall from Exp (from explicit) and Imp (from implicit) sources is possible (Jacoby, Toth, & Yonelinas, 1993). The probability of generation during exclusion performance is given by  $P(E) = \text{Imp}(1 - \text{Exp})$ , and inclusion performance by  $P(I) = \text{Imp} + \text{Exp} + \text{Imp} \times \text{Exp}$ . The logic of the test (Jacoby et al., 1993)<sup>5</sup> infers that the difference between the inclusion and exclusion performance provides a 'pure' measure of the explicit process,  $\text{Exp} = P(I) - P(E)$ , and a measure of the implicit process,  $\text{Imp} = P(E) / (1 - \text{Exp})$ .

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<sup>5</sup> The original work used Recollection (R) and automaticity (A).

Recently, this approach has been adapted by other authors of the field (e.g., Q. Fu, X. Fu, & Dienes, 2008). In a typical application of the PDP in an SRT test, the participants receive an instruction to generate sequences that either include, or exclude, parts of the sequence they saw earlier (e.g., *Experiments 1.1-3* in this work) or to continue (or avoid continuing) a sequence from a presented fragment (e.g., Wilkinson & Shanks, 2004). Despite the elegance of this approach, according to the logic put forward by Wilkinson and Shanks only a specific pattern of results,  $I = E > B$ , where B refers to the performance baseline, unambiguously indicates the use of unconscious knowledge. A pattern of results of  $I > B > E$  is consistent with knowledge that was wholly conscious (Wilkinson & Jahanshahi, 2007).

In previous studies unconscious knowledge has been reported based on application of the PDP technique to the analysis of sequence learning (e.g., Destrebecqz & Cleeremans, 2001; Goschke, 1997). Destrebecqz and Cleeremans (2001) claimed that the design of SRT with delay intervals between responses and the following stimuli led to explicit knowledge while the condition where there was no delay between the responses and the following stimuli, the zero response-stimulus interval (RSI) condition, led to implicit learning. However, replication studies by Wilkinson and Shanks (2004) and Norman, Price, and Duff (2006) did not find evidence of unconscious knowledge in Destrebecqz and Cleeremans' crucial zero RSI condition using the 'E > B' approach. Rather they found the pattern of responding ( $I > B > E$ ) which is consistent with sequence learning being explicit. Fu, Fu and Dienes (2008), however, successfully replicated the original findings of Destrebecqz and Cleeremans, showing an 'E > B' pattern, and suggested that the rewards for performance in Wilkinson and Shanks' study may have reduced the above-chance exclusion performance to baseline. This latter argument implies, however, that the knowledge had to be explicitly controllable.

The usage of the PDP is not uncontroversial even for the supporters of the multiple system view. The procedure conceptualises independent conscious and unconscious processes, thus its logic is not evident from the view of interactive processing. If, say, the two processes positively correlate, then the exclusion condition will underestimate their effect (Ferreira et al., 2006). Jacoby's assumption that the PDP is an objective test of awareness and that the exclusion condition measures conscious knowledge is also debated. Fu, Fu and Dienes (2008) claim that the PDP can be taken as a type of subjective measure in the sense that refraining from the generation of the sequence depends on the participants' assessment of whether they know the sequence or not. It is also claimed that exclusion can happen without conscious awareness of the sequence. The participant can develop a feeling of '*rightness*' about certain answers and avoid it along the trials. The sense of *feeling of knowing* is enough for correct exclusion. In this way the exclusion condition measures the judgment knowledge of the person, but it is not informative about the structural knowledge. This feeling-of-knowing state is described by the concept of *fringe consciousness* (Norman et al., 2006), or *intuition* (Dienes, 2008).

In general, an obvious limitation of any post-experimental evaluation is that it is capable of reflecting only whether there is an intact or fragmented consciously available memory of what was learned, not whether the process of learning occurred with or without awareness during the test. Still, many claim that the presence of unconscious knowledge indicates that the acquisition of this knowledge occurred unconsciously (e.g., Jimenez, 1997).

### *The Present Study*

The following experiments aim to answer two main questions: (1) Can learning occur incidentally without focused attention on the stimuli? (2) Do the different post-experimental tests of awareness measure the phenomenon in concordance?

A single measurement of awareness seems to be unable to offer an accurate assessment of conscious knowledge. For this reason it is suggested that systematic application of several awareness tests could capture more of the phenomena than any of them alone (Destrebecqz & Peigneux, 2006). In the present study all of the measures were attached to the same incidental learning test. To promote incidental learning a typical SRT design was modified by a feature often applied in attentional learning research.

Previous studies comparing the effects of central and peripheral spatial cues showed that the processing of central cues is sensitive to conscious control (Lambert, 2003), whereas the processing of peripheral cues is more rapid, reflexive and unaffected by secondary tasks (Müller & Rabbitt, 1989). Lambert and his colleagues (Lambert, Naikar, McLachlan, & V. Aitken, 1999) found in several experiments that participants learned to predict target locations (as reflected by RT decrease) by the identity of peripheral cues (letters) even when they appeared very briefly (100 ms or shorter) before the onset of the target. The participants did not seem to have explicit understanding about the cue-target relationships, as shown by post-experiment questionnaires.

This pattern of results was found even when the predictor stimuli were the colours of the frame of the display (Lambert & Roser, 2001). The participants were able to learn the cue-target associations with very similar (green and blue-green) colours and still 40% of the participants failed to gain awareness about this knowledge. The authors claimed that even though the peripheral cues are of apparently incidental nature, learning can be based on covert attentional responses resulting in implicit learning. These studies originated from the notion of *derived attention* (James, 1890/1998; Lambert, 2003) which describes the passive process whereby “*the cue events come to attract attention by virtue of their association with target locations*” (Lambert, 2003, p. 265).

Some studies in the priming literature also observed learning without conscious attention resulting in ‘implicit effects’ measured by indirect tests such as word-stem completion, or repetition priming (e.g., Merikle & Daneman, 1996; Parkin, Reid, & Russo, 1990). This so called residual processing (Vuilleumier, Schwartz, Duhoux, Dolan, & Driver, 2005), which takes place without focused attention, was reported to happen at as high a level as semantic priming (Merikle, Smilek, & Eastwood, 2001).

For this study a task was devised where peripheral visual stimuli (colour frames) probabilistically predicted the location of the target stimulus (asterisk) in an SRT task. While the locations of the asterisks followed a random sequence, the colours of the frame of the screen were probabilistically related to stimulus locations. Attention to the changing colour of the frame was not required as part of the task. Instead, the participants had to report the location of the appearing stimulus by pressing one of the four corresponding keys.

In this design the predictive stimuli were not presented in a way to prevent them receiving attention from the participants, but they were not instructed to attend to them. Although deliberate attention to the colour frames was not expected from the participants, post-experimental assessments were included to detect the degree of attention paid. Based on Lambert and his colleagues’ observations and the assumption of the derived attention paradigm, it was anticipated that the participants would be able to learn the predictive relationship between the peripheral cues (colours) and the target locations (asterisks), and that this learning would be, to some degree, incidental and unintentional.

## Experiment 2.1: Incidental Learning Study 1

### Methods

#### *Participants*

The participants were 20 undergraduate students (13 female and 7 male;  $M = 21.30$  years,  $SD = 3.80$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Each participant received 1000 HUF (approximately 5 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the first half of the session.

#### *Materials and Design*

The testing was conducted in one group session in the same classroom at separate computers. The participants were seated approximately 60 cm from the computer monitor and were presented with the instructions on the screen. The task program was written using *REALbasic 2007 Standard Edition, Academic Version* software. The test application was run under *Microsoft Windows XP* operating system on a set of identical desktop computers; responses were collected via the keyboard.

The test consisted of two phases. The first phase resembled a classic SRT task (Nissen & Bullemer, 1987), where four horizontal dashes appeared on the computer screen and the participants were instructed to detect the location of the asterisk appearing above one of the dashes as quickly and as accurately as possible. The colour of the four dashes and the asterisk was white; the background of the screen was black. A rectangular frame was 50 pixels wide, and was presented along the four sides of the screen (Figure 18). The colour of the frame changed with each trial. The colours were selected from an array of 16 distinct colours (see Appendix B), which were created by the adjustment of the saturation of red, green and blue

components. The dashes appeared in font size 140, the asterisks were in font size 50. The four allocated keys were *Y C N* and *;* of the Hungarian language keyboard (which correspond in location to *Z C N* and *,* on the standard UK English language keyboards).

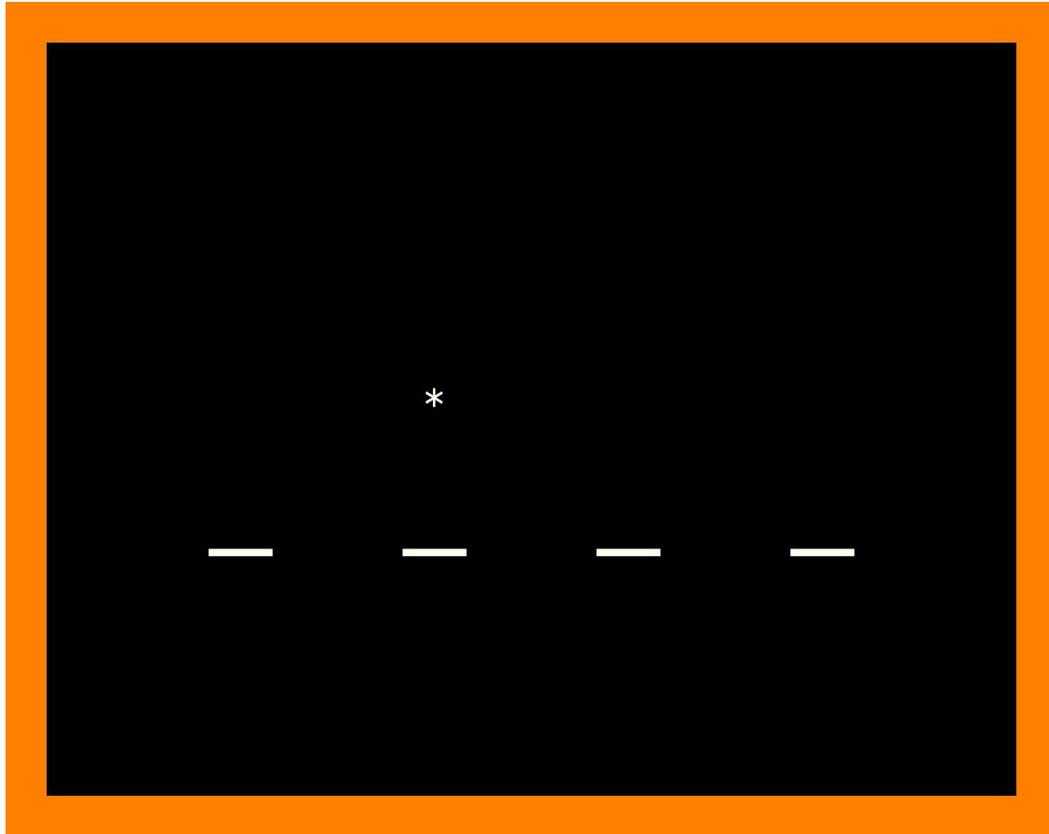


Figure 18. Screenshot of the Colour-Frame Task as presented to participants in Experiments 2.1, 2.2 and 2.4.

The appearances of the asterisk did not follow any repeating sequence. Across trials, the colour of the frame was probabilistically related to the location of the asterisk. Each colour of frame was always followed by one of two possible locations, one of which (regular location) was presented along with that frame colour more often than another, irregular location. By varying the number of regular and irregular locations presented, the different colours were given different degrees of predictive value (see Table 5). The physical colours corresponding to each colour number within Table 5 were randomised for each participant, but the colour-location pairings followed the same fixed, pseudo-random sequence for all participants.

Table 5

*Probability Structure of the Colour-Frame Task*

Colour	Regular Pairing			Irregular Pairing		
	Location	Frequency	Probability	Location	Frequency	Probability
Colour 1	1	41	91.1	3	4	8.9
Colour 2	3	40	88.9	2	5	11.1
Colour 3	1	39	86.7	3	6	13.3
Colour 4	3	38	84.4	2	7	15.6
Colour 5	1	35	77.8	3	10	22.2
Colour 6	3	34	75.6	2	11	24.4
Colour 7	1	31	68.9	3	14	31.1
Colour 8	3	30	66.7	2	15	33.3
Colour 9	2	37	82.2	4	8	17.8
Colour 10	4	36	80.0	1	9	20.0
Colour 11	2	33	73.3	4	12	26.7
Colour 12	4	32	71.1	1	13	28.9
Colour 13	2	29	64.4	4	16	35.6
Colour 14	4	28	62.2	1	17	37.8
Colour 15	2	27	60.0	4	18	40.0
Colour 16	4	25	55.6	1	20	44.4

*Note.* The values of Location represent the position of the asterisk numbering the location increasingly from left to right.

The second part of the test was designed to assess the level of knowledge about the relationship of the colour frames and the location of the target stimuli. For this purpose a task

based upon the Process Dissociation Procedure (PDP; Jacoby, 1991) was used, along with a combination of Subjective Measures (Dienes, 2008) and Post Decision Wagering (PDW; Persaud et al., 2007). On each PDP trial, a colour frame was presented and the participant was requested to press a single response key. The PDP consisted of 32 inclusion trials and 32 exclusion trials. In the inclusion condition, participants were asked to press the key for the location that was most commonly associated with that colour frame during the first stage; in the exclusion condition they were asked to press a key that had not been associated with the colour frame. In both of the phases of the PDP each of the 16 colour frames appeared twice in random order. Each trial was followed by either a confidence assessment or a PDW question. Each trial ended with an assessment of structural knowledge as described in the *Procedure* section.

The paper questionnaire (Appendix D) that the participants were asked to fill out after the experiment consisted of questions about their knowledge and risk aversion. In the first knowledge question they were asked to choose the degree to which they found the location of the asterisk predictable. The scale had five levels: (1) Totally Random; (2) Mostly Random; (3) Half-Half; (4) Mostly Predictable; (5) Totally Predictable. The next verbal report question asked “*If you noticed any regularity in the relation of the asterisk and the colours, what are you able to say about it? When did you first notice this?*”. In a further categorical scale the participants were asked to report how risk-averse they think they are. The scale ranged from 1 (risk-averse) to 7 (risk seeker). Finally, the participants had to report what risk they would take for different monetary gains. Each of the five pairs of options consisted of one fixed money gain and 50% chance of an increasing amount of win. The fixed amount was 1000 HUF (about 3 pounds), the risky amount increased from 1500 HUF (about 5 pounds) by 500 HUF in each choice.

### *Procedure*

The test was introduced to the participants as a reaction time measuring experiment. After signing the ethical consent form (Appendix C) and reading the instructions on the initial screen of the test, the participants could ask further questions from the experimenter or start the test with a designated key. At the start of each trial, the colour frame appeared along with the dashes on the screen, then there was a 200 ms delay before the appearance of the asterisk. If the participant detected the asterisk with the correct key press within five seconds then the new trial started following a 50 ms interval. If the participant pressed an incorrect key or failed to respond within the time limit, then an error message appeared on the screen and the data of the given trial were excluded from the RT analysis. The task was 720 trials long. After each 90-trial block they had the opportunity to take a short break.

In the PDP phase, the participants were informed that there was a hidden relationship between the colour of the screen frames and the location of the target stimuli. The task was to choose where the asterisk would most likely appear. They were also told that after each decision they can wager a small amount of money (10 - 50 HUF, approximately .03 - .15 GBP) on their decision. By wagering they can increase their real payment up to 2000 HUF (approximately 6 GBP). The participants were also informed that they would get feedback about the correctness of their decisions only at the end of the experiment. They were also informed that if they were to not win any money or if they were to lose more money than they would win, then they would receive only their participation fee.

For practice with wagering, a 10-trial game was introduced where an imaginary coin was tossed and they could put money on the outcome, winning or losing some game money. The participants could wager between 10 and 50 HUF by moving the bar of a slider on the

screen. After each trial the outcome and the amount of money won or lost was displayed on the screen together with the accumulated amount of wagered money.

After the wagering practice trials the participants were informed again about the task in this phase of the test. They were also told to rely on their intuitions if they could not recollect the location of the asterisk after a given colour frame. As this phase of the test started, the four dashes appeared on the screen with one of the colours of the frame. Without time pressure the participants could choose one of the locations of the asterisk by pressing the corresponding key. At this point the asterisk appeared in the chosen location without any feedback as to whether their choice was correct. This was followed by one of two questions. On odd-numbered trials the participants were asked how confident they were that their choice was correct. To answer the question the participants could move the bar of a slider between 50% representing '*complete guess*' and 100% representing '*completely certain*' (Figure 19). The confidence scale ranged from 50% to 100% instead of 0-100% to preclude ambiguity in interpretation of 50% as either complete chance, or halfway between guess and certainty (Dienes et al., 1995). On every second trial they had to wager between 10 and 50 HUF on their correctness in the manner described above (Figure 20). On each trial after either question they were also asked to choose whether they based the given decision on guess/intuition or memory/rule as an assessment of structural knowledge.

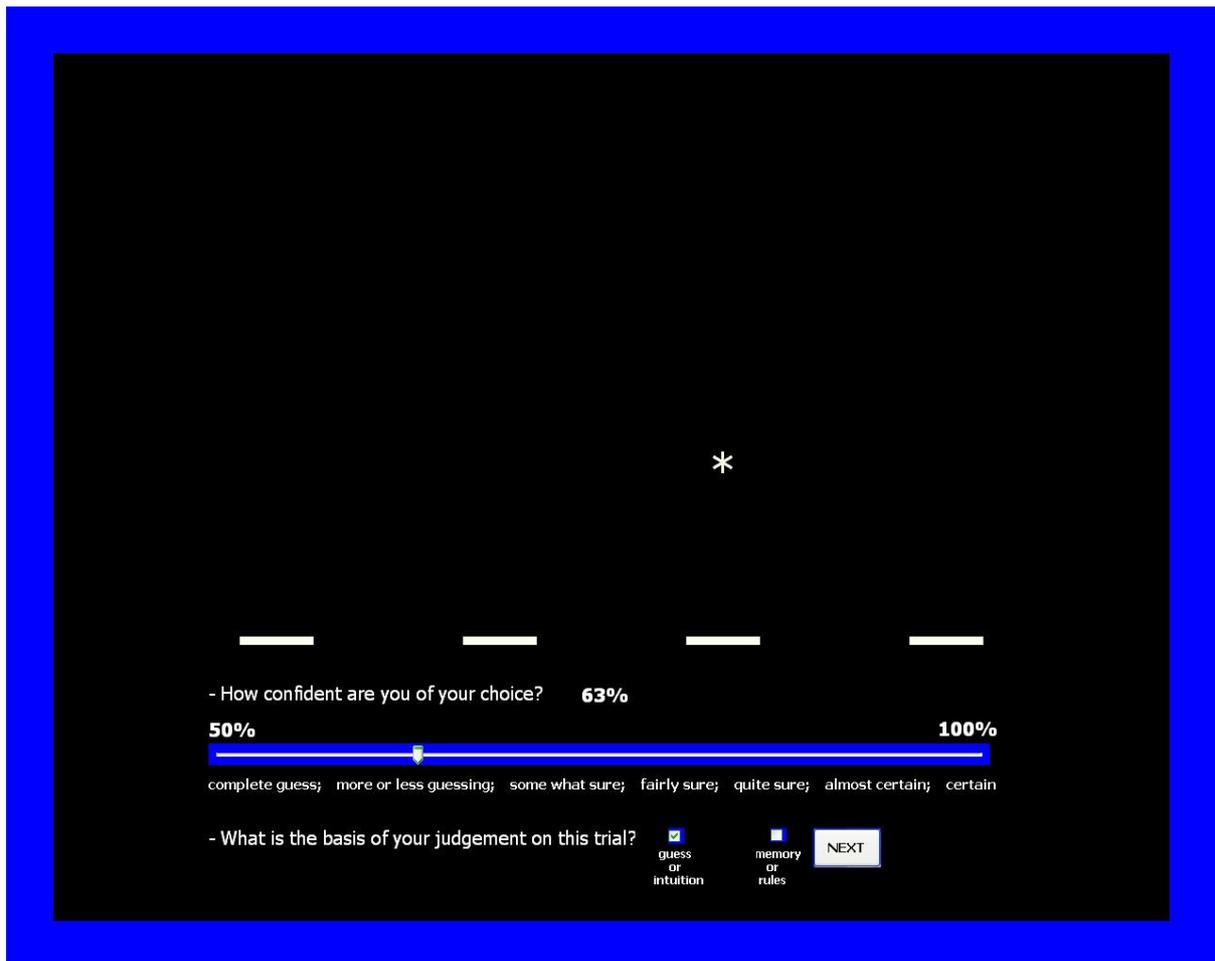


Figure 19. Screenshots from the English version of the Knowledge Assessment part of the test. On odd-number trials of the PDP, the confidence in the decision of the participants was assessed. They were also asked to choose whether they based their given decision on guess/intuition or memory/rule as an assessment of structural knowledge.



Figure 20. Screenshots from the English version of the Post Decision Wagering part of the test. In every second trial of the PDP the participants had to wager money on whether their decision was right. After their bet they were asked – just as after the confidence rating – to choose whether they based the given decision on guess/intuition or memory/rule as an assessment of structural knowledge.

When the computer task ended, the participants were asked to fill out the paper questionnaire (Appendix D) to assess their impression of predictability in the test, their verbalisable knowledge of the regularities in the test and their level of risk aversion, as described above.

## Results

### *RT Measures*

The RTs of the regular and the irregular trials were averaged into nine blocks. Each block consisted of 80 trials: 5 repetitions of all the colour-location pairings. The prediction

was that, if learning had occurred, the RTs from the irregular trials would be longer than those from the regular trials. Surprisingly, however, the RTs in the irregular trials were faster on average than in the regular trials (irregular  $M = 480.22$ ,  $SD = 11.99$ ; regular  $M = 493.74$ ,  $SD = 11.79$ )<sup>6</sup>. An ANOVA with Regularity and Block as within-subject factors confirmed that this effect of Regularity was reliable,  $F(1, 19) = 34.03$ ,  $p < .001$ ,  $\eta^2_p = .64$ ; along with an effect of Block,  $F(3.68, 69.87) = 3.73$ ,  $p = .010$ ,  $\eta^2_p = .16$ ; and a Regularity  $\times$  Block interaction,  $F(4.33, 82.17) = 6.96$ ,  $p < .001$ ,  $\eta^2_p = .27$ , (Figure 21).

A correlation analysis was performed to determine whether the predictive strength (proportion of ‘regular’ pairings) on each trial was related to the RTs on the regular, and on the irregular locations. Neither of the analyses showed evidence that RT reflected the relationship between colours and location, the average correlational coefficients were not significantly different from zero, regular trials: (mean  $r = -.01$ ,  $SD = .05$ ),  $t(19) = 1.5$ ,  $p = .149$ ,  $d = .34$ ; irregular trials: (mean  $r = .01$ ,  $SD = .11$ ),  $t(19) < 1$ .

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<sup>6</sup> Reaction times reported in this study are always measured in *ms*.

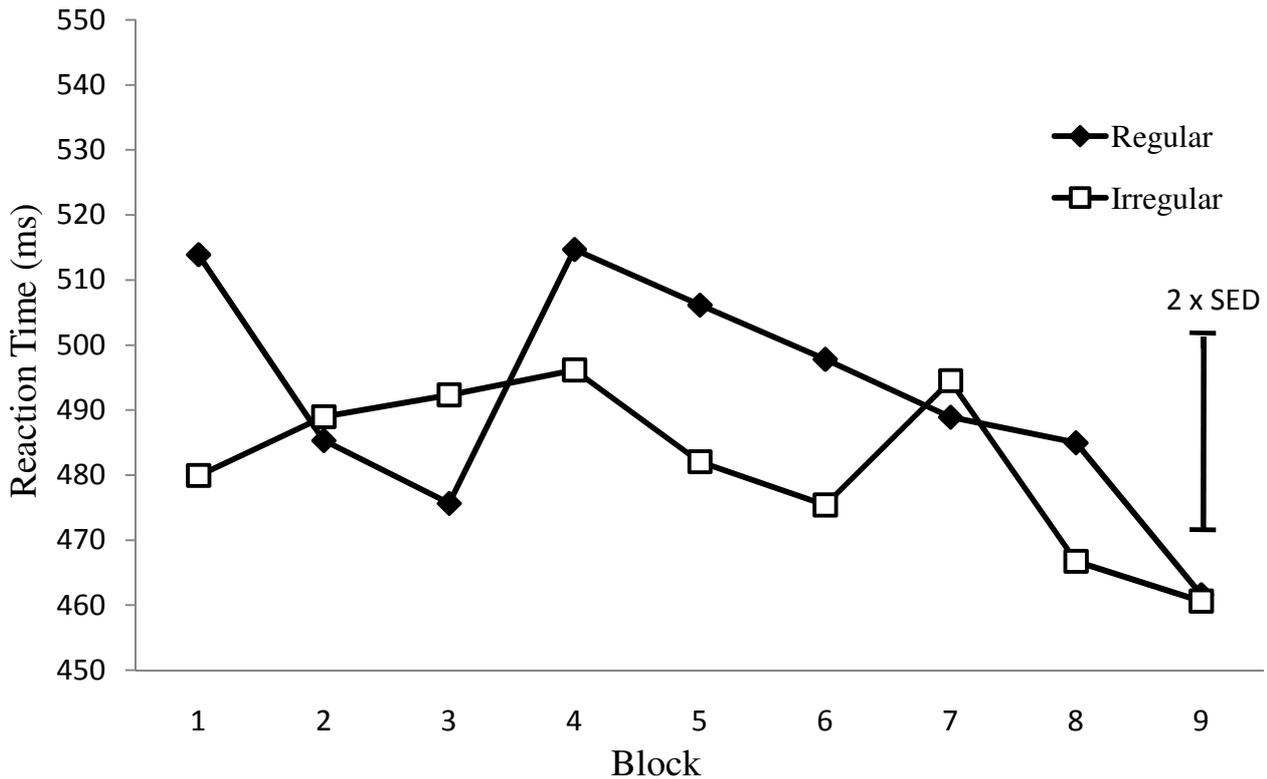


Figure 21. Average reaction times of the regular and irregular trials in the 9 blocks. The error bar represents the adjusted  $2 \times \text{SED}$  of the Regularity  $\times$  Block interaction.

To investigate this unexpected result, further factors that may have had a systematic effect upon the RT measures were assessed, namely the hand required for response, and the hand required for the previous response. As the trial sequence was fixed, such factors may have been confounded with regularity, meaning that the faster responding to irregular trials occurred independently of any learning. In general, the RTs were longer on trials where the previous key was pressed by the other hand than by the same hand of the given trial,  $F(1, 19) = 49.74, p < .001$  (Figure 22). Although this hand-shift effect was large,  $\eta^2_p = .72$ , the ratio of hand-shift to same-hand trials was 50:50 for both the irregular and the regular trials, and there was no evidence of a Regularity  $\times$  Hand-shift interaction,  $F(1, 19) = 3.49, p = .077, \eta^2_p = .16$ .

Right- and left-hand RTs were also compared; whilst it is reasonable to suppose that most of the participants were right-handed, dominant hand responses cannot be contrasted as

handedness was not recorded. Left-hand RTs were numerically slower ( $M = 500.78$ ,  $SD = 12.97$ ) than right-hand RTs ( $M = 473.18$ ,  $SD = 10.59$ ), although this effect did not reach significance,  $F(1, 18) = 3.25$ ,  $p = .088$ ,  $\eta^2_p = .15$ , nor did the Hand  $\times$  Hand-shift interaction,  $F(1, 18) = 4.21$ ,  $p = .055$ ,  $\eta^2_p = .19$ . The ratio of the left to right hand responses was approximately equal on the regular and irregular trials.

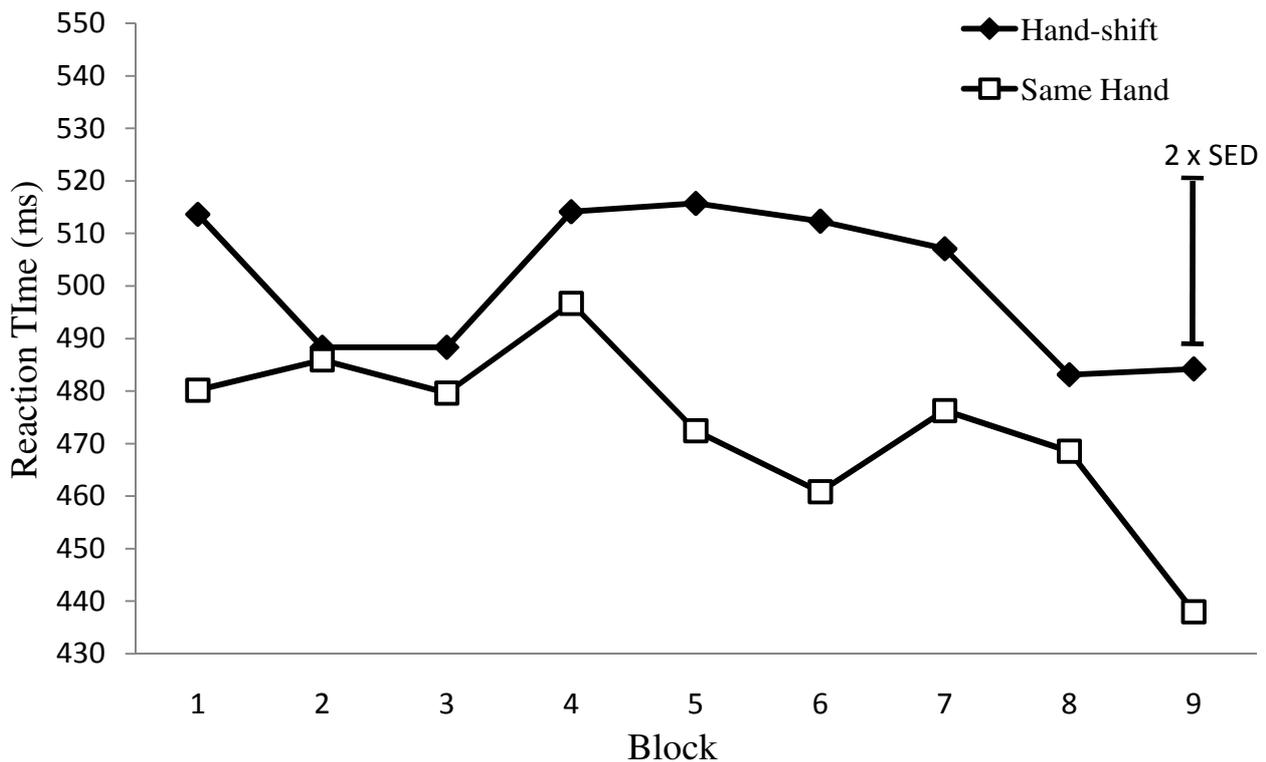


Figure 22. Average reaction times of the ‘hand-shift’ and ‘same hand’ trials in the 9 blocks. RTs were longer in trials where the previous key was pressed by the other hand than by the same hand of the given trial. The error bar represents the adjusted  $2 \times$  SED of the Hand-shift  $\times$  Block interaction.

Whatever the reason may be for the faster RTs on the irregular trials, it seems unlikely to arise from the reduced predictability of the locations due to the association between the colours and the locations, as it was in the opposite direction to that predicted, and did not increase across blocks. Therefore, analysis of the RTs did not show a pattern of results that could reasonably suggest that learning had occurred.

### *Post-Experimental Measures*

The Process Dissociation Procedure did not indicate that the participants could perform differently from the chance level (8) in either the Inclusion ( $M = 8.85$ , 95%  $CI = 6.77 - 10.93$ ), nor in the Exclusion part ( $M = 8.40$ ,  $CI = 7.01 - 9.79$ ), with no evidence of a difference between these conditions,  $ts(19) < 1$ . In the absence of any evidence of learning in either the RT data, nor in the PDP test, the Subjective Measures and the Post Decision Wagering measures could not be meaningfully analysed; these tests are designed to ascertain the conscious status of knowledge, and thus cannot be informative when there is no knowledge to discuss.

When the participants were asked about the predictability between the colours and the locations of the asterisks on a scale from 1 (*totally random*) – 5 (*totally predictable*) the group choose on average around the label '*mostly random*' ( $M = 2.35$ ,  $SD = .81$ ). In the verbal reports, however, 11 of the 20 participants mentioned that they had noticed some regularity between the colour frames and the target locations.

### Discussion

The aim of this study was to investigate whether probabilistic incidental learning happens in this design, producing faster detection of the target stimuli when the colour frames of the screen probabilistically predicted their locations. The RT results did not show any advantage for the regular trials over the irregular ones. In fact, the mean RT on the irregular trials was smaller than the mean RT on the regular trials. The reason for this is unclear. As a consequence of the task structure, there were fewer irregular trials (184) than regular trials (536), and it is possible that the fixed random order of these trials allowed hidden procedural or sequential biases to produce the observed regularity effect on reaction times. No such

biases were revealed during the analysis, nevertheless, if the regularity effect is not the result of learning, it is not relevant to the aims of the study.

### Experiment 2.2: Incidental Learning Study 2

One possible reason why no evidence of learning was detected in the previous experiment may have been that the delay between the appearance of the colour of the frame and the appearance of the asterisk was too short (200 ms) to reliably affect the RTs of target detection. Therefore, the previous experiment was replicated with a slightly longer, 300 ms delay between the onset of the colour frames and the appearance of the asterisks.

### Methods

#### *Participants*

The participants were 25 undergraduate students (13 female and 12 male;  $M = 21.84$  years,  $SD = 3.44$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Each participant received 1000 HUF (approximately 4 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the first half of the session.

#### *Materials and Procedure*

The materials and the procedure of the present study were identical to the previous experiment with the only exception that the asterisks appeared on the screen 300 ms after the appearance of the colour frames, instead of the previous 200 ms delay.

## Results

### *RT Measures*

Once again, the mean RT was faster again for the irregular ( $M = 465.32$  ms,  $SD = 10.59$ ) than the regular trials ( $M = 472.77$  ms,  $SD = 10.59$ ). The ANOVA model used in the previous experiment was applied to these data, with Regularity, Block, Hand and Hand-shift as factors. This confirmed that the irregular trials were significantly faster, as shown by a main effect of Regularity,  $F(1, 24) = 6.047$ ,  $p = .022$ ,  $\eta^2_p = .20$ ; There was also an effect of Block,  $F(3.12, 74.86) = 5.25$ ,  $p = .002$ ,  $\eta^2_p = .18$ ; and an interaction of Regularity  $\times$  Block,  $F(5.18, 124.30) = 10.02$ ,  $p < .001$ ,  $\eta^2_p = .30$ .

The mean of the right hand RTs ( $M = 466.48$  ms,  $SD = 10.50$ ) was faster than that for those made by the left hand ( $M = 471.61$  ms,  $SD = 10.13$ ), but this effect did not reach significance in the ANOVA model,  $F(1, 24) = 1.31$ ,  $p = .263$ ,  $\eta^2_p = .05$ . As in the previous study, the Hand-shift effect was considerable,  $F(1, 24) = 42.35$ ,  $p < .001$ ,  $\eta^2_p = .64$ , with no reliable Regularity  $\times$  Hand-shift interaction,  $F(1, 24) < 1$ .

A combined between-subjects comparison of the two studies showed no group difference,  $F(1, 42) = 1.41$ ,  $p = .242$ ,  $\eta^2_p = .03$ , indicating that setting the delay between the colours and locations from 200 ms to 300 ms did not cause any observable change in the pattern of measures (Figure 23). The joint analysis of the two groups showed a significant interaction between the Regularity and Hand-shift factors,  $F(1, 42) = 10.51$ ,  $p = .002$ ,  $\eta^2_p = .20$ , as well as an effect of Hand,  $F(1, 42) = 5.05$ ,  $p = .030$ ,  $\eta^2_p = .11$ . However, the latter had no effect on the regular and irregular RTs, Regularity  $\times$  Hand,  $F(1, 42) < 1$ .

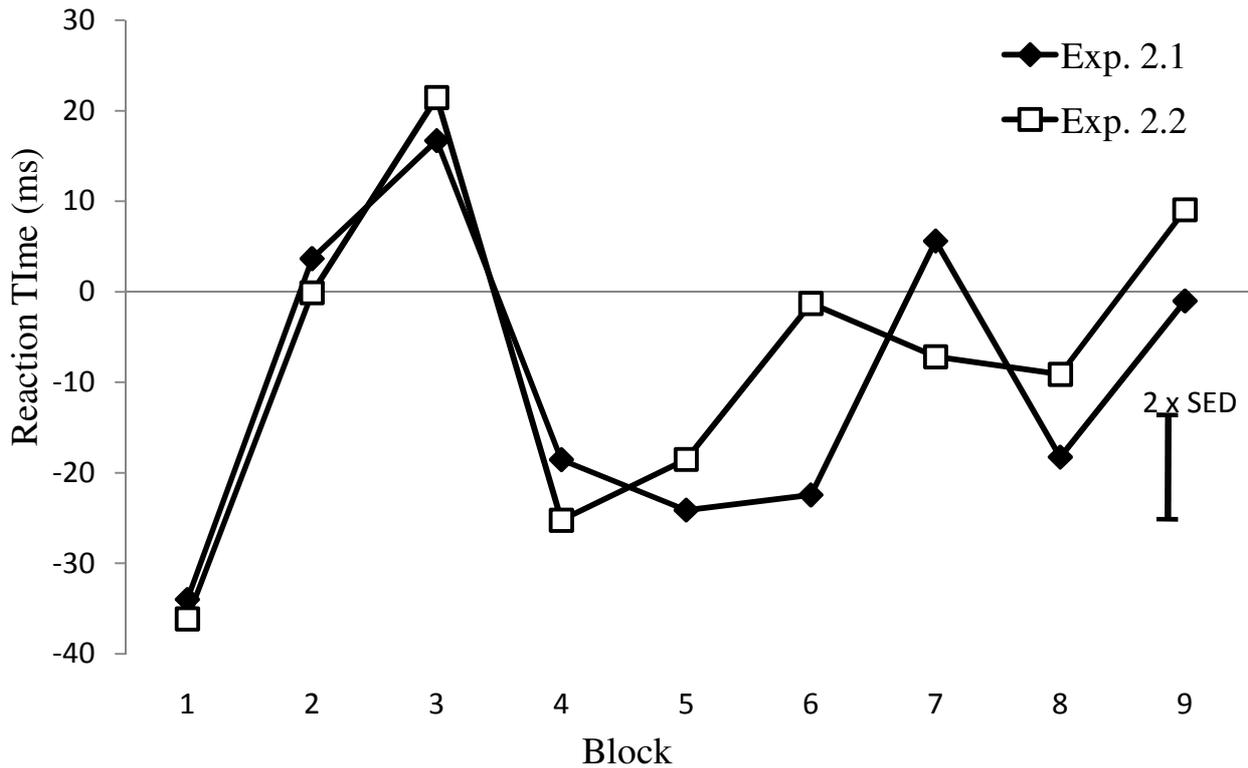


Figure 23. The difference scores of the previous (*Experiment 2.1*) and the present study (*Experiment 2.2*). The difference scores were computed by subtracting the mean regular RTs from the mean irregular RTs in each block. The error bar represents the adjusted  $2 \times \text{SED}$  of the Group  $\times$  Regularity  $\times$  Block interaction.

### *Post-Experimental Measures*

The PDP measures showed that the participants of the present experiment did not perform differently from chance level (8) in the Inclusion condition ( $M = 8.72$ ,  $SD = 4.08$ ),  $t(24) < 1$ . However, in the Exclusion condition this measure was difference from chance ( $M = 6.44$ ,  $SD = 2.31$ ),  $t(24) = -3.38$ ,  $p = .003$ ,  $d = .68$  (Figure 24).

The results of the Exclusion condition demonstrated explicit control over the choice. Interestingly, by comparison, the subjective measures and the PDW test did not indicate conscious knowledge. The average correlation between the confidence ratings and the performance on the Exclusion trials was not different from zero, one tailed  $t(20) < 1$ ; neither did the amount of money wagered on correctness of the Exclusion trials correlate with the

correctness, the average correlation coefficients was not significantly above zero, one tailed  $t(19) < 1$ .

According to the proposed *guessing criterion*, unconscious knowledge is indicated if, on those trials where the participants reported guessing, their performance is above chance. The guessing criterion did not detect unconscious knowledge, as the performance was not reliably above chance level (.25) on trials where the participants reported guessing,  $t(17) < 1$ .

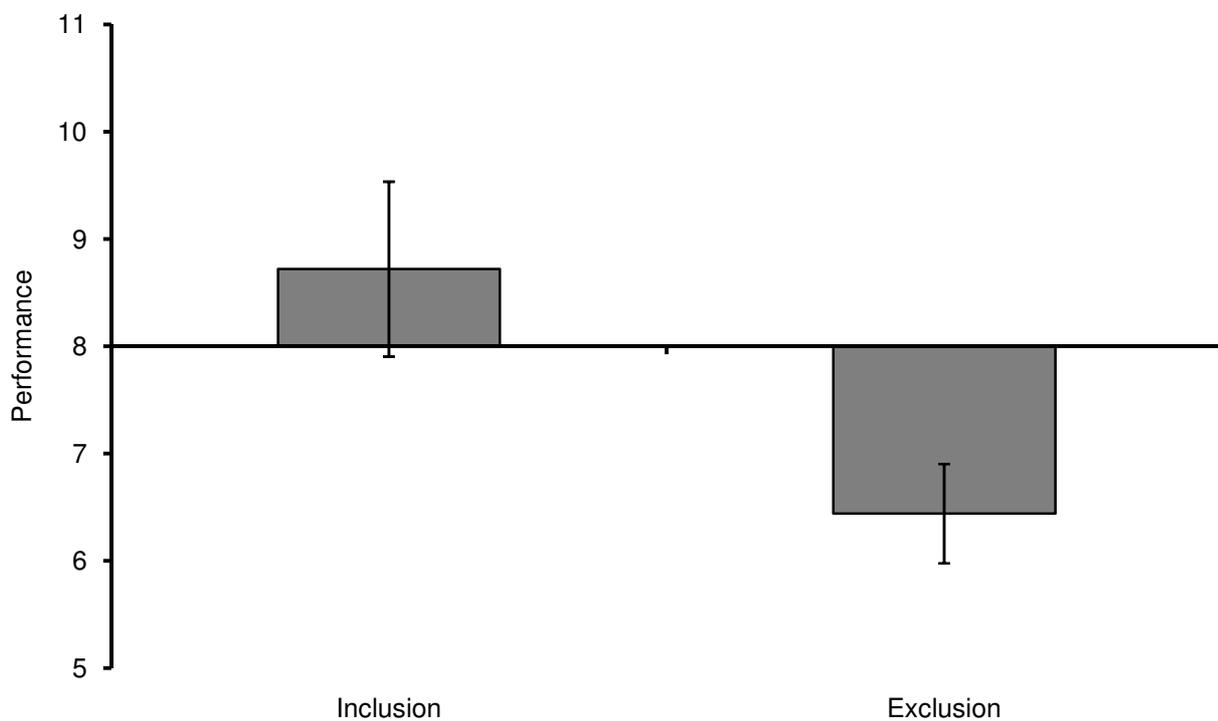


Figure 24. The Inclusion and Exclusion conditions of the PDP result. The chance level was 8 in the task. The error bars represent SEMs.

Taking the zero-correlation criterion and the PDW measure alone might suggest the conclusion that any knowledge used to perform on the PDP task was implicit. However, given that the PDP performance differed from chance only in that participants were able to avoid 'correct' responses in the Exclusion condition, a conclusion of implicit knowledge is not tenable: by the nature of the PDP task, this pattern requires the presence of conscious control.

In the Inclusion condition the amount the participants wagered significantly correlated with how risk averse they reported themselves to be in the paper questionnaire,  $r(25) = .40$ ,  $p = .049$ . The positive correlation indicates that the more risk-averse the participants were the less they were willing to wager.

When the participants were asked about the predictability between the colours and the locations of the asterisks on a scale from 1 (*totally random*) – 5 (*totally predictable*) the group choose in average around the label '*mostly random*' ( $M = 2.32$ ,  $SD = .85$ ). In the verbal reports, however, 5 of the 20 participants mentioned that they had noticed some regularity between the colour frames and the target locations.

## Discussion

In this experiment the delay between the onset of the colour frames and the target locations was 300ms instead of the 200ms in the previous experiment. In *Experiment 2.1*, learning was detected neither in the RT measures, nor in the PDP. Then it was speculated that the brief latency between the appearance of the cues and the target stimuli prevented any learning. The present study still showed no learning in the RT analysis, in that the participants did not respond to predictable 'regular' targets faster than the irregular ones.

By contrast, the exclusion measure of the PDP showed below-chance performance, indicating the presence of explicit knowledge; the longer delay was sufficient to trigger explicit learning about the cue-target associations. What is not clear, however, is why the irregular RTs were significantly *shorter* on average. Does it represent learning in some unexpected way, or is it the result of some artefact arising from the particular fixed order of the stimuli? The question can be answered by a test where the participants respond to the

same sequence of target stimuli in the same fixed order, without any possibility of learning from the colour frame cues.

### Experiment 2.3: Incidental Learning Study 3

The aim of the present experiment was to investigate whether the colour–location associations were responsible for any of the previously found behavioural patterns: that is whether the RT differences can indicate any learning in the task. For this control experiment the colours were removed, keeping other features of the test identical with the previous description. If the behavioural data under these circumstances is not different from the previous findings then it cannot be concluded that the previous measures reflected learning in any way.

### Methods

#### *Participants*

The participants were 25 undergraduate students (16 female and 9 male;  $M = 21.00$  years,  $SD = 1.63$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Each participant received 1000 HUF (approximately 5 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the first half of the session.

#### *Materials and Procedure*

The materials and procedures of the present test were the same as the previous description with the only exception being that the colour frames were removed, such that all the trials appeared with identical black screen background. Since there was nothing to learn about colours in this test, only the RTs were measured, the PDP, the SMs, the PDW and the paper questionnaire was not included in the design.

## Results

Analysis of the RTs was conducted using the same model as the previous studies. Trials were described as ‘regular’ or ‘irregular’ based upon whether those trials that were regular or irregular in the previous designs (in the absence of colours, regularity does not apply directly to the present test). Once again, on average, the RTs of the ‘irregular’ trials were faster again ( $M = 452.77$ ,  $SD = 6.89$ ) than the ‘regular’ trials ( $M = 462.00$ ,  $SD = 7.96$ ), with the corresponding main effect being significant,  $F(1, 24) = 11.13$ ,  $p = .003$ ,  $\eta^2_p = .32$ . There were also significant effects of Block,  $F(3.37, 78.42) = 4.97$ ,  $p = .003$ ,  $\eta^2_p = .17$ ; Hand-shift,  $F(1, 24) = 65.20$ ,  $p < .001$ ,  $\eta^2_p = .73$ ; along with a significant interaction between Regularity  $\times$  Block,  $F(4.04, 97.03) = 4.97$ ,  $p = .001$ ,  $\eta^2_p = .17$ .

The effect of which hand was used was not reliable in this study,  $F(1, 24) = 2.99$ ,  $p = .097$ ,  $\eta^2_p = .11$ , although unlike previous studies, handedness was recorded. For those with dominant right hand ( $n = 18$ ) the right hand key trials were still numerically faster, right:  $M = 453.65$  ms,  $SD = 7.75$ ; left:  $M = 461.60$  ms,  $SD = 8.51$ . For those with dominant left hand ( $n = 2$ ) the left hand key trials were faster, left:  $M = 452.62$  ms,  $SD = 17.52$ ; right:  $M = 456.55$  ms,  $SD = 25.73$ .

Crucially, a mixed model ANOVA including the data from this study with those from the previous study showed no main effects of Group, nor any interaction between Group  $\times$  Regularity,  $F_s(1, 48) < 1$  (Figure 25). These results confirm that the effect whereby irregular RTs were shorter did not indicate learning about colour–location associations; the predictive peripheral stimuli did not induce measurable learning effects in the RT data.

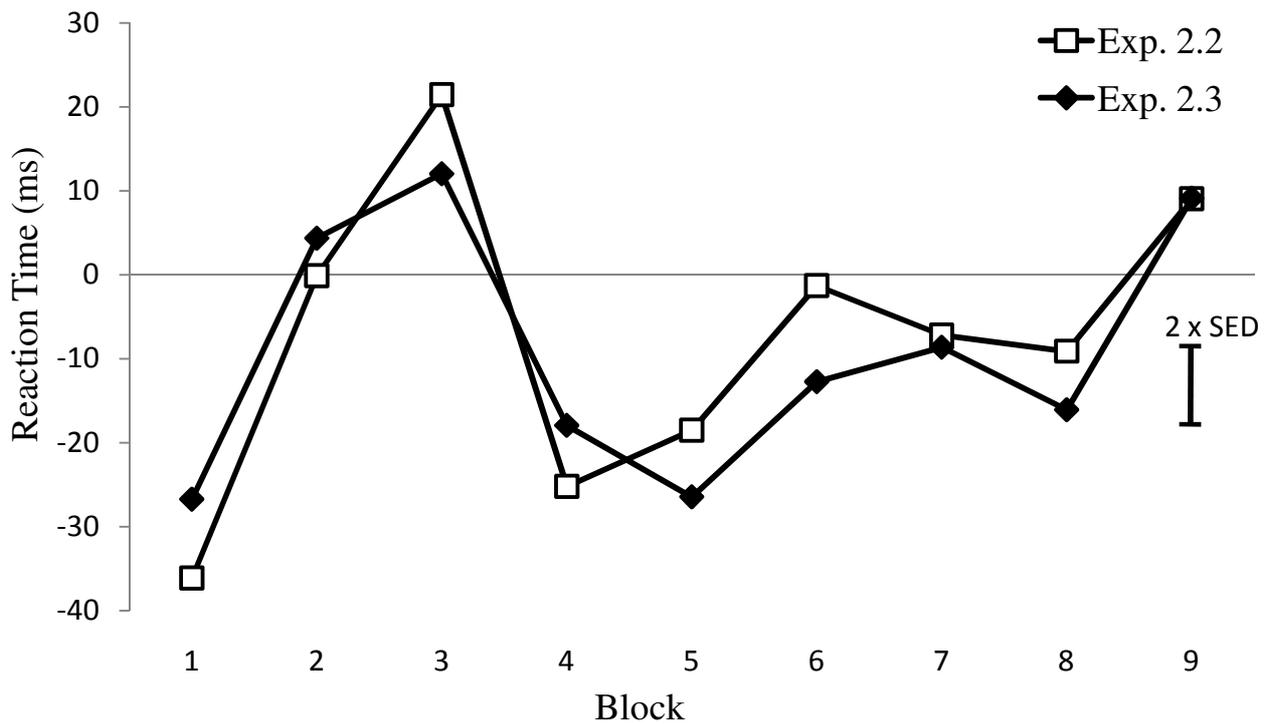


Figure 25. The difference scores of the previous (Exp. 2.2) and the present study (Exp 2.3). The difference scores were computed by subtracting the mean regular RTs from the mean irregular RTs in each block. The error bar represents the adjusted  $2 \times \text{SED}$  of the Group  $\times$  Regularity  $\times$  Block interaction.

## Discussion

The present experiment was conducted to provide a between-subject control group to explore whether the faster irregular trials observed in the previous experiments reflected learning to any degree. The results of the present work clarify that the faster responding to irregular trials were not, in fact, related to learning about the colour frames, but that they arose as artefacts of the stimulus sequence rather than through any learning between the stimuli of interest (colour frames and locations).

It seems, therefore, that in terms of RT measures, the participants in *Experiments 2.1* and *2.2* did not acquire any effective knowledge about the cue-target relationship in this incidental learning design. Was such a lack of observable learning due to the lack of conscious attention? This crucial question could be answered by a further test where the

participants are informed about the predictive nature of the colour frames, thus converting the task to a non-incidental design.

### Experiment 2.4: Attentional Learning

The aim of this study was to explore whether the previous lack of learning in the RT measures was due to the lack of attention to the colour frames. Participants in this study were, therefore, informed that the colours predicted the locations, and were urged to find these relationships.

### Methods

#### *Participants*

The participants were 23 undergraduate students (13 female and 10 male;  $M = 21.87$  years,  $SD = 3.68$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Data from one participant had to be discarded from the analysis because of the number of incorrect key presses represented an extreme outlier. Each participant received 1000 HUF (approximately 5 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the first half of the session.

#### *Materials and Procedure*

The materials and procedure of the present experiment were identical to the second experiment (when the colour frames were present). However, an extra piece of information was given to the participants in the introduction to the test. They were instructed: “*Pay attention to the colours in the frame of the computer screen. They predict the location of the next asterisk. Try to find out which colours best predict which asterisk.*”

## Results

### *RT Measures*

The irregular trials remained to be the ones with the faster RTs ( $M = 461.27$ ,  $SD = 13.07$ ) compared to the regular trial RTs ( $M = 470.78$ ,  $SD = 14.16$ ),  $F(1, 21) = 9.28$ ,  $p = .006$ ,  $\eta^2_p = .31$ . The effects of Block,  $F(1.96, 41.06) = 16.00$ ,  $p < .001$ ,  $\eta^2_p = .43$ ; Hand-shift,  $F(1, 21) = 39.92$ ,  $p < .001$ ,  $\eta^2_p = .66$ , were significant again.

Inclusion of a between-subjects factor in the ANOVA model allowed comparison of these data with those of the second (uninstructed) experiment. This analysis showed no reliable differences: no main effect of Group, nor Group  $\times$  Regularity interaction,  $F_s(1,45) < 1$  (Figure 26). This result indicated that the new instruction did not cause a reliably different pattern of results to that found in the second experiment. In other words, no evidence was found of directed attention modulating the amount of learning in the RT measures.

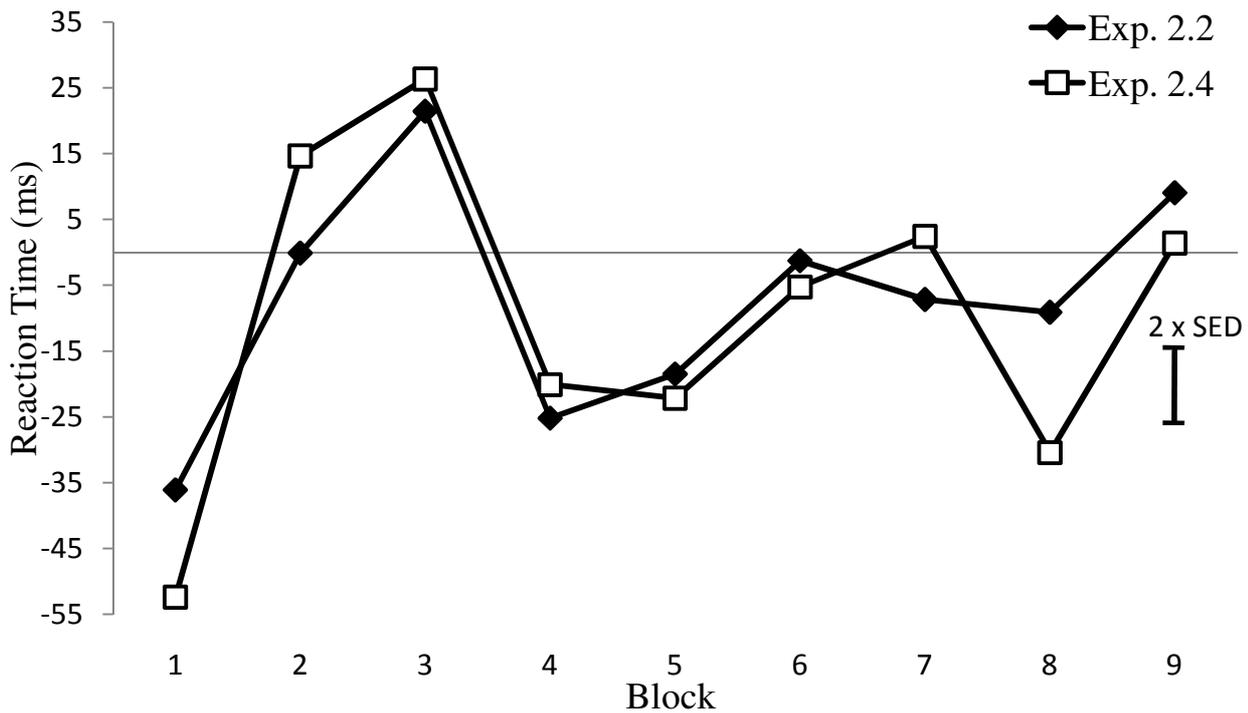


Figure 26. The difference scores of the previous (Study 2) and the present study (Study 4). The difference scores were computed by subtracting the mean regular RTs from the mean irregular RTs in each block. The error bar represents the adjusted  $2 \times \text{SED}$  of the Group  $\times$  Regularity  $\times$  Block interaction.

#### *Post-Experimental Measures*

The PDP test revealed that participants produced the correct response significantly more often than chance level (8) for Inclusion ( $M = 9.77$ ,  $SD = 3.78$ ),  $t(21) = 2.54$ , one tailed  $p = .010$ ,  $d = .54$ ; and significantly less often than chance in the Exclusion condition ( $M = 6.83$ ,  $SD = 2.93$ ), one tailed  $t(21) = -1.82$ ,  $p = .042$ ,  $d = .39$  (Figure 27).

Once again, for a further investigation of the conscious status of the knowledge revealed by the PDP test, the question was tested by analysis of the subjective measures and the PDW data.

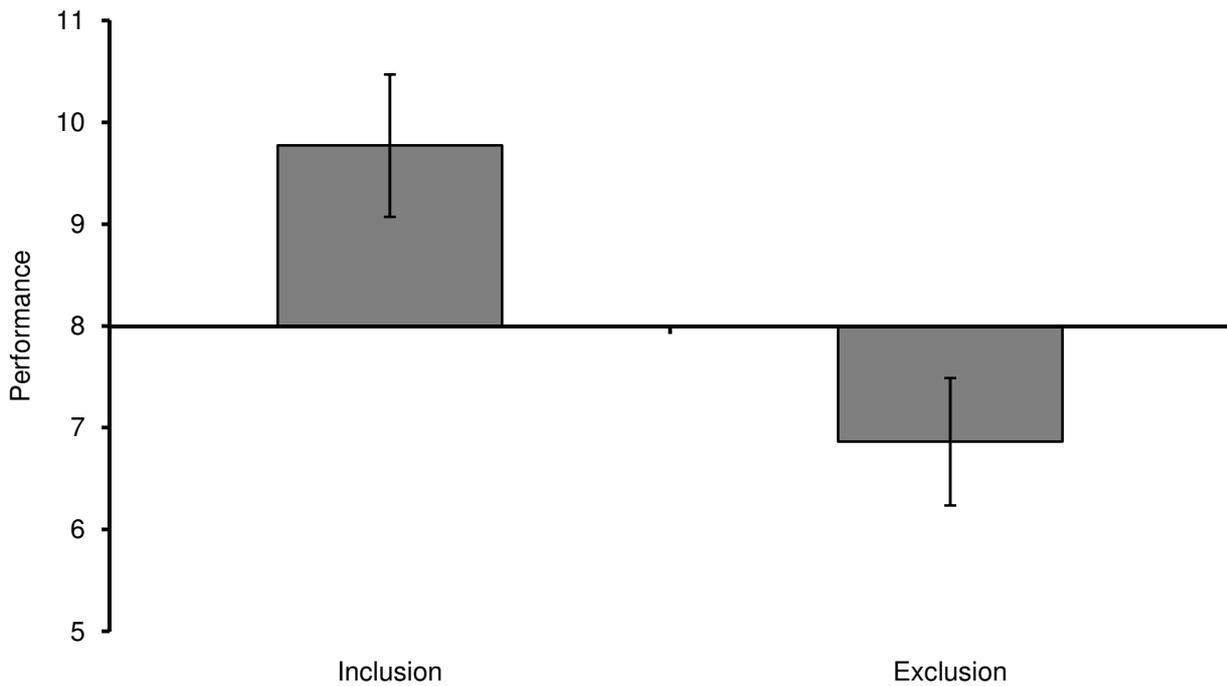


Figure 27. The Inclusion and Exclusion conditions of the PDP result. The chance level was 8 in the task. The error bars represent SEMs.

*Inclusion Condition.* Following the logic of the *guessing criterion* the proportion of correct responses was compared to chance level (25%) on those trials where the participant reported guessing in the Inclusion condition. This proportion was not significantly different from chance,  $t(19) = 1.29$ , one tailed  $p = .106$ ,  $d = .29$ .

The average correlation between the confidence ratings and the performance on the Inclusion trials was significantly above zero, (mean  $r = .13$ ,  $SD = .24$ ),  $t(22) = 2.60$ , one tailed  $p = .016$ ,  $d = .54$ . The amount of money wagered on correctness of the Inclusion trials did not correlate with the correctness, the average correlation coefficient was not significantly above zero, (mean  $r = .01$ ,  $SD = .29$ ),  $t(22) < 1$ .

*Exclusion Condition.* The guessing criterion did not indicate unconscious knowledge about the colour–location associations in the Exclusion condition either, ( $M = 22.79\%$ ,  $SD = 9.10$ ),  $t(22) < 1$ . The average correlation between the confidence ratings and the performance

on the Exclusion trials was not different from zero, (mean  $r = .04$ ,  $SD = .22$ ),  $t(20) < 1$ ; neither did the amount of money wagered on correctness of the Exclusion trials correlate with the correctness, the mean of the correlation coefficients was not significantly above zero, (mean  $r = .01$ ,  $SD = .22$ ),  $t(22) < 1$ .

Following the logic of SMs and the PDW the conclusion of zero correlation in the Exclusion condition would be the evidence of 'unconscious knowledge' in the PDP task. However, the logic of PDP claims that better-than-chance performance (i.e. successful avoidance of predicted responses) in the Exclusion condition is indicative of explicit knowledge.

## Discussion

This final experiment in this chapter showed that learning about the predictive relationships is possible in this design, although the learning was limited to the PDP test, the RT measures could not detect any effect of learning. One explanation for this lack of sensitivity could lie in the fact that the present design was considerably more complex than the previous similar tasks (e.g., Lambert and Roser, 2002), also it is possible that the delay between the identification of the colour frames and the appearance of the target stimulus was still too short to let anticipatory knowledge give an RT advantage.

Another interesting observation can be made by contrasting the results of the different tests of awareness. The below-chance exclusion performance indicated conscious control of the knowledge. However, the subjective measures and the PDW showed no evidence of conscious knowledge, which (according to their logic) is evidence for unconscious knowledge. One explanation is that the participants based their responses upon their intuition

in the exclusion condition – by avoiding the one about which they had a ‘hunch’ - and this was sufficient for the resulting good performance.

An alternative explanation is that the participants failed to exercise sufficient introspection about their confidence or accurately weigh the monetary risk of their wagering in each of the 64 trials of the PDP task, such that the subjective measures were insensitive to their level of explicit knowledge. Participants may have been indiscriminate with their confidence or wagering scaling, or they may have settled down at a certain point on the scale.

## Chapter Discussion

The aim of the experiments presented in this chapter was to investigate implicit learning in an incidental learning design. The incidental learning technique was a modified SRT task, with peripheral predictive cues. Based on the reports of previous similar studies (Lambert & Roser, 2001), it was hypothesised that the participants would learn the associations between the peripheral cues and the target locations while remaining unconscious of them.

In *Experiment 2.1* and *2.2* the colour of the frame predicted (probabilistically) the new location of the target stimulus, and thus provided an incidental learning situation. The instructions drew the attention of the participants only to the locations of the asterisks (except in *Experiment 2.4*). Thus, presumably, a voluntary, endogenous control of attention on the asterisks would not focus attentional processing upon the predictor colour frames. However, a possible caveat of this design could be that exogenous (reflexive) control of orienting (Posner, 1980) may have drawn attention to the change in colour of the peripheral colour frame, causing them to draw focal attention, as well as simply being perceived. The lack of

observable learning in *Experiment 2.2*, and the very limited effect of learning (PDP) in *Experiment 2.3* suggest that this was not the case. The frames had little or no impact on behavioural responding.

When comparing the RTs on regular trials with those on the irregular trials, no learning advantage was found for trials on which the asterisk was predicted by the colour frame. The overall absence of learning was confirmed in *Experiment 2.3* where the task was administered without the colour frames. The results of this latter experiment, where the target stimulus followed the previous fixed random sequence, were not reliably different from the data of the previous two experiments. The predictive colour frames of the task were within the visual field of the participants across the 720 trials of the task on the first two experiments and yet, contrary to the previous expectations, learning was not induced.

In *Experiments 2.2* and *2.4*, learning was measured in the forced choice PDP. This learning was more pronounced in *Experiment 2.4*, when the participants were informed about the relationship of the colours and target stimuli. Surprisingly, this learning did not facilitate RT difference between the regular and irregular trials. Also, the knowledge was measured as explicit in the PDP (successful avoidance of predicted locations) and by the positive correlation between the correct choices and the subjective confidence (at least in the Inclusion condition), but met the criteria for unconscious according to the PDW, the guessing criterion, and the subjective confidence (only in the Exclusion condition).

Overall, these results trigger two important questions: (1) why the participants did not show RT learning in this task, and (2) why the post-experimental tests did suggest different conclusions about the knowledge awareness of the participants.

The first possible reason why the participants did not show learning in terms of RTs in this task might be design specific. One difference between the present experiment and the

previous spatial cueing and attentional learning studies is that here a more complex design was employed. This modification seemed to be necessary to ascertain the incidental nature of the test. In Lambert and Roser's study (2001), where the two target locations were predicted by two peripheral colour cues 17 out of the 30 participants reported some awareness of the associations. It is possible, however, that the probabilistic contingencies of the 16 colours and the four locations in the present design was too demanding, and thus this complexity lead to learning measurable only by the PDP test.

Another reason for this lack of learning might be that these colour cue–target location associations are not prone to be learned that easily. The predictive features were colours in this task and not locations as in a traditional SRT task such as those in Chapter II. It has been argued in the visual perception literature that position and presence changes are qualitatively different from colour changes (Treisman & Gelade, 1980). Aginsky and Tarr (2000) found that while the position and presence can be automatically encoded the colour change needs active engagement of attention. This notion may be of key relevance to learning, since many researchers of implicit learning acknowledge that focused attention to the task stimuli is necessary for learning to happen (Dienes, Broadbent, & D. Berry, 1991; Jimenez & Mendez, 1999; e.g., A. S. Reber, 1993; Rowland & Shanks, 2006a).

The second question relates to the disagreement between the applied awareness tests. In the informed version of the experiment (2.4) both the inclusion condition and, critically, the exclusion condition of the PDP reflected an effect of learning. The inclusion performance was reliably above chance, while the exclusion performance was reliably below chance. This  $I > B > E$  pattern of results indicated the presence of explicit knowledge (Wilkinson & Shanks, 2004). Furthermore, the subjective confidence measures in the Inclusion condition indicated that the participants had higher confidence in their correct choices than in their incorrect choices. In contrast, the guessing criterion and the PDW and the subjective

confidence reports (in the Inclusion condition) did not indicate the presence of conscious knowledge. Above-chance behavioural performance in the absence of corresponding subjective reports is typically interpreted as evidence for unconscious knowledge.

Some authors (Q. Fu et al., 2008; Norman et al., 2006) have argued that successful, (below-chance) performance in the PDP Exclusion condition does not necessitate the presence of conscious structural knowledge. That is, the sense of *feeling-of-knowing* is enough for correct exclusion. If this argument is accepted, and the subjective measures of awareness are taken at face value, the learning observed in this chapter might indicate implicit knowledge.

On the other hand, there might be simpler explanations of the absence of correlation observed between these subjective measures and performance. An essential problem with PDW is that an absence of increasing betting on correct trials could be the result of risk aversion. Therefore, such a lack of correlation is not direct evidence of the absence of conscious processing. In accord with critics in recent literature (Schurger & Sher, 2008), this conjecture was supported by the present data in that the reported risk aversion positively correlated with the amount the participants were willing to wager.

In the present design it is also plausible that the participants may not have exercised accurate introspection about their confidence or precisely weighted the monetary risk of their wagering in each of the 64 trials of the PDP task. Some participants may have wagered or reported their confidence in a random fashion, or simply settled for a certain point on the scale.

A further peculiar finding in this study was that the participants produced faster RTs on the irregular trials than on the regular trials. This pattern of results, as shown in *Experiment 2.3*, could have not been the result of regularity, but rather some circumstantial

biases. It is clear, therefore, that this outcome arose from using the same fixed pseudo-random orders for each participant. This was an unexpected by-product of the original plan of this study, which involved a trial-by-trial analysis of the development of learning between participants; a fixed order was reasoned to be more suitable for this purpose.

The significant effects of hand-shift and dominant hand on RTs are of peripheral interest in this study, but are worth mentioning from a methodological perspective. In each of the experiments in this chapter the RTs were reliably faster on trials which did not require hand-shift, where the previous location was reported by the same hand. In a typical deterministic four choice SRT sequence the average probability of hand-shift is  $2/3$  and the probability of same hand location is  $1/3$  since the sequences avoid the consecutive repetition of any location. If, however, in a fully random control sequence any of the four locations have equal chance to follow the given location then the probability of hand-shift and same-hand locations will become equal,  $2/4$ . This dissimilarity can be advantageous for an unconstrained random sequence having more of the faster same-hand trials<sup>7</sup>. Therefore, any SRT study allowing for location repetition in the random control sequence would decrease the power of finding RT difference between the two types of sequences, whereas a design such as that used in Chapter II, where the ‘random’ sequences are made up of valid SOC sub-sequences, avoids this issue.

The other unplanned observation in this study was the measured faster right-hand RTs compared to the left-hand RTs. It is unsurprising that the dominant hand might be faster in SRT tasks because in general it is more trained in sequential skills (Deroost, Zeeuws, & Soetens, 2006). Functional imaging data suggests that the two hands have asymmetric cortical representations in the execution of movement selection, where during right hand

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<sup>7</sup> This pattern was confirmed in a post-hoc analysis of the RTs of the random sequences in Experiment 1.2 as well. The same hand RTs were reliably faster than the hand-shift RTs,  $t(12) = 2.40$ ,  $p = .034$ ,  $d = .07$ .

movements the left hemisphere representations are active, while during left hand movement both hemispheres are engaged (Schluter, Krams, Rushworth, & Passingham, 2001). Consequently, varying proportions of left- and right-hand responses across sequences would represent another source of uncounted biases in sequence learning tasks.

These four experiments aimed to assess awareness in an incidental learning design. The attempts failed to demonstrate learning in the typical implicit learning RT measure. In the PDP test some learning was measurable, which was clearest when explicit instructions were given. The results shed light on some central issues of peripheral learning and testing techniques of awareness assessment, as well as provide new support for the models of learning (e.g., Jimenez & Mendez, 1999) that claim that perception is not sufficient for implicit learning to happen, but that the stimuli must be selected by attention.

#### IV. SELECTIVE ATTENTION AND LEARNING

This chapter is dedicated to the investigation of the relationship between attention and learning. The central question of this research was to determine whether learning is a necessary consequence of selective attention.

In agreement with a considerable number of studies in the field, the results of the previous experiment suggested that selective attention on the relevant features of the related stimuli is *necessary* for learning of their association. The idea that attention is *sufficient* for learning (e.g., Logan & Etherton, 1994), however, represents a different suggestion: that whenever the relevant features of the stimuli are selectively processed (and baseline conditions are provided) their relationship will be learned. This criterion has two central aspects. Firstly, it tacitly infers that consciousness is not necessary for learning. Secondly, it claims that learning of an association between co-occurring stimuli is an obligatory consequence of attention on these stimuli. Before describing the experimental approach taken to address these questions of selective attention, awareness and learning, it is essential to review these concepts and what is already known about their relationship.

##### *Attention and Awareness*

According to the Higher Order Thought theory (HOT; Rosenthal, 2005), the term awareness refers to a knowledge that we are consciously aware of knowing. As described previously (Chapter III), the HOT theory states that a conscious mental state is a mental state of which we are conscious. To understand the implications of this statement for the learning literature, it is useful to understand what is meant by first- and second-order consciousness, and how these terms relate to each other.

There are generally two levels of consciousness discussed in the literature. *First-order consciousness* simply refers to the experience (*qualia*) or knowledge. A mental state is first-order conscious if it has experiential properties, even though this mental state is not represented by any of the agent's mental states (Block, 1995). The next (higher) level of consciousness is the *second-order consciousness*. A mental state is second-order conscious if we have a representation of currently having that mental state (Cleeremans, 2008). Therefore, meta-knowledge (knowing about knowledge) is a second-order mental state where we represent ourselves as having a first-order representation (in this case knowledge). In the implicit learning literature, the term conscious or explicit refers either to these second-order mental states (e.g., Dienes, 2008), or to a super-system with the ability to flexibly control behaviour (e.g., Frensch, 1998).

Like awareness, the term attention has no universally accepted definition either. In the learning literature, two main forms of attention are generally distinguished: *resource* (or *central*) *attention* and *selective* (or *input*) *attention* (Johnston & Dark, 1986). Resource attention is a limited resource that requires mental effort and relies on working memory. The function of selective attention, however, is to focus cognitive resources on the relevant stimuli while ignoring the irrelevant information (Lavie, Hirst, de Fockert, & Viding, 2004). Taking an example, when we are trying to listen to our friend at a party, we use our resource attention to follow what she is saying, but we use our selective attention to select her voice from the other voices in the room. This chapter will focus only on the role of selective attention in learning.

There is no general agreement in the literature about the relationship of attention and consciousness. Baars (1997) defined attention generally as the “*selection and maintenance of conscious contents*” (p. 363). This implies that properties of attention should be viewed as properties of consciousness. According to this view, consciousness and attention are still

different concepts: attention is an access to consciousness. To use his analogy, attention is like selecting a television channel and what appears on the screen is consciousness. In Baars' model attention can trigger consciousness and consciousness can also interact with attention.

In line with this approach, Cowan (1995) argues that we should regard the content of consciousness as equivalent to the focus of attention for the sake of being able to link it to some observable quantity. Cowan assumed awareness (in a healthy population) to be a unified entity, so in this sense we can talk only about something being in and out of awareness or attention. Under attention he refers to only 'new, unpractised selection' differentiating it from 'automatic selection'.

Other theorists have attempted to distinguish selective attention from consciousness. In Posner's (1993) attentional system model, attention is separated from consciousness and has three basic functions: "*orienting to sensory stimuli, particularly locations in visual space; detecting target events, whether sensory or from memory; and maintaining the alert state*" (2000, p. 617). Based on psychophysiological research, Koch and Tsuchiya (2007) claimed that selective attention and consciousness are two distinct brain processes. In their description, the two processes have substantially different functions. The functional role of attention is to select information of current relevance, while neglecting non-attended, irrelevant information: "*[t]op-down attention selects input defined by a circumscribed region in space (focal attention), by a particular feature (feature-based attention) or by an object (object-based attention)*" p.16. The function of consciousness is to perform tasks such as summarising all information, detecting anomalies, decision making, language, setting long-term goals, and rational thinking.

This distinction of functions implies that it is possible for attention and consciousness to work in opposition to one another. Analysing the processing of visual events and

behaviours, Koch and Tsuchiya (2007) provided examples of the four possible ways that attention and consciousness can interact. (a) *Attention with consciousness*: working memory, full reportability; (b) *No attention, no consciousness*: e.g., formation of afterimages, zombie behaviours; (c) *Attention, no consciousness*: e.g., priming, visual search; (d) *Consciousness in the near absence of attention*: pop-out in search, iconic memory, gist (Koch & Tsuchiya, 2007).

### *Attention and Learning*

Resource attention and selective attention seem to have a different influence on learning. The influence of resource attention upon implicit learning is often assessed by comparing performance on an implicit learning task with and without a concurrent secondary task (e.g., Frensch, Lin, & Buchner, 1998; Nissen & Bullemer, 1987; Shanks & Channon, 2002). Early works implied that implicit learning is unaffected by the burden of secondary tasks (e.g., Jimenez & Mendez, 1999; Mayr, 1996; Reed & P. Johnson, 1994). However, more recent studies have found that load on central attention impairs learning on the task (e.g., Shanks, Rowland, & Ranger, 2005). Therefore, an impairment due to central attention load seems to imply that the learning is not entirely implicit. It has been suggested, however, that the interference of a secondary task may be restricted only to the expression of learning, while not affecting the learning itself (e.g., Deroost, Coomans, & Soetens, 2009; Frensch et al., 1998).

Selective attention, on the other hand, seems to be resistant to perceptual load or input complexity in implicit learning (Rowland & Shanks, 2006a, 2006b). That is, under increased selection difficulty, performance is not decreased if the selection is purely perceptual (Deroost et al., 2009). These findings may be explained by *perceptual load theory* (Lavie et al., 2004), which describes two mechanisms of selective attention: an *early passive selection*

that focuses attention to task-relevant stimuli when the perceptual load is high, and a *late selection* that is needed to ignore task-irrelevant stimuli if the perceptual load is low and in the case that the spare perceptual capacity would otherwise “*involuntarily spill over to the task-irrelevant stimuli*” (Deroost et al., 2009, p. 85) without executive control. The proposed first, perceptual selection mechanism leaves performance unaffected by high perceptual load since irrelevant distractors are not perceived. The second, active selection mechanism depends on higher cognitive function and is, therefore, of limited capacity (Lavie et al., 2004). This theory might explain the seemingly contradicting results showing that the performance on sequence learning tasks can be unaffected (e.g., Rowland & Shanks, 2006a) or even increased (Deroost et al., 2009) by high perceptual load, but is impaired by cognitive load (e.g., tone-counting: Nissen & Bullemer, 1987).

As described in Chapter III, Lambert and his colleagues used a spatial cueing technique to investigate the role of *derived attention* in learning. In the spatial cueing research the Jamesian notion of *derived attention* is used to “*describe the propensity of cue stimuli to capture attention, by virtue of learned associations between cue attributions and target location*” (Lambert, 2003, p. 272). Mere exposure to a predictive relationship of cues and target locations is enough for learning to occur, processed by either overt or covert attention (Lambert & Duddy, 2002; Lambert et al., 1999; Lambert & Roser, 2001; Lambert, Roser, Wells, & Heffer, 2006).

A series of recent studies demonstrated that classic implicit learning tasks require selective attention (Hoffmann & Sebold, 2005; Jimenez & Mendez, 1999). Jimenez and Mendez (1999) administered a probabilistic Serial Reaction Time task (SRT) where the participants had to report the appearance of the stimulus on the screen by pressing the corresponding keys. They found that the predictability of the shape of the stimuli contributed to the performance only when the task instructions directed attention to the given dimension

of the target stimuli. These findings suggest that automatic associative learning happens only among those events that are attended to in the task (Stadler, 1995).

The importance of selective attention in implicit learning has been demonstrated with negative priming designs (Cock, D. C. Berry, & Buchner, 2002; Deroost, Zeischka, & Soetens, 2007). Negative priming in sequence learning refers to the observation that performance is impaired if to-be-learned sequences have previously been ignored. The negative priming effect can be explained by the suggestion that the selective attention required to discriminate between relevant and irrelevant stimuli results in learning, even for irrelevant stimuli (Cock et al., 2002; Deroost et al., 2007).

Results such as these have led many researchers to view associative learning as an automatic process that associates all the concurrently present components in the focus of attention (e.g., Frensch & Miner, 1994; Pacton & Perruchet, 2008; Logan & Etherton, 1994). Pacton and Perruchet (2008) proposed an attention-based associative account for (nonadjacent dependency) learning in which they claim that “*selective attention is a necessary and sufficient condition for learning to occur*” (p. 92). By the word *sufficient* the authors mean that “*no other condition is required, neither in participants’ disposition (such as their intention to learn) nor in the external display (such as the spatial or temporal relationship between the events)*” (p. 82). The authors go on to clarify that “*this proposal is consonant with the position [... that views] construed associative learning as an automatic process that associates all the components that are simultaneously present in the attentional focus*” (p. 93).

This idea resembles Treisman’s binding theory, which is described as “... *focal attention provides the “glue” which integrates the initially separable features into unitary objects*” (Treisman & Gelade, 1980, p. 98). Similarly, the Obligatory Encoding principle of

Logan's Instance Theory predicts that "... *people will learn the co-occurrences they attend to. Attention is sufficient for learning co-occurrences; it may even be necessary.*" (Logan & Etherton, 1994, p. 1023).

### *The Present Study*

The work to be presented in this chapter will focus on two aspects of these claims. Firstly, the joint attention that is assumed necessary for learning will be interpreted narrowly as the concurrent activation of the representation of the cue and the target stimuli (rather than a representation of their association). It is difficult to find an operational definition of attentional activation which will ensure that stimuli will be 'simultaneously present' in the attentional focus. Even if two stimuli are positioned on the same screen, they may be attended to in succession, separated by the time taken for saccadic eye movements between the two locations. In practice, however, if attention is the enhanced activation of some information (a subset of working memory), then simultaneity is assumed unless the information exceeds capacity (3 to 5 chunks), or the persistence time (activation fading: 10 to 20 s), limits of working memory (Cowan, 1999).

Secondly, the notion of attention being sufficient for learning will be interpreted as implying that a participant's intention to learn about or awareness of the relationship between the presented features is not needed.

The aim of these experiments is thus to test the hypothesis that learning an association between two stimuli is a compulsory consequence of the concurrent processing of each of the two stimuli. To this aim a new test, the Selective Attention Learning Task (SALT), was devised. During the SALT, participants were performing two tasks. The first task was to detect the location of a target stimulus appearing in one of the four corners of the screen and to report the appearance by key-pressing. In a later part of the task a secondary task was

introduced. Between the target detection trials, a coloured geometrical form appeared in the middle of the screen. Each form was one of the nine possible combinations of three colours and three geometrical shapes. The participants were asked to detect specific shape-colour combinations and respond by key-press. The two tasks were related in that the identity of the shapes was predictive of the location of the target cues.

Participants were initially not informed about the relationship between the shapes and the target location. The key manipulation involved some participants subsequently being informed that the colour of the forms predicts the target locations; these participants were not informed about the predictive power of the shapes (the features were counterbalanced for another group of participants).

Since the participants were asked to be as fast and as accurate as possible in responding to the targets, the RTs for target detections act as a measure of the degree to which learning had allowed the target location to be anticipated. If selective attention is *sufficient* for learning then selecting the relevant features of the cue and target stimuli should result in learning of their association. As the informed (e.g., shape) and uninformed (e.g., colour) information were equally taking part in the detection task, in the case of above-chance detection performance the relevant stimuli must have been attended to.

Should this learning happen, RT decrease is expected to be found for the location detection trials preceded by predictive cues, relative to the trials following unpredictable control cues. By combining predictive and non-predictive features, RTs could be assessed after presentation of cues whose predictive power derived solely from the 'informed' perceptual dimension and compared with RTs for equivalent stimuli which were predictive only on the basis of the 'uninformed' dimension.

### Experiment 3.1: SALT Study 1

In the first experiment of this study, the participants received the SALT task in two groups. One group was informed about the predictive power of either the colour or the shape within the test, while the other group was not informed about any association between the cues and target stimuli. Participants' conscious knowledge about the cue-target associations was assessed in a variety of post-experimental tests: PDP, PDW, Confidence Ratings, Structural Knowledge Assessment and a Verbal Report test.

#### Methods

##### *Participants*

The participants were 63 undergraduate students (35 female and 28 male  $M = 23.06$  years,  $SD = 3.90$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Five persons had to be discarded from the analysis due to not having followed the test instructions<sup>8</sup>. Each participant received 1500 HUF (approximately 6 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the first half of the session.

##### *Materials and Design*

The task contained two types of trial: coloured cue trials and visual search task (VST) trials. On VST trials, the computer displayed four filled black circles which appeared in square location markers in each of the four corners of a gray computer screen. Three circles were distractor stimuli, 50 pixels in diameter, and the fourth was the target circle, 12% larger than the distractors.

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<sup>8</sup> Three persons did not complete the whole test, one person misunderstood the instructions and another person produced not enough valid values for the analysis.

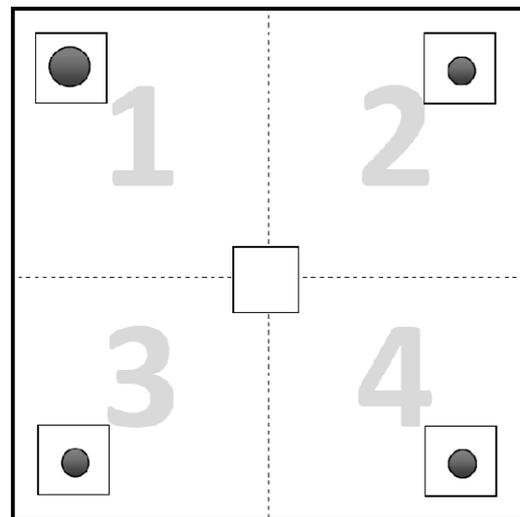
On the detection task trials, cue forms were presented in the centre of the screen which predicted the location of the target in the following VST trial. The coloured cues were formed by all possible combinations of three shapes (square, cross, triangle) and three colours (red, blue, yellow). The resulting nine different cues predicted the possible locations of the target stimulus in the following VST trial (Table 6). Colours I and II, and Shapes I and II always indicated that the target cue on the following VST trial would appear on a specific half of the screen (e.g., Shape I indicates left, Shape II indicates right; Colour I indicates top, Colour II indicates bottom). If the vertical position was indicated by shape, the colours indicated horizontal position, and vice versa. Shape III and Colour III had no predictive power. The shapes and colours acting as I, II and III were counterbalanced across the participants.

Table 6  
The Relationship of the Cues to the Target Stimuli

A

		SHAPE		
		I	II	III
COLOUR	I	<b>1</b> Cue 1	<b>2</b> Cue 2	<b>1,2</b> Cue 3
	II	<b>3</b> Cue 4	<b>4</b> Cue 5	<b>3,4</b> Cue 6
	III	<b>1,3</b> Cue 7	<b>2,4</b> Cue 8	<b>1,2,4,5</b> Cue 9

B



*Note.* Table 6A displays the relationship of the nine possible combinations (cues) of the three shapes and three colours to the target locations of the VST. The target locations are the four corners of screen in the order as shown in the figure (B). The bold numbers in A correspond to the possible locations of the target stimuli as numbered in B.

The nine cues were grouped into different types reflecting the degree to which they predicted target cue location (See Table 7). The four possible combinations of Colours I and II, and Shapes I and II, were labelled Type A stimuli, as they fully predicted the location (corner) of the target stimuli and, thus, had the same predictive power. Type B stimuli were Cues 3, 6, 7, 8 (containing either Shape III, or Colour III, but not both) which determined only which half of the screen where the target stimulus would appear in (top or bottom; left or right). Cue 9 (the combination of the nonpredictive Colour III and Shape III) was Type C, followed equally often by all four target locations. Type D cues were cues made of unfilled Shapes I and II, or circles filled with Colour I or II, which appeared only in the PDP phase.

During the main task, participants were also required to perform a detection task which required responses to two Type A stimuli: the combinations of Colour I and Shape I, and Colour II and Shape II. These stimuli, whose presentation was tied to an action in the dual-task phase, were denoted Type A1. The action tied to Type A1 was the press of the four keys in the detection task. The remaining Type A stimuli (combinations of Colour I and Shape II, and Colour II and Shape I) were not action-tied, and denoted Type A2.

During the task, participants in the Informed group were instructed about one of the two predictive dimensions (e.g., some colours predict that the next targets will appear on the top or bottom of the screen). In the case of the Informed group those Type B & D cues for which the predictive dimension matched this information were denoted Type B1 & D1; for Types B2 & D2 the predictive features were those about which the participants were not informed. For the Uninformed group there was no distinction within Types B & D. These stimulus types are summarised in Table 7.

Table 7

## Types of Cues by Predictive Power and Action

Type	Cue	Predictive Power	Description
Type A1	1, 5	Full	Action-tied
Type A2	2, 4	Full	Not action-tied
Type B1	3, 6, or 7, 8	Half	Informed feature is predictive
Type B2	3, 6, or 7, 8	Half	Uninformed feature is predictive
Type C	9	None	Not predictive
Type D1	-	(Half)	Informed feature alone
Type D2	-	(Half)	Uninformed feature alone

*Note.* Full predictive power determined the exact location (corner) of the target stimulus after the cue. Half predictive power means that the cue predicted only the side of the screen where the stimulus would appear. Type D cues appear only in the PDP test.

*Procedure*

The test consisted of three phases which was followed by a PDP test. The first (Practice) phase of the task involved VST trials only. The participants were instructed to detect the large (target) circle in one of the corners in each trial by pressing down one of the four fingers placed on the four corresponding keys: Alt (left thumb), W (left index finger), AltGr (right thumb), and P (right index finger). They were told to be as quick and as accurate as possible with the key presses. The first phase of the test consisted of 45 randomly ordered trials. The stimuli stayed on the screen for 1000 ms or shorter in the case of accurate

detection. After each accurate detection the next trial appeared with a 500 ms delay, during which time the target locations remained empty. The participant was allowed 3000 ms to respond, after which time a message appeared on the screen informing them that their time had run out.

In the second phase a Dual Task was presented. This Dual Task included 450 pairs of cue trials and VST target trials presented in alternation (Figure 28). A secondary task instruction was introduced at the beginning of this phase: to press all the four keys together if a cue appearing in the centre of the screen before each trial is one of two named cues. The two target cues were the two stimuli of Type A1 (combinations of Shape I and Colour I, and Shape II and Colour II). Verbal descriptions of the two target cues remained displayed at the top of the screen throughout. The cues stayed in middle of the screen for 1400 ms or shorter in the case of accurate detection. Each cue appeared on the screen 50 times in random order.

The target locations appeared on the screen after the disappearance of each cue with a 500 ms delay. When the detection of the target cues was missed a message appeared on the screen informing them about their miss. The total number of cue detection responses, the number of cue detection, and the percentage of cue targets detected were constantly displayed on the left side of the screen to motivate accuracy. The next trial started after the detection of the target stimulus with a 300 ms delay during which time the target locations remained empty.

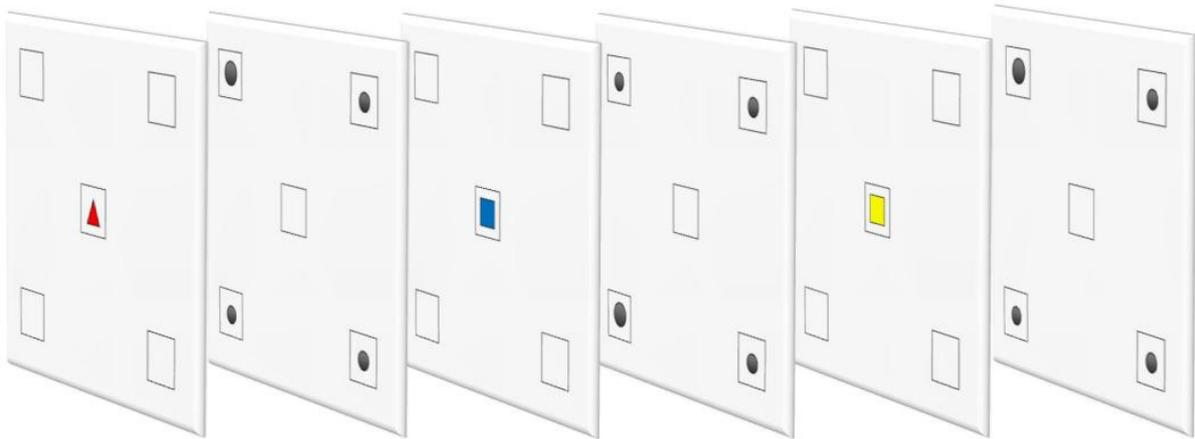


Figure 28. An example of cue and stimuli trials from the second phase of the experiment. The cue in the middle of the screen predicts the location of the target-stimulus (greater filled circle) in the following trials as described in Table 6.

After each block of 45 trial pairs, which contained 5 presentations of each cue, the participants received feedback about their performance in the previous block and had a short break. In the second break of this phase, half of the participants (Informed group) were told that they could be faster in the task if they pay attention to the relationship between one aspect of the cues (shape for half the group, colour for the remainder) and the location of the target-stimuli. For example, a participant might be informed that the shapes of the cues determine whether the following target stimuli appear at the top or at the bottom part of the screen. The remaining participants (Uninformed group) were not informed about the relationship between the cues and the location of the target stimuli.

The third phase (Single Task) of the test was similar to the second phase without the additional dual task requirement to make a response to Type A1 stimuli. The coloured cues still appeared on the middle of the screen between the VST trials, but the participants were required only to detect the VST target circles. This third phase consisted of 90 randomly ordered cue-stimulus pairing trials.

After the main task, the participants were presented with a test based on the logic of a PDP. In the inclusion condition, the previously seen cues or empty (colourless) shapes or

colours appearing in a new shape (circles) were presented in the middle of the screen. The instruction was to indicate in which corner the target-cue would appear after the presented cue by pressing one of the corresponding keys. The cues were presented in random order, each cue appearing twice. After each prediction the participants were asked to rate their subjective confidence in their decision (50 – 100%), or (on every second trial) to wager how much they would bet (50 – 100 HUF) that their decision was right, and then to report whether their decision was based more on memory or on guess.

The exclusion condition of the PDP was identical to the inclusion condition, with the exception that the participants were asked to show where the target-cues would *not* appear after the presented cues.

After the experiment, the participants were asked to fill out a one-page paper questionnaire about their verbalisable knowledge and their risk aversion (Appendix F). The verbal report question asked “*If you noticed any regularity in the appearance of the bigger filled circles then what was it and when did you notice it?*” The participants also had to report what risk they would take for different monetary gains. On each such trial, participants were asked to choose between 100% certainty of winning 1000 HUF (10 pounds in the English version) and 50% chance of winning a larger amount. The value of the larger amount began at 1500 HUF and increased by 500 HUF (5 pounds) with each trial.

## Results

### *Detection Task*

The aim of the detection task in the Dual Task phase was to induce selective attention to the relevant features. Performance in this detection task showed that the participants followed the instructions and correctly categorised the selected cues. For the Uninformed

group, Hit Rate 94%, False Alarm 7%. For the Informed group, Hit Rate 93%, False Alarm 5%. There was no evidence that the two groups differed in their hit rate, nor false alarm rate,  $t(56) < 1$ . These results confirm that in both groups the participants attended to the relevant features of the cues.

### *Reaction Time Measures*

If participants in this experiment learn about the relationship between the cues (coloured shapes) and the target stimuli then one way in which this may be indicated is in terms of a difference in RT for detecting the target stimuli after cues with different predictive power. Figure 29 shows the RTs from the third phase of the experiment, where the task of the 90 randomly ordered cue-stimulus pairing trials did not require active categorisation. These means were analysed by means of a Group (Informed versus Uninformed)  $\times$  Type (A1, A2, B, C) mixed ANOVA. A significant effect of Type,  $F(1.89, 105.53) = 16.65, p < .001, \eta^2_p = .23$ , confirms that some learning occurred in that different cues produced different RTs. Figure 29 suggests that the learning effects are different in the Informed and Uninformed groups, confirmed by the interaction of Group  $\times$  Type,  $F(1.89, 105.53) = 22.82, p < .001, \eta^2_p = .29$ . In fact, the Uninformed group alone showed no evidence of learning (main effect of Type,  $F < 1$ ).

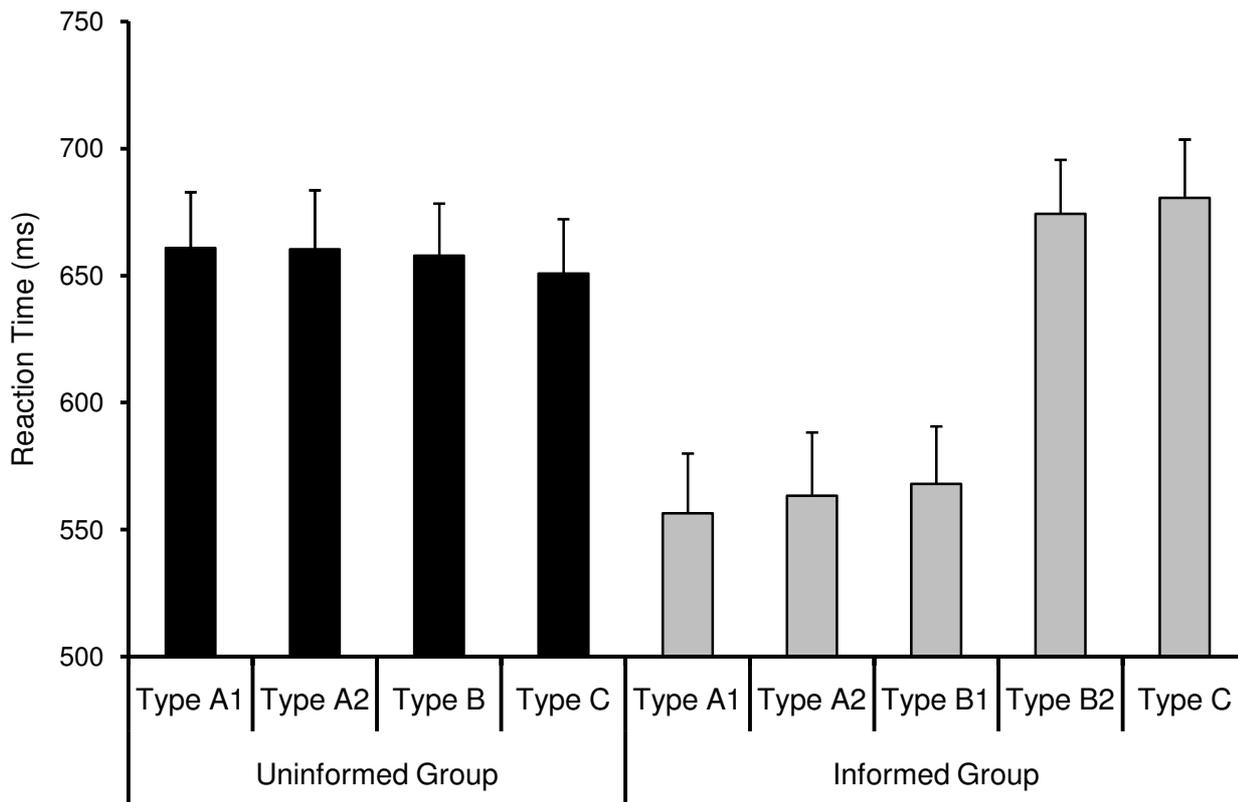


Figure 29. Mean RTs of the two groups in the five types of trials in the Single Task phase. For Type A1 and A2 the cue – target relationship was fully deterministic, but A1 was also action-tied; for Type B trials only one of the features (shape/colour) was predictive. For the Informed group on Type B1 trials the predictive feature was the one that they were informed about; on Type B2 trials the predictive feature was the one that they were not informed about. For the Uninformed group Type B1 and B2 trials were equivalent. Type C cues had random relationship to the target locations. The error bars represent SEMs.

A more detailed analysis of learning in the Informed group was performed by means of pairwise comparisons, which showed that participants were faster on Type A1, A2 and B1 than on the random Type C,  $t(26) \geq 5.54$ ,  $ps < .001$  (Bonferroni corrected  $\alpha = .01$ ),  $ds \geq .87$ . Despite being action-tied in the Dual Task phase, RTs after the Type A1 cues were similar to those after Type A2 cues in the third, single-task phase,  $t(26) < 1$ . There was no evidence of a difference between Type A and B1 RTs,  $t(26) < 1$ , suggesting that the participants were as fast following ‘half’ predictive power as on the ‘full’ predictive power trials.

As it was described above, the Informed group were told that they could be faster with the detection of the target stimuli if they notice that one feature (e.g., colour) of the cues can help predict the stimuli to appear on one side (e.g., top or bottom) of the screen (the conditions were counterbalanced). The crucial hypothesis in this design was that attention to one piece of information about the task (e.g., colour of cue – vertical stimulus position relationships), would preclude attention to the other, equivalent relationship between the cues and target stimuli (e.g., shape of cue – horizontal stimulus position relationships). If attention to the relationship is required for learning, this will lead to selective learning of the informed relationship. Alternatively, if participants learn purely from the selective processing of cue features (induced by the detection task) and the target locations, then learning should be similar for both the informed and non-informed feature relationships.

The key test trials were Type B, where the stimuli were predicted only by the colour (Cue 3, 6) or only by the shape (Cue 7, 8) features. For the Informed group, Type B1 trials were those where the predictive feature was the one that they were informed about; Type B2 trials were those where the predictive feature was the one those that they were not informed about. In accord with the hypothesis, participants in the Informed group were much faster on Type B1 ( $M = 568.04$ ,  $SD = 115.49$ ) trials than on Type B2 trials ( $M = 674.27$ ,  $SD = 110.08$ ),  $t(26) = 6.31$ ,  $p < .001$ ,  $d = .94$ . In fact, the mean RT for Type B2 was not significantly different from that of the random Type C,  $t(26) < 1$ . These results show that although participants in the Informed group showed learning, it was selective to the informed relationship: there was no evidence of learning about predictive features about which they were not informed.

One could reasonably argue that it is possible that the Uninformed group did not show learning in the final Single Task phase because the removal of the dual-task categorisation requirement reduced attention to the cues. The analysis of the RT differences in the Dual

Task learning phase, however, argues against this account. Analysis of the Dual Task phase (Type A1 trials were excluded from this analysis since their RTs were biased by additional key presses<sup>9</sup>) showed a significant Group  $\times$  Type interaction,  $F(1.57, 87.79) = 16.34, p < .001, \eta^2_p = .23$ , with no evidence of any difference between responses to the different stimulus types in the Uninformed group,  $F(1.81, 54.37) = 2.24, p = .12, \eta^2_p = .07$ . As for the Single Task phase, for the Informed group both Type A2 and Type B1 received faster responses than the random trials (Type C), both  $t(26) \geq 4.30, ps < .001, ds \geq .45$ , whereas Type B2 trials were not different in speed from Type C,  $t(26) < 1$ , (Figure 30). These results indicate that the learning measured in the final test phase was already measurable during the learning phase, with no evidence of learning in the Uninformed group, despite the requirement that they attend to the relevant stimuli.

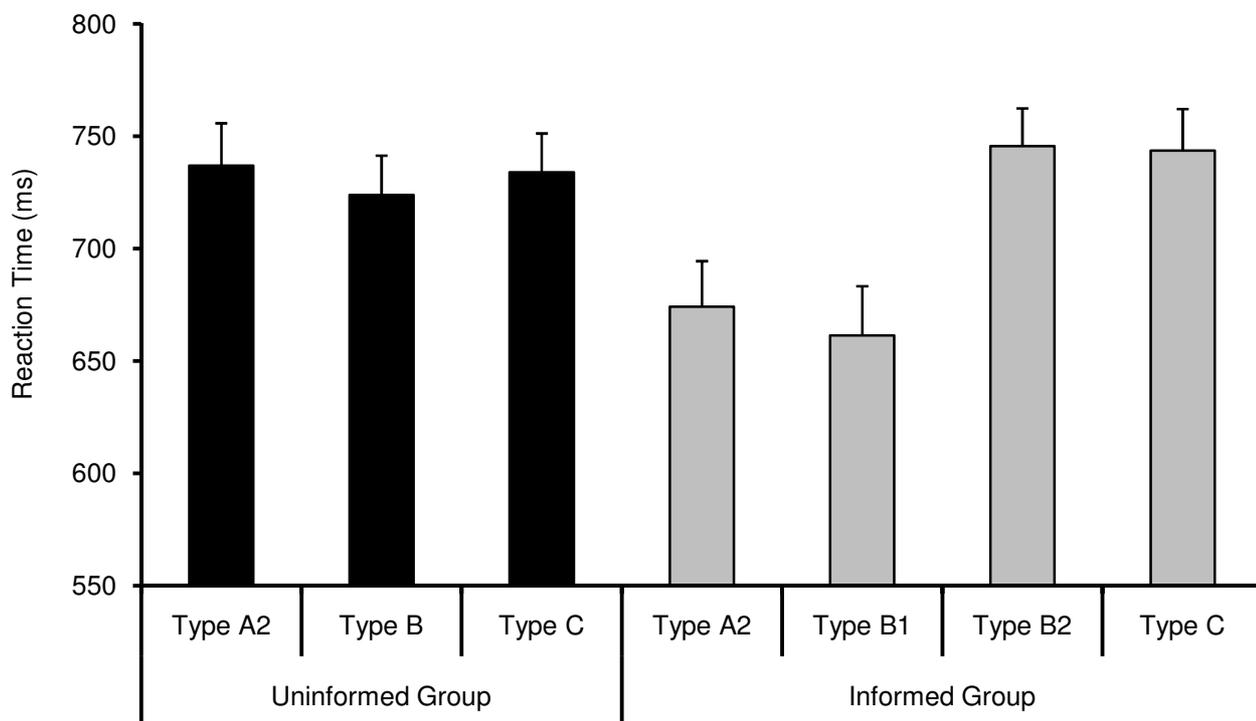


Figure 30. Mean RTs of Types of the two groups in the Dual Task phase. Type A1 was excluded from the analysis since those trials were part of the categorisation task and their RTs were biased by

<sup>9</sup> This is the reason why the Single Task was included, to allow an unbiased measure of the learning effects.

additional key presses; for Type A2 the cue – target relationship was fully deterministic; for Type B trials only one of the features (shape/colour) was predictive. For the Informed group on Type B1 trials the predictive feature was the one that they were informed about; on Type B2 trials the predictive feature was the one that they were not informed about. For the Uninformed group all Type B trials were equivalent. Type C cues had random relationship to the target locations. The error bars represent SEMs.

### *Process Dissociation Procedure*

After the RT task the participants' knowledge about the cue-stimuli relationship was assessed, as described above. Inspection of the PDP results depicted in Figure 31 clearly reflects the considerable difference in knowledge between the two groups. A Group  $\times$  Condition (Inclusion-Exclusion)  $\times$  Type (A, B, D)<sup>10</sup> mixed ANOVA revealed a significant effect of Condition,  $F(1, 54) = 67.41, p < .001, \eta^2_p = .56$ . The difference between groups is confirmed by a Group  $\times$  Condition interaction,  $F(1, 54) = 33.54, p < .001, \eta^2_p = .38$ . Analysing the Uninformed group alone, interestingly a reliable effect of Condition was found,  $F(1, 29) = 4.36, p = .046, \eta^2_p = .13$ , showing some evidence of flexible knowledge. One-sample  $t$  tests showed that no types differed significantly from chance level, except for Type B in the Inclusion condition,  $t(29) = 2.74, p = .010$  (corrected  $\alpha = .013$ ),  $d = .50$ . Thus, despite showing no evidence of learning in the RT data, it appears that at least some members of the Uninformed group acquired some knowledge about certain cue-stimuli relationships.

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<sup>10</sup> Since Type C had no predictive power, performance on those trials could not be evaluated.

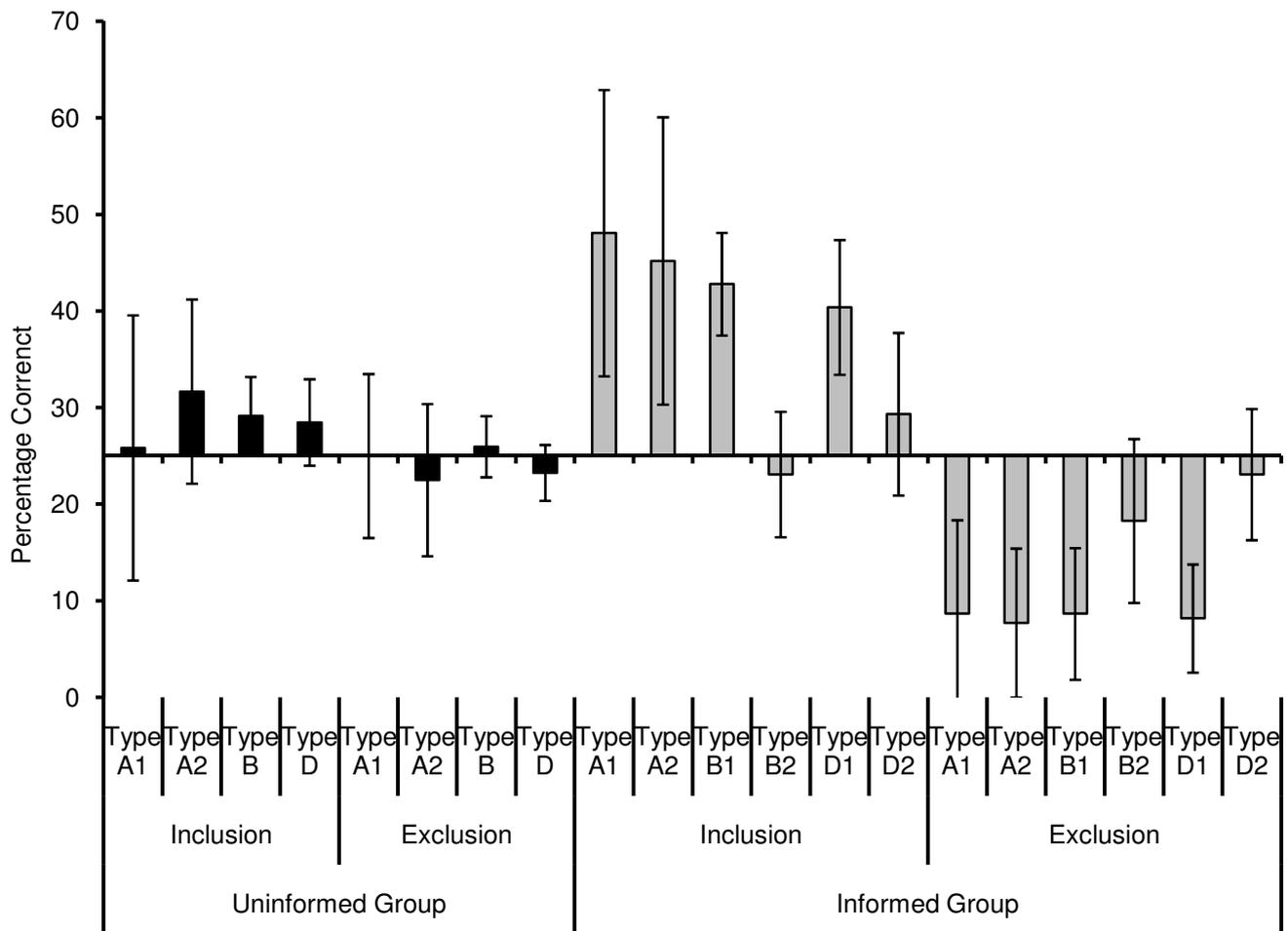


Figure 31. The performance of the Uninformed and the Informed Groups in the Inclusion and Exclusion conditions along the different types of cues. The locations of the target stimuli were predicted in the case of Type A1 and A2 cues both by shape and colour; Type B1 only by the informed features; Type B2 only by the uninformed features (only the Informed group was informed about these features). Type D1 and Type D2 were previously not seen ‘only colour’ or ‘only shape’ stimuli, Type D1 were the informed featured; Type D2 were the not informed features. The chance level was unified to 25%. The error bars represent the confidence intervals with corrected  $\alpha$ .

In the Informed group Type A1, A2, B1 and D1 were all significantly different from chance level in both conditions,  $t_s(25) \geq 3.89$ ,  $p \leq .001$ ,  $d \geq .76$ . Analysis of types B2 and D2 showed no reliable evidence of learning the predictive relationships about which the participants were not informed. Although the mean of Type B2 is below chance-level in the Exclusion condition, suggesting successful responding, after a Bonferroni correction this difference is not significant,  $t(25) = 2.27$ ,  $p = .032$  (corrected  $\alpha = .008$ ),  $d = .45$ . The crucial

Type D2 test was also not different from chance, Inclusion:  $t(25) = 1.47, p = .153, d = .29$ ; Exclusion:  $t(25) < 1$ .

### *Subjective Measures*

*Confidence measures.* After each PDP trial the participants were asked about their confidence about the correctness of their choices or (on every second trial) about how much money they would wager on it. It was expected that people would be more confident about their choices about the more predictable cues than the less predictable cues if they were aware that they had learned about their association. A Group  $\times$  Type mixed ANOVA revealed a significant effect of Type,  $F(4.83, 246,20) = 13.72, p < .001, \eta^2_p = .21$ ; and Group  $\times$  Type interaction,  $F(4.74, 246,34) = 11.01, p < .001, \eta^2_p = .18$  (Figure AF). The between-subjects Group effect was also significant,  $F(1, 51) = 6.03, p = .018, \eta^2_p = .11$ . A repeated-measures ANOVA showed that the difference between the types within the Uninformed group was not significant,  $F(3.03, 87.93) = 2.37, p = .076, \eta^2_p = .08$ . The confidence measures could not reveal any differentiation of the types within the Uninformed group.

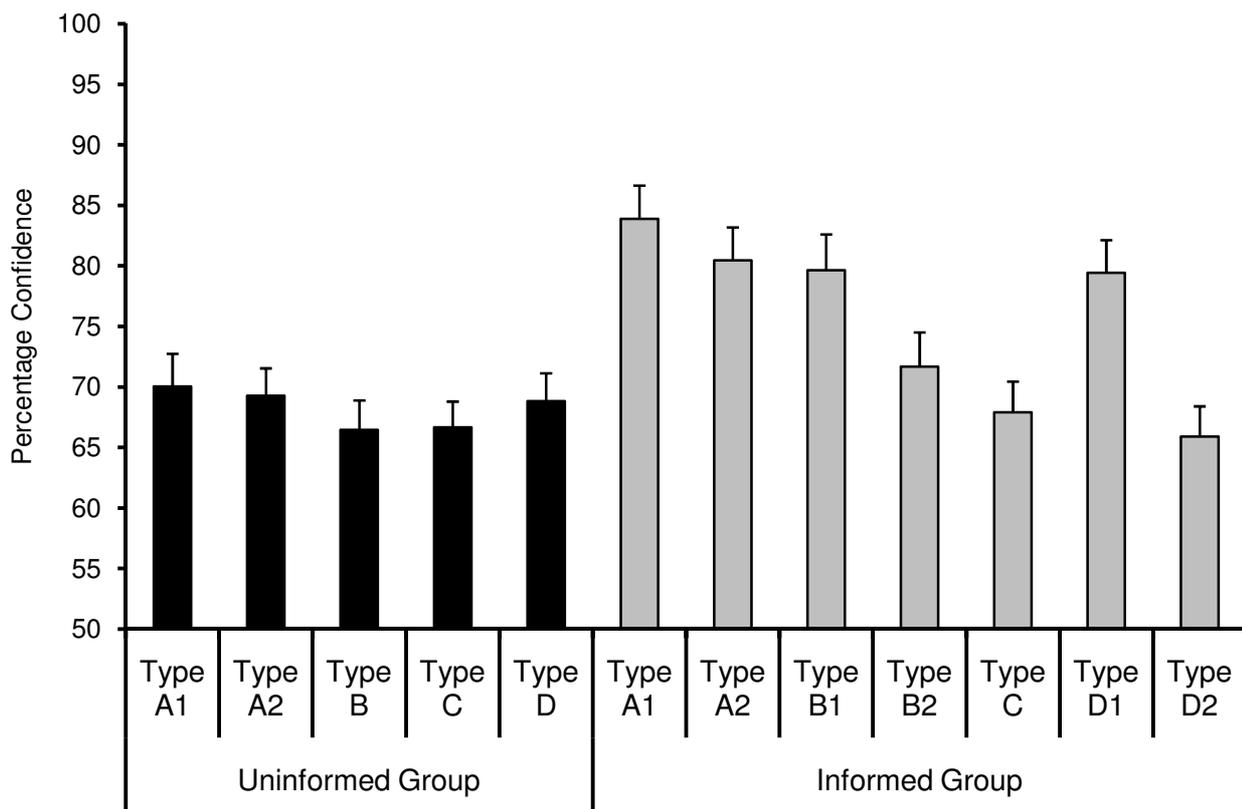


Figure 32. The reported confidence measures of the Uninformed and the Informed groups in their decisions about the different types of cues. 50% confidence represents complete uncertainty, 100% confidence represents complete certainty. The error bars depict SEMs.

Pairwise comparisons of the types within the Informed group showed that the participants were significantly more confident about their decisions about Type A1, A2, B1 and D1 cues than about the control Type C,  $t(24) \geq 5.36$ ,  $ps \leq .001$  (corrected  $\alpha = .007$ ),  $ds \geq .83$ . Importantly, the participants had no more confidence about Type D2 than Type C,  $t(24) < 1$ .

*Post-Decision Wagering.* Similarly to the confidence measures, in the wagering test the Group  $\times$  Type mixed ANOVA showed a significant effect of Type,  $F(3.93, 208.108) = 11.78$ ,  $p < .001$ ,  $\eta^2_p = .18$  and Group  $\times$  Type interaction,  $F(3.93, 208.108) = 7.75$ ,  $p < .001$ ,  $\eta^2_p = .13$  (Figure 33). The between-subjects Group effect was also significant,  $F(1, 53) =$

7.67,  $p = .008$ ,  $\eta^2_p = .13$ . A mixed ANOVA showed that the difference between the types within the Uninformed group was not significant,  $F(3.01, 87.41) = 1.51$ ,  $p = .218$ ,  $\eta^2_p = .05$ .

The PDW test did not measure any effect of knowledge in the Uninformed group.

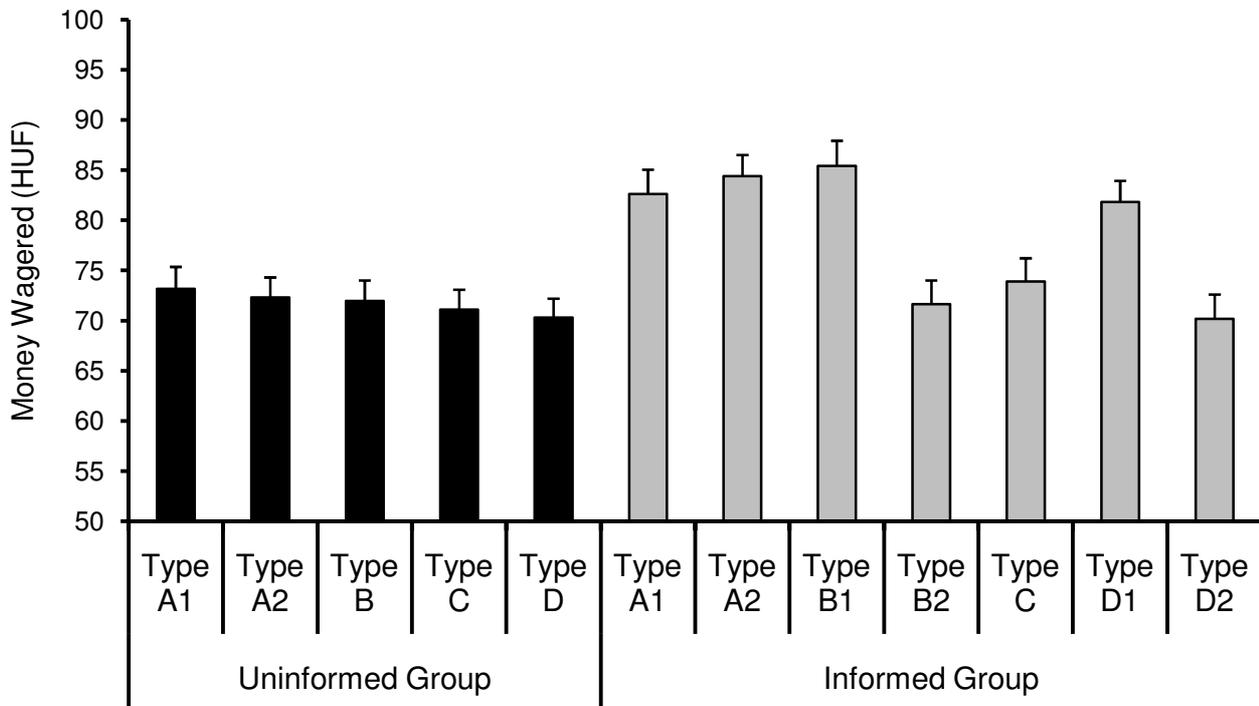


Figure 33. The average money wagered on the correctness of the knowledge about of the different types of cues in the Uninformed and the Informed groups. The error bars depict SEMs.

Pairwise comparisons of the amount wagered on different types within the Informed group showed that the participants wagered significantly more on their decisions about Type A1, A2 and B1 cues,  $t_s(24) \geq 3.16$ ,  $p_s \leq .004$  than about the control Type C, (corrected  $\alpha = .007$ ),  $d_s \geq .73$ . Crucially, the participants wagered more on decisions about Type D1 than Type D2,  $t(24) = 3.93$ ,  $p = .001$ ,  $d = 1.01$ . However, Type D2 wagering was not significantly higher (after the correction of  $\alpha$ ) than it was for Type C,  $t(24) = 2.56$ ,  $p = .017$ ,  $d = .70$ .

*Conscious State Assessment.* After each trial in the PDP the participants were also asked to report if they relied on *memory* or *guess* in their decisions. This test gave similar description about the effects: Type,  $F(3.66, 193.95) = 16.62$ ,  $p < .001$ ,  $\eta^2_p = .24$ , and Group  $\times$

Type interaction,  $F(3.66, 193.95) = 15.41, p < .001, \eta^2_p = .23$  (Figure 34). In general, the groups were different in this measure,  $F(1, 53) = 21.98, p < .001, \eta^2_p = .29$ . There was no Type effect within the Uninformed group,  $F(3.54, 102.67) < 1$ , indicating that in a group level this measure could not detect any evidence that memory was used more subjectively for predictive than for non-predictive stimuli.

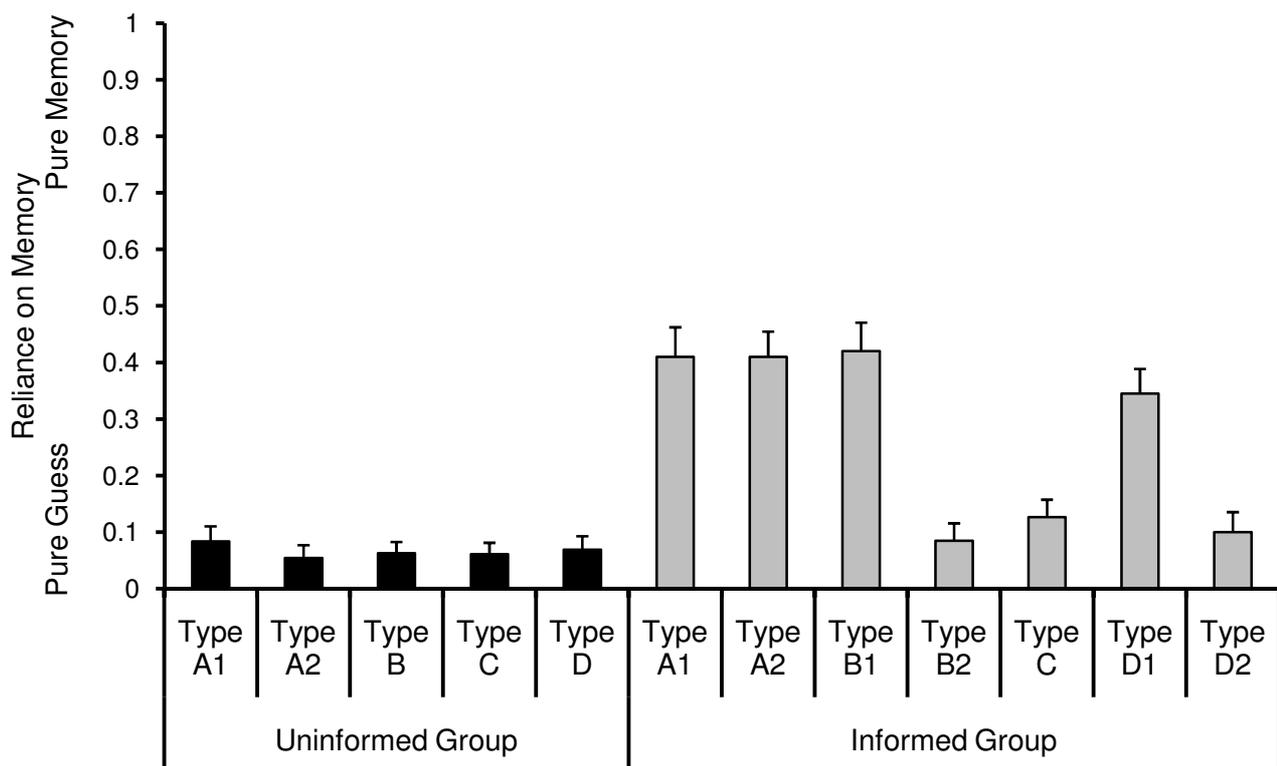


Figure 34. Reported reliance on memory/guess in the trials of the PDP in the Uninformed and the Informed groups. The error bars depict SEMs.

Pairwise comparisons of the types within the Informed group showed that the participants reported more reliance on memory about Type A1, A2, B1 and D1 cues,  $t_s(24) \geq 3.88, p_s \leq .001$  than about the control Type C, (corrected  $\alpha = .007$ ),  $d_s \geq .90$ . Crucially, the participants did not seem to remember more about Type D1 cue – location associations than when it was random (Type C),  $t(24) < 1$ .

The PDP unveiled some knowledge about the cue-stimuli relationship in the Uninformed group. The question remains whether this knowledge was gained purely by the attentional processes or by the emerging conscious knowledge of some of the members of the Uninformed group. This question was investigated by the *guessing criterion* of unconscious knowledge (Dienes, 2008). According to the guessing criterion, if the discrimination performance of the participants is above baseline on those trials where they reported “guess”, then that would be evidence that knowledge is not conscious.

The level of performance of each participant of the Uninformed group was analysed on those predictable trials where they reported that they had based their decisions on a guess. The mean performance of the Uninformed group was not above chance level (.25) on ‘guess’ trials which were fully determined (Type A) trials, ( $MS = .27$ ,  $SD = .12$ ),  $t(29) = 1.07$ ,  $p = .293$ ,  $d = .20$ . However, the mean performance was above chance level (.50) for the ‘half deterministic’ (Type B) trials ( $MS = .60$ ,  $SD = .19$ ),  $t(29) = 2.87$ ,  $p = .008$ ,  $d = .52$ . There were many fewer “memory” reports. On average, a participant in the Uninformed group reported “memory” on fewer than 2 trials, whilst reporting more than 14 “guesses”, resulting in too few datapoints for a reliable analysis of the memory reports.

## Discussion

The aim of this experiment was to investigate the question of whether selective attention on the relevant features is sufficient for learning about their relationship, or whether this relationship also requires dedicated processing as well. The SALT was devised to construct an experimental situation where the amount of selective attention and explicit information could be modulated for the groups and conditions.

None of the RT measures reflected observable learning about any relationships in the Uninformed group or about the uninformed relationships in the Informed group. The pattern of results was not different in the Single and Dual Task phases, indicating that effective learning was not measurable regardless of the concurrent engagement of selective attention with the predictive features.

The results of the confidence measure, the PDW and the guessing criterion reflected no difference between the knowledge of the predictable and the unpredictable types for those who were not informed about this predictability. One measure of the PDP alone showed generation performance different from chance level in the Inclusion condition of the Uninformed group. The corresponding Exclusion performance was not different from baseline, thus the PDP data does not provide clear evidence that this was the effect of implicit or explicit learning.

These results of the *guessing criterion* analysis suggest that there may be some evidence for implicit learning in this group, in terms of evidence that some participants in the Uninformed group acquired knowledge about the cue-location associations in a way that they did not ascribe to their available memories at time of test. The overall pattern, however, suggests that little or no learning was detectable in the Uninformed group (in terms of RT results, confidence measures, PDW). It is also possible that the participants in the Uninformed group reported guessing when a little knowledge was available during the PDP task. Whereas 20% of participants reported in the paper questionnaire some evidence of rule awareness about the test, only 7% of the PDP decisions were described as based on memory.

As a whole, the measures provide a coherent picture, one which gives no support to the assertion that selective attention to the stimuli is, in itself, sufficient for learning to occur. In general, it appears that selective attention to the relationship is crucial. A few participants

who were not directed to attend to a relationship may have acquired some fragmented knowledge about the cue-target associations (which only the PDP was able to measure), but it is unclear whether the repeated engagement of attention on the predictor cues and predicted locations triggered this learning. There are numerous examples in the implicit learning literature showing that few members of the experimental group spontaneously realise, and may thus attend to, the hidden structure of the implicit learning task. Therefore, it would be not surprising to observe this phenomenon here.

Importantly, the information provided about one of the predictive features did not produce learning about the other, equivalent relationship between the cues and target stimuli for the Informed group. Thus predictive learning did not occur, even though the selective attention of the participants was firmly engaged with the cues and target stimuli, as demonstrated by the accurate performance on the Detection Task, and the learning of the ‘informed’ relationship.

Although, the test showed that the participants attended to the relevant features, one could argue that the two representations were never *concurrently* active. It is possible, however somewhat unlikely, that the activation of the representation of the cue as a whole (but not those features which informed participants were instructed to learn about) decayed during the 500 ms delay between the disappearance of the cues and the onset of the target locations after each of the 450 trials. If this were the case, the failure to find learning may be a result of a lack of *concurrent* selective attention of the to-be-associated features.

To investigate this possibility, the test was modified in the next experiment to ensure that the representation of all features of the cue predictors would be maintained, and thus the would be active simultaneously with the target locations.

## Experiment 3.2: SALT Study 2

In this experiment the dual task was modified in a way such that the participants were directed to compare stimuli from the one trial to the next in terms of one feature (i.e. colour or shape). The reasoning behind this change of task was that the accurate detection of similarity between the features of the consecutive trials would imply that the representation of compared features must have remained active in between the two trials. If the detection of the target stimuli happens during this interval then it is reasonable to think that the representation of the cues and the target locations were active at the same time. If the concurrent activation resulting from selective attentional processing is sufficient for learning about an association, then we should expect to measure learning irrespective of any explicit information provided.

### Methods

#### *Participants*

The participants were 50 (32 female and 18 male;  $M = 26.34$  years,  $SD = 3.84$  years) volunteers and university students of University of Cambridge, UK. One person had to be discarded from the analysis because of the extreme outlier number of incorrect key presses. Each participant received 6 GBP for participation in a 45-minute experiment.

The participants were randomly allocated into two groups and two subgroups: Informed (match Colour), Informed (match Shape), Uninformed (match Colour), Uninformed (match Shape).

#### *Materials and Procedure*

The materials and procedures in this task were identical with the previous study (*Experiment 3.1*) with one modification. Instead of detecting the two selected stimuli, the

secondary task was to press down all the four keys together when a particular feature (the *colour* for the ‘match Colour’ sub-groups, *shape* the ‘match Shape’ sub-group) of the cue stimulus is the same as the previous cue stimulus.

Similarly to the previous study, half of the participants of the Informed group were informed about some relationship between the cues and the target stimuli. Those in the Informed (match Shape) sub-group, who had the secondary task of detecting the shapes, were all informed about the predictive nature of the *colours* of the cues; those in the informed (match Colour) sub-group, who had the secondary task to detect the colours, were informed about the predictive nature of the shapes of the cues.

As the dual task required attention to a single dimension, there was a difference between two types of Type B trials for all participants. Type B1 trials were those where only the dimension **not required** in the dual task was predictive (this was the instructed dimension for Informed groups); Type B2 trials were those where only the dimension **required** in the dual task was predictive (this was the uninstructed dimension for the Informed groups).

After the RT task and the awareness tests (PDP, SMs and PDW) the participants filled out the previously described paper questionnaire (Appendix F).

## Results

### *Detection Task*

The performance in this detection task showed that the participants followed the instruction and correctly categorised the selected cues Uninformed group: Hit Rate: 82%, False Alarm: 8%; Informed group: Hit Rate: 85%, False Alarm: 7%. The two groups did not differ in their measures of hit rate,  $t(44) < 1$ , and false alarm,  $t(44) < 1$ . Therefore, it is

plausible again to infer from these results that in both groups, the participants attended the relevant features of the cues, and maintained their representations between cue presentations.

### *Reaction Time Measures*

In the first block of the Dual Task phase, both of the groups were uninformed about the hidden relationship between the cue forms and target circles. However, they had to attend to and compare the shapes or the colours of the subsequent cues. Selective attention on the relevant features in itself could have promoted learning, and so, the first analysis examined performance of the whole sample in the first block of the Dual Task was assessed.

The design of the task provides two cues where only the shape and two cues where only the colour has predictive relationship to the target locations. RTs on the trials of these cues were compared to the control cue, which randomly related to the target location. If selective attention is enough for learning then we could expect faster RTs in the predictable than in the unpredictable trials. Three participants had to be discarded from the RT analysis because the numbers of their errors were extreme outliers from the sample and one further participant had to be discarded due to having not followed the instructions of the Dual Task.

A mixed ANOVA with Type as within-subjects factor showed no RT difference between the four type of trials (A, B1, B2, C),  $F(2.05, 94.25) < 1$ . A selected pairwise comparison between *Type B1* (when only the selectively non-attended features had predicting power) and *Type B2* (when the attended features had predicting power) indicated no RT difference, paired  $t(45) < 1$ .

Comparing the Informed and Uninformed groups across the Types in the rest of the blocks of the Dual Task (after the Informed group received the explicit information), Figure 35 suggests a pattern similar to the previous study. This was confirmed using a mixed model

ANOVA with Group as between-subjects factor and Type as within-subjects factor. A different amount of learning (in terms of sensitivity to predictive status) between groups was confirmed by the interaction of Group  $\times$  Type,  $F(1.87, 82.18) = 7.42, p = .001, \eta_p^2 = .14$ .

As is clear from Figure 35, there was no evidence of RT difference between the different types of trials in the Uninformed group,  $F(3, 69) < 1$ , whereas the Informed group RTs differentiated between the types, being faster on Type A and Type B1 compared to the rest of the types,  $F(1.45, 31.00) = 7.43, p = .005, \eta_p^2 = .26$ . Type B2 was not reliably different from the random Type C in the Informed group, paired  $t(22) < 1$ . This result might be due to Type B2 consisting of those trials where the provided information was not predictive. Alternatively, the requirement to select the predictive feature for the detection task could, somehow, have interfered with the expression of learning about that feature in the target detection RTs during this phase. As in the previous study, the Single Task phase provides the best test for these differences.

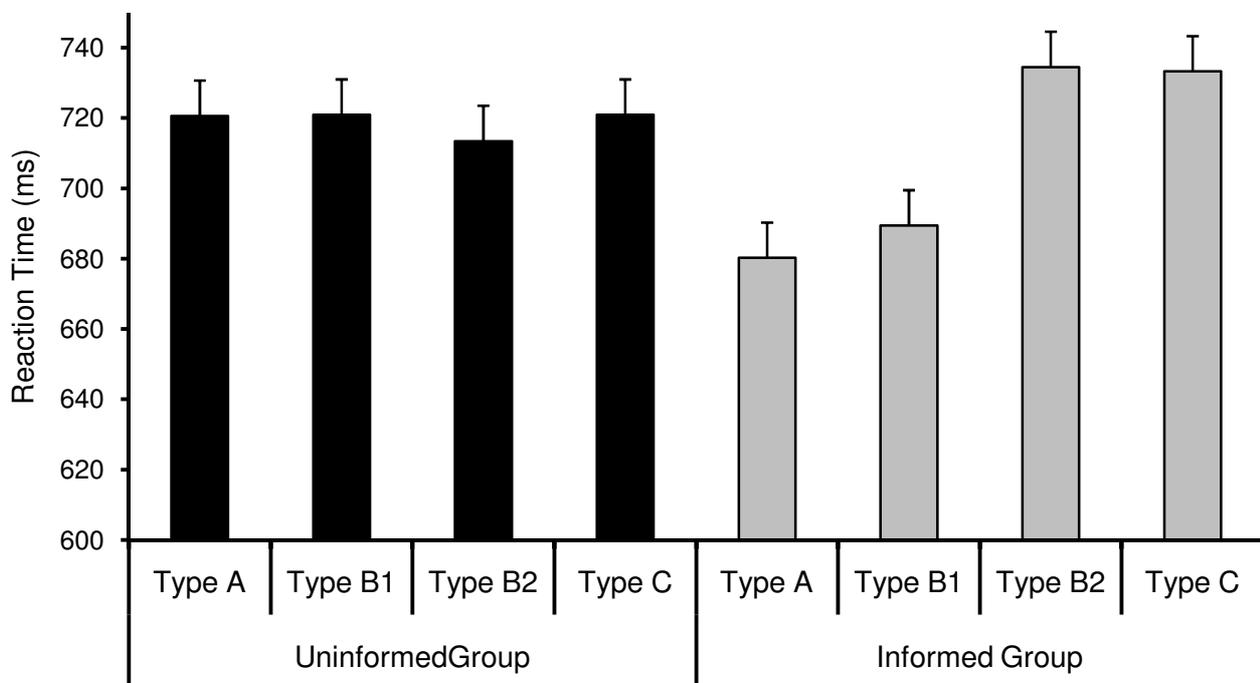


Figure 35. Mean Reaction Times of the two groups in the four types of trials in the Dual Task phase. For Type A the cue – target relationship was fully deterministic; on Type B2 trials only the to-be-

selected features were predictive, on Type B1 trials the to-be-selected features were not predictive, but the Informed group was informed about their predictive power; Type C cues had random relationship to the target locations. The error bars represent SEDs.

The crucial phase of this experiment is the Single Task where the participants are presented with cues prior to each response target, but are not instructed to press the keys at colour/shape match detection. Responding in this phase was analysed with a mixed ANOVA model, with Group as between-subjects factor and Type as within-subjects factor. This revealed learning, in terms of different RTs to different stimulus Types,  $F(2.55, 112.11) = 16.29, p < .001, \eta^2_p = .27$ . Learning was not equal in the two groups, as shown by the interaction of Group  $\times$  Type,  $F(2.55, 112.11) = 8.92, p < .001, \eta^2_p = .17$ . As Figure 36 demonstrates, there was no evidence of a difference between the RTs for different stimulus types in the responding of the Uninformed group,  $F(2.26, 51.99) = 1.15, p = .330, \eta^2_p = .05$ , *i.e.* no evidence was found that the Uninformed group learned anything about the cue – target associations that enabled them to respond faster when the cues were predictive.

In the Informed group, by contrast, there was a difference between the response speeds for different types of stimulus,  $F(1.72, 38.05) = 19.41, p < .001, \eta^2_p = .48$ . Dunnett Pairwise comparisons showed a difference from the control, random Type C was for Type A,  $t(22) = -4.88, p < .001, d = .82$ ; and Type B1,  $t(22) = -3.44, p = .002, d = .56$ , but not for Type B2,  $t(22) = 1.37, p = .187, d = .16$ . This pattern suggests that it was the information provided, and not any concurrent selective attention, that was over and above the key factor in determining the amount of learning.

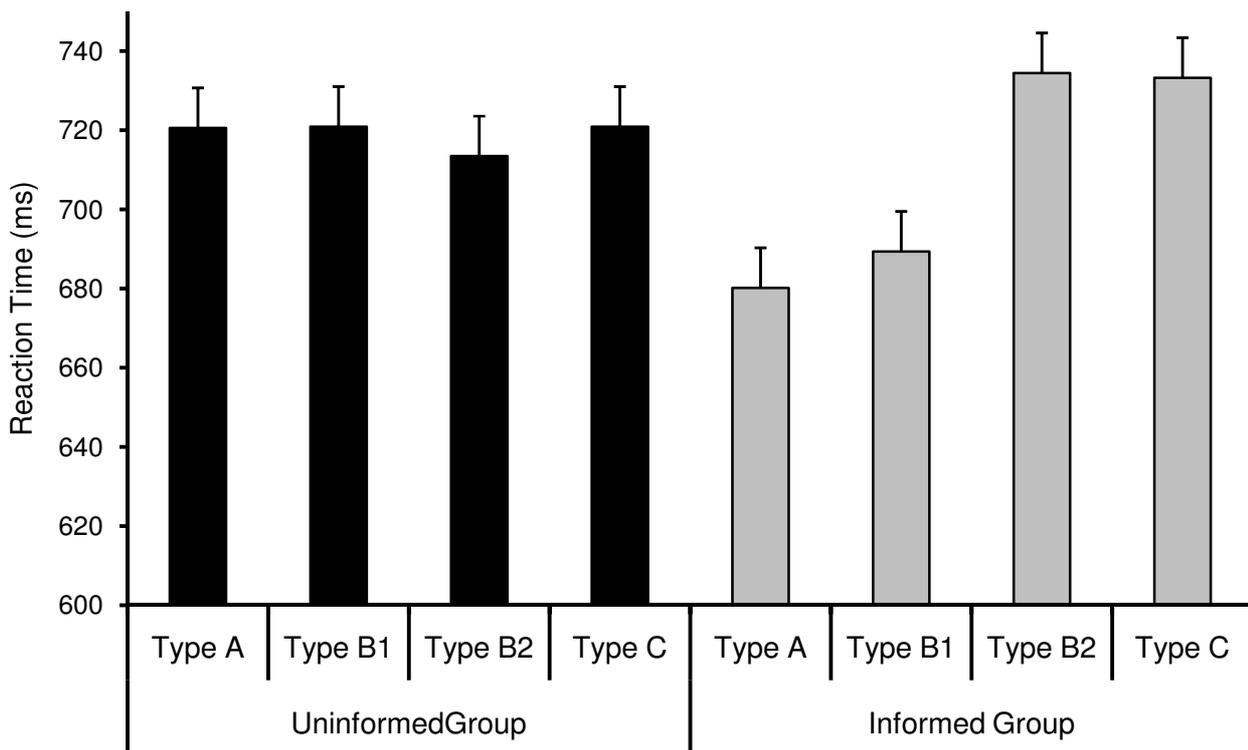


Figure 36. Reaction Time means of the two groups in the four types of trials in the Single Task phase. For Type A the cue – target relationship was fully deterministic; on Type B2 trials only the to-be-selected features were predictive, on Type B1 trials the to-be-selected features were not predictive, but the Informed group was informed about their predictive power; Type C cues had random relationship to the target locations. The error bars represent SEDs.

### *Process Dissociation Procedure*

After the RT task, the participants' knowledge about the cue-stimuli relationship was assessed using the PDP test. Inspection of the PDP results depicted in Figure 37 clearly reflects the considerable difference in knowledge between the two groups. A Group (Informed vs. Uninformed)  $\times$  Condition  $\times$  Type mixed ANOVA revealed a significant main effect of Condition (Inclusion-Exclusion), showing that some flexible knowledge was acquired,  $F(1, 43) = 27.91, p < .001, \eta^2_p = .39$ ; a Group  $\times$  Condition interaction, showing that the knowledge was different in the two conditions,  $F(1, 43) = 22.53, p < .001, \eta^2_p = .34$ ; and a Condition  $\times$  Type interaction effect,  $F(3.73, 160.36) = 4.56, p = .002, \eta^2_p = .01$ .

Analysing the Uninformed group separately revealed no evidence of learning in terms of different responding between conditions,  $F(1, 23) < 1$ ; the greatest numerical difference from the chance level did not reach (corrected) significance,  $t(23) = 2.6$ ,  $p = .016$  (corrected  $\alpha = .008$ ),  $d = .53$ . In the Informed group, by contrast, there was a significant effect of Condition,  $F(1, 20) = 33.43$ ,  $p < .001$ ,  $\eta^2_p = .63$ , and a Condition  $\times$  Type interaction,  $F(3.10, 61.95) = 10.61$ ,  $p < .001$ ,  $\eta^2_p = .35$ , indicating flexible knowledge that was sensitive to the degree of cue-location prediction. The scores of Type A, B1, D1 were significantly above chance level in the inclusion condition, one sample  $t_s(20) \geq 3.4$ ,  $p_s \leq .003$ ,  $d_s \geq .74$  (corrected  $\alpha = .008$ ), and below chance in the exclusion condition,  $t_s(20) \geq -3.98$ ,  $p_s \leq .001$ ,  $d_s \geq .87$  (corrected  $\alpha = .008$ ).

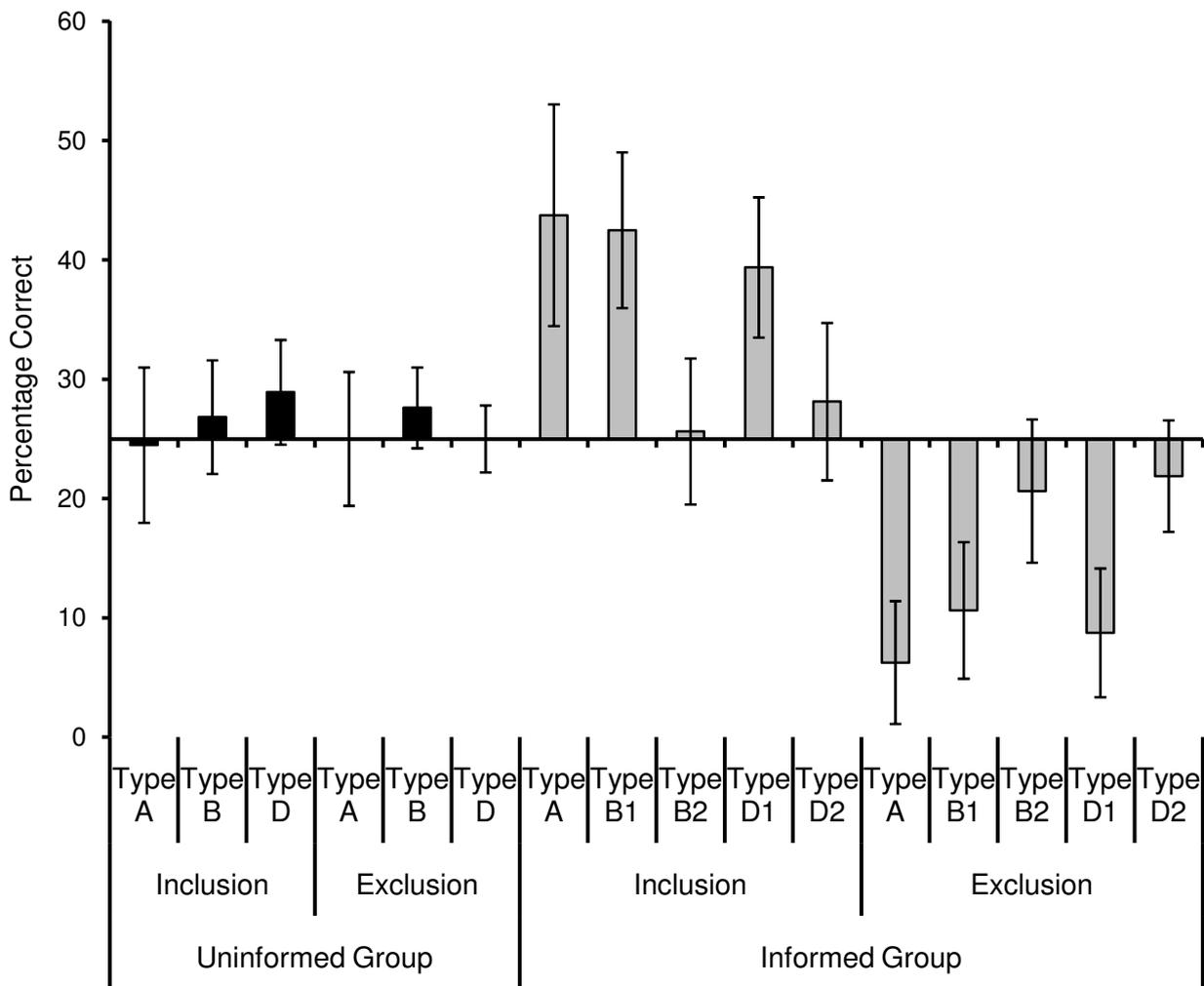


Figure 37. The performance of the Uninformed and the Informed groups in the Inclusion and Exclusion conditions along the different types of cues. The locations of the target stimuli were predicted in the case of Type A cues both by shape and colour; Type B2 only by the attended features; Type B1 only by the unattended features (the Informed group was informed about these features); Type D1 and D2 were previously not seen ‘only colour’ or ‘only shape’ stimuli, Type D2 were those features that were attended before; Type D1 were not attended (the Informed group was informed about these features). Type C was random, performance on those trials could not be evaluated. The chance level was unified to 25%. The error bars represent the 95% confidence intervals.

### Subjective Measures

*Confidence measures.* After each PDP trial the participants were asked about either their confidence in the correctness of their choices, or (on every second trial) about how much money they would wager on it. The measures are based on the logic that people will be more confident about their choices for predictable cues to the extent that they have learned explicitly about the predictive relationship. A Group  $\times$  Type mixed ANOVA model revealed

a significant effect of Type,  $F(3.60, 143.85) = 4.94, p = .001, \eta^2_p = .11$  and Group  $\times$  Type interaction,  $F(2.32, 118.17) = 3.75, p = .008, \eta^2_p = .09$ . The Group effect was also significant,  $F(1, 40) = 8.07, p = .007, \eta^2_p = .17$ . There was no evidence for a difference in confidence of prediction across the types within the Uninformed group,  $F(4, 41) < 1$  (Figure 38).

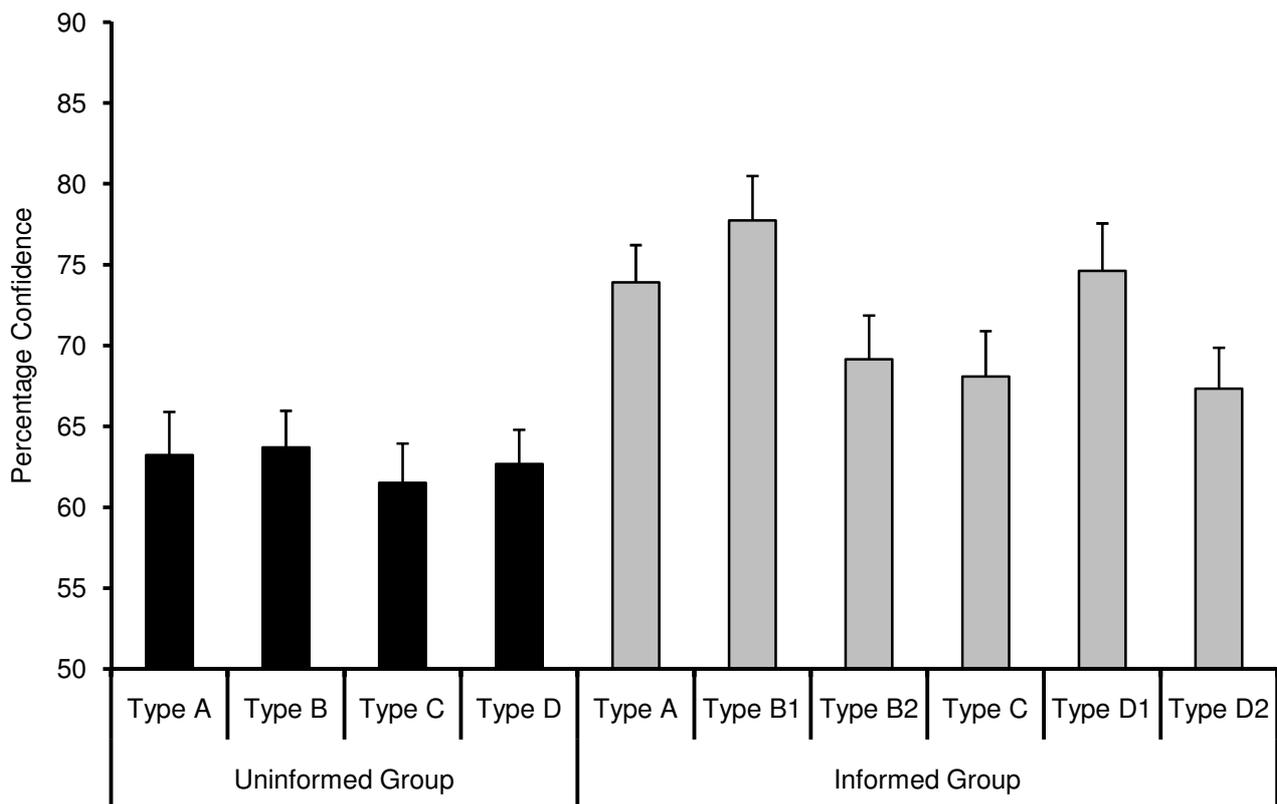


Figure 38. The reported confidence measures of the Uninformed and the Informed groups in their decisions about the different types of cues. 50% confidence represents complete uncertainty, 100% confidence represents complete certainty. The error bars depict SEMs.

Pairwise comparisons within the Informed group showed that the participants were significantly more confident about cues of Type A, B1 and D1 compared to their confidence in the random Type C cues (Type A: planned one-tailed  $t(18) = 1.80, p = .044, d = .48$ ; Type B1 one-tailed  $t(18) = 2.98, p = .004, d = .73$ ; Type D1 one-tailed  $t(18) = 2.03, p = .028, d = .49$ . Confidence in Type B2 and Type D2 cues were not reliably different from Type C,  $ts(18) < 1$ . Although, the Informed group had numerically more confidence in the random cues than the Uninformed group, this difference was not significant,  $t(40) = 1.74, p = .090, d = .40$ .

*Post Decision Wagering.* Similarly to the confidence measures, for the wagering test the Group  $\times$  Type ANOVA showed a significant effect of Type,  $F(2.87, 114.82) = 7.71, p < .001, \eta^2_p = .16$ , and Group  $\times$  Type interaction,  $F(2.87, 114.82) = 10.64, p < .001, \eta^2_p = .21$ , suggesting that predictability effects on wagering was larger in the Informed group. There was no evidence of Type having an effect on wagering within the Uninformed group,  $F(4.37, 96.10) < 1$ , again consistent with their being no detectable knowledge of differences between stimulus types in the Uninformed group (Figure 39).

In the Informed group, pairwise comparisons of the amount of money wagered relative to the random Type C cues showed more wagering on predictions following Type A, B1 and D1 cues,  $ts(18) \geq 2.97, ps \leq .008, ds \geq .59$ . Again, there was no evidence of knowledge about the uninformed feature, measured by the difference between Type D2 vs Type C,  $t(19) < 1$ . These results are consistent: participants learn the predictive relationship about which they received explicit information, despite the dual-task requirement to process and remember another, equally predictive, feature.

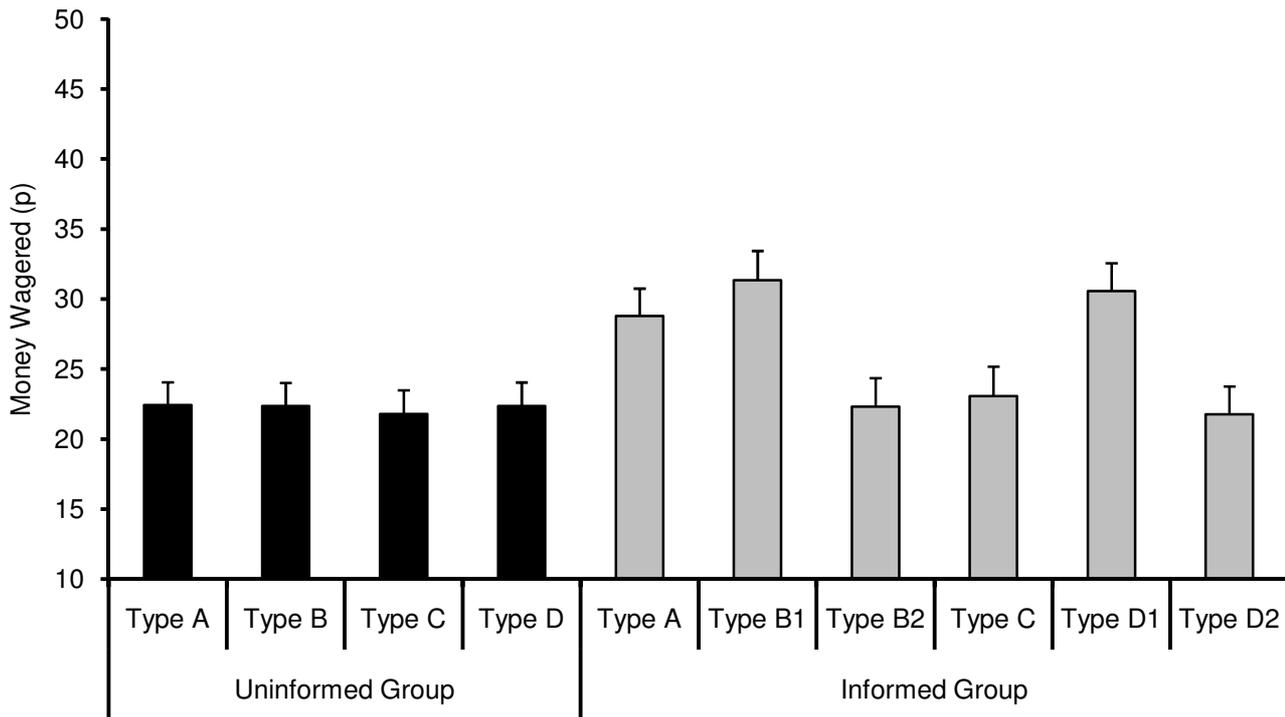


Figure 39. The average money (penny) wagered on the correctness of the knowledge about of the different types of cues in the Uninformed and the Informed groups. The error bars depict SEMs.

Surprisingly, for each stimulus type the amount of money wagered in the Uninformed group correlated strongly positively with the level of risk aversion as reported in the paper questionnaire,  $r \geq .56$ ,  $p \leq .010$ . For the Informed group, none of these correlations were significant,  $r \leq -.38$ ,  $p \geq .087$ .

*Conscious State Assessment.* After each trial in the PDP the participants were also asked to report if they relied on memory or guesses in their PDP response. Analysis of this test gave a similar description to the other measures: A main effect of Type,  $F(2.74, 117.92) = 5.86$ ,  $p = .001$ ,  $\eta^2_p = .12$ , and a Group  $\times$  Type interaction,  $F(2.74, 117.92) = 8.18$ ,  $p < .001$ ,  $\eta^2_p = .16$ ., plus a main effect of Group  $F(1, 43) = 11.39$ ,  $p = .002$ ,  $\eta^2_p = .21$ , (Figure 40). There was no Type effect within the Uninformed group,  $F(2.31, 53.12) < 1$ , indicating this measure could not detect any evidence of conscious knowledge in this group.

Pairwise comparisons of the memory reliance of the different types compared to the random Type C confirmed what Figure 40 suggests, the participants in the Informed group reported significantly higher reliance on memory in the case of Type B1,  $t(20) = 2.92$ ,  $p = .008$ ,  $d = .64$ , and Type D1 cues,  $t(20) = 2.53$ ,  $p = .020$ ,  $d = .65$ . This finding is not that surprising since the group received explicit information about these cues. The level of memory use in responding to D2 cues was not different from that for the random Type C,  $t(20) < 1$ .

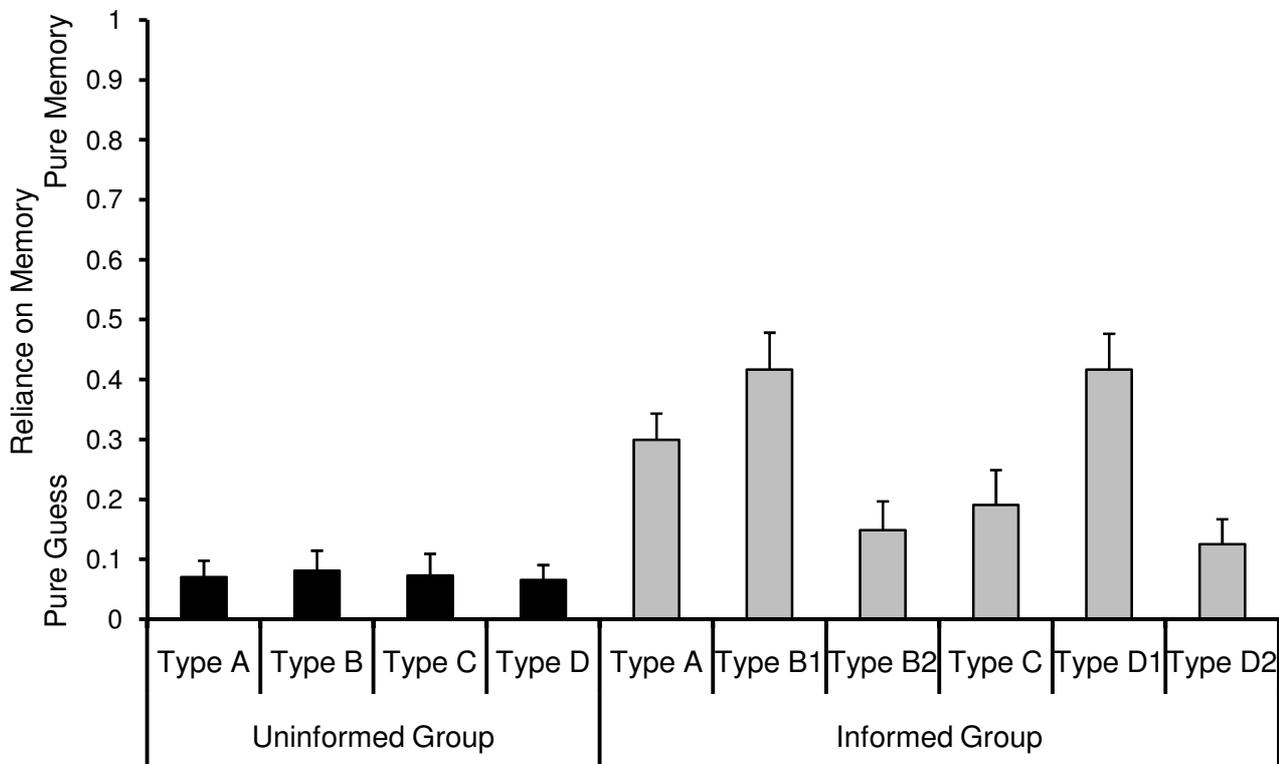


Figure 40. Reported reliance on memory/guess in the trials of the PDP in the Uninformed and the Informed groups. The error bars depict SEMs.

In the verbal report of the paper questionnaire only one member of the Uninformed group reported finding regularity in the locations of the target stimuli. In contrast, 55% of the Informed group verbalised a memory or rule in the task.

In short, this experiment confirmed that learning can happen in this design, and that whilst explicit instruction to attend to a relationship promotes learning about that relationship, the requirement to attend and remember features is not sufficient for learning. In the previous study some evidence of learning was found in Uninformed group in the overall PDP performance, whilst above-chance performance was observed in some situations where participants reported that they were guessing. These results allowed the possibility that some unconscious knowledge may be responsible for performance. Those indices which, in *Experiment 3.1*, suggested some implicit knowledge, show no sign of the effects in this study. Neither the overall PDP performance of the Uninformed group, nor the performance of the Informed Group on Type B2, and D2 trials, differed reliably from chance performance, all  $t_s < 1$ .

## Discussion

In this experiment the design of the SALT was modified to ensure simultaneous activation of the representations of the cue and target stimuli. The central question of this study was whether effective learning is a consequence of such simultaneous attention to the to-be-associated stimuli.

The mean RTs of the trials of different types diverged between the two groups after the Informed group received explicit information. The pattern of these results was not different from the previous test, as the Informed group showed learning only about those cue-target associations of which they received explicit information. Learning was not observed about non-informed associations. However, the detection task results implied that the specific features were selectively attended to before, and kept in memory at the time of, attention to the target locations.

The results of the confidence measure, guessing criterion, PDP, PDW and the verbal report mirrored the findings of the RT analysis, indicating that all objective knowledge led to subjective knowledge, i.e., was explicit. The amount of money wagered in the PDW was related to the reported risk-aversion level for the Uninformed group. Surprisingly, the correlation between these measures was positive, whereas all the six (non-significant) correlational coefficients were negative for the Informed group. Whilst the pattern of the relationship is not simple to explain, the data clearly show that risk-aversion affects the PDW in relation to the level of learning.

In summary, the main finding of this study is that the simultaneous co-activation of stimuli was not sufficient for effective learning. Participants paid attention to the relevant stimuli: the identity of the cues and the representation of the location of the target stimuli were active simultaneously for the 360 trials. Nevertheless, the only evidence of learning was in those participants whose attention was also drawn to that particular predictive relationship between stimuli.

### Chapter Discussion

The research in this chapter began considering whether *learning is a necessary consequence of selective attention*. Studies in Chapter III suggested that attention may be necessary for learning to occur, but those experiments did not address whether attention will always result in learning.

Evidently, when *sufficient* conditions are mentioned in learning research then it is always meant to be a selection from a plausible list of conditions such as awareness, intention, or instruction. Other baseline conditions such as visibility, motivation or cognitive capacities are tacitly assumed. In this work, selective attention as a sufficient condition of learning was interpreted as implying that awareness about or attention to the association of

the cues and target stimuli are not needed. The new test, the SALT was devised and applied to test this hypothesis.

*Experiment 3.1* and *Experiment 3.2* approached the question from different angles. In the first experiment the predictive cues were introduced to the participants as part of an independent dual task through which attention was drawn to the predictive cues 500 ms before the appearance of the associated target locations. The second experiment ensured that the representation of the cues and associated target locations were concurrently active.

The level of awareness about the relationship between the stimuli was manipulated in two ways. Firstly, the two groups differed in whether they received explicit information about an association between the cues and the locations. Secondly, the Informed group was informed about only half of the predictive features, they remained uninformed about the other half. In this manipulation, the between-groups comparison of the behavioural data and the post-experimental knowledge tests of the second experiment showed no learning without contingent explicit information, although the first experiment indicated the presence of some element of knowledge in the Uninformed group. From those data it was not clear whether this subtle effect is the result of selective attention causing learning, or simply that a few participants guessed, or became aware of, the hidden rules in the task.

The second type of manipulation turned out to be at least as effective, since in both of the experiments strong learning was demonstrated for the half of the relationships the participants were made conscious of. However, importantly, these participants showed no evidence of learning about the other half of the predictive cues. This manipulation devised in the SALT is novel in the sense that it ‘disguises’ certain rules in the task by drawing attention to other ones.

In a similar implicit learning task Norman and her colleagues (Norman, Price, Duff, & Mentzoni, 2007) showed four colour stimuli arranged in a square layout on the screen. Following an SRT task structure, the participants had to detect the location of the one target stimulus which was filled; the rest of the stimuli remained unfilled. During the task the location, colour and shape of the four stimuli changed in each trial. However, the target stimulus was predicted only by the location of the previous trials, the shape and colour features serving as a disguise. Despite the similarities, in that test the people could not learn anything about the predictive powers of the other attended features. Therefore, that test was not capable of testing derived attention this way.

No previous implicit learning task was found in the literature that used explicit information to set an interpretation about how the test works which prevents the participant seeking for other rules. The successful application of this decoy may suggest that a satisfactory rule can prevent the participant looking for and learning other rules.

Another important aspect of these findings is the size of effect of explicit knowledge. Both experiments showed partial effect sizes greater than .80 in the crucial RT results (Cohen considered those 'large', 1988). In other words, attention on the association between the stimuli has what is considered to be, statistically, a large effect on learning. One could further speculate on this notion that an even more limited opportunity for attention to the rule would still have a considerable effect on the behavioural figures. If this is the case, then probably even reduced attention to a relationship can cause observable differences in a RT learning task. Furthermore, if the memory of this attention decays faster than the effect of the attention, then many previous implicit learning results might have been the product of this differential decay, as this 'conscious attention' may not be recalled during post-experimental assessments.

Finally, it is important to emphasise that this study indicates only that learning is not a simple, obligatory consequence of selective attention to the stimuli. The data do not, however, rule out the possibility of learning without awareness, yet they provide an example of when attention to the associated stimuli only is insufficient to produce observable learning about the association between the stimuli. It cannot be excluded that here or in other learning situations different factors such as motivation or the intensity of attention play more direct roles. It seems, nevertheless, that awareness is an important factor for learning to occur.

## V. ATTENTION AND DECISION MAKING

Decision theorists have long distinguished between analytical and intuitive decision making (e.g., Brunswik, 1956; Simon, 1955), often attributing them with different processing modes (e.g., Epstein, 1994; Evans, 2008; Stanovich & West, 2001). The overlap of the copious definitions of *intuition* (for a review see Hodgkinson, Langan-Fox, & Sadler-Smith, 2008) shows that intuition is an available feeling about an unavailable knowledge. This knowledge is often referred to as *tacit knowledge* (Polanyi, 1967), gained by experience (Hogarth, 2001) or implicit learning. Despite the flourishing theoretical literature supporting this dichotomous view, the number of empirical attempts to contrast the effects of intuition and deliberation is limited. One reason for this lack of research could be ascribed to the difficulty of assessing the goodness of any particular decision (Wilson & Schooler, 1991). Another reason could originate from the traditional assumption that reasoning and analysis always lead to better outcomes (e.g., Koriat, Lichtenstein, & Fischhoff, 1980). However, some of the theories that subscribe to this view assume that under certain circumstances the intuitive decisions can bring more optimal results than rational thinking. Operationalising Brunswik's notions, Hammond and his colleagues (Hammond, Hamm, Grassia, & Pearson, 1987) suggested that there are certain areas in which intuitive decisions will be more beneficial than reasoned decisions. They argued that the different decision making situations demand different decision making strategies in a continuum between pure intuition and pure rational analysis. Thereby, the validity of a decision will always depend on the match between the demands of the task and the applied cognitive style. Empirical studies have given support to the notion that, for some tasks, we are really better off with intuition (e.g., emotion recognition: Halberstadt, 2005; basketball prediction: Halberstadt & Levine, 1999; perceptual training: Melcher & Schooler, 2004).

Intuition has been explained as the use of complex knowledge patterns based on experience-based learning (Hogarth, 2001) and regarded as a crucial component of expertise (Eraut, 2000). Experts relying on their intuition were found to make better judgments in various fields ranging from chess playing (De Groot, 1986) to the stock market (Harteis & Gruber, 2008) than when they tried to reason before their decisions. Wilson and his colleagues (e.g., Wilson, Dunn, Kraft, & Lisle, 1989; Wilson & Schooler, 1991) contrasted in several experiments the optimality of decisions made by people with or without analysing their reasons. They asked people to rate objects such as different brands of strawberry jams or different college courses. They repeatedly found that those who analysed their reasons behind their choices always made decisions that corresponded less with expert opinions than those who did not. The authors explained the results by the hypothesis that reasoning can lead people to focus on nonoptimal criteria and subsequently, to make worse decisions. Another stream of researchers emphasise that the benefits of intuitive decisions may lie in the use of '*smart heuristics*' that can represent an advantageous solution to real-world decision problems by reducing their complexity to simple rules of thumb (Gigerenzer, 2007).

The Unconscious Thought Theory (UTT) (Dijksterhuis & Nordgren, 2006), however, goes further: it defines intuition as the result of unconscious thought. The UTT presents a strong argument that the restricted capacity of conscious thought (working memory) can lead to poor decisions in complex circumstances, while unconscious thought is not constrained by complexity. In this model unconscious processing is regarded as an active, creative mode of thought.

Evidence in favour of UTT comes from a series of studies. Dijksterhuis and colleagues (e.g., Dijksterhuis, 2004; Dijksterhuis, Bos, Nordgren, & van Baaren, 2006) used an experimental situation in which the participants were presented with a long list of positive and negative attributes describing some features of the objects of choice (e.g., apartments,

cars, roommates). After the presentation, one group, the Conscious Thought condition, had four minutes to think about the ratings of the presented objects. Another group, the Unconscious Thought condition, received the task just as for the Conscious Thought group with the exception that during the four minutes following the presentation their attention was diverted with an irrelevant explicit task before being asked to rate the items. The third group, the Immediate Decision condition, had to make their decision without delay after the presentation.

The principal findings of these experiments suggested that the performance of the Diverted Attention groups was significantly better compared to the other two groups. According to the UTT theory these results can be interpreted as the diverted attention task engaging the conscious processing capacity during the time of the delay leading to an unconscious processing of the information under that condition. This explanation suggests that unconscious thought weights the various dimensions appropriately through distributed, bottom-up processing and integrates them to produce decisions better than those reached by conscious thought. The conscious thought is postulated to be disadvantageous in complex decisions because it can rely only on a hierarchical processing of a limited number of items at the same time, thus biasing impression formation (Dijksterhuis & Nordgren, 2006).

These findings seem to present direct evidence that in cases when the complexity of the information is high, unconscious decisions are often more reliable than conscious decisions. The general picture regarding the power of intuition remains, however, more controversial as several empirical attempts have failed to prove the claims of the UTT and questioned the reliability of the supporting data (e.g., Acker, 2008; Newell, Wong, Cheung, & Rakow, 2008; Payne, Samper, Bettman, & Luce, 2008). The claim of support from these data was criticised on several grounds. It was pointed out that the effect could be explained not only by superior performance of the unconscious group, but also by some detrimental

performance of the conscious group due to, for example, simple memory retrieval interactions (Shanks, 2006). The validity of such criticism is supported by the fact that some of the previous works failed to include a control immediate decision condition (Dijksterhuis et al., 2006) and that the contrast of such a control to the Unconscious Thought has group brought mixed results (Dijksterhuis, 2004). In addition, some replications have failed to confirm the original effects (Rey, R. M. Goldstein, & Perruchet, 2009). These findings support the explanation that the effect lies in the suboptimal performance of the Conscious Thought group.

Rey and his colleagues analysed the decision strategies in a task based on choosing the best car. The authors asked independent raters about how influential they thought the certain attributes of the cars are in making a decision. Using these evaluation scores they found that comparing two cars on the basis of 2-5 attributes gives the biggest difference between the 'best' car and the others, but observed a steep decrease in this difference with the inclusion of further attributes in the consideration. This analysis suggests that the greater difference observed in the unconscious group, which is taken as superior performance, may simply be due to their relying on only a few retrievable items.

Others (e.g., Newell et al., 2008) have observed that the task in its typical design may be performed as an on-line judgment task, suggesting that the decisions are already made during the presentation phase, rather than during the 'unconscious processing interval'.

Despite these criticisms, the DWA task remains popular and further experiments have been reported in support of the original assumptions of the UTT (e.g., Ham & Van Den Bos, in press; Ham, Van Den Bos, & Van Doorn, in press). In a recent meta-analysis, Strick and his colleagues (Strick et al., n.d.) found support for the original claims of the UTT, interpreting the mixed results of the published studies as revealing moderating factors which determine when the effect does and does not happen.

In the experiments reported in this chapter, intuitive decision making was investigated using a replication of the DWA design. Intuition was interpreted as previously defined by researchers of implicit learning: conscious judgment knowledge about unconscious structural knowledge (e.g., Dienes, 2008). If UTT is tenable then the following criteria must be fulfilled: (1) the performance of the unconscious group should be superior to the performance of the conscious group and the unconscious group; (2) the performance of the unconscious group must be better than the performance of the immediate group; and (3) performance in the conscious group should report a reliance on conscious knowledge (memory) while the unconscious group should reflect a beneficial effect of what is subjectively reported as guessing.

#### Experiment 4.1: Deliberation-without-Attention Test Study

This experiment was conducted to allow a fuller examination of the assumptions of UTT using additional measures to those in the original design (Dijksterhuis & Nordgren, 2006). More specifically, the conscious status of structural knowledge was investigated after the participants made their judgments; furthermore, their subjective preference before the presentation was also measured. These measures were employed to assess the optimality as well as the conscious nature of these judgments.

In addition, a *Number Mean Estimation Test* and a *Bar Length Estimation Test* were designed to explore the phenomena using a paradigm which does not depend upon subjective judgments (allowing performance to be objectively assessed). Previous analyses have revealed that the subjective preference for the complex stimuli (e.g., cars, housemates) in the DWA task depends on the presentation order and some individual difference, neither of which is reflected by the ratings of individual attributes (Newell et al., 2008).

Therefore, instead of multi-attribute stimuli such as housemates, the participants were presented with blue and red digits in fixed order in the *Number Mean Estimation Test*. The participants were then asked to estimate the average of the red digits and the average of the blue digits, in a counterbalanced order. In a similar fashion, the *Bar Length Estimation Test* presented bars of different lengths in one of two colours. Here the task was to assess the average length of the bars of each colour after all presentations. These tests should make it possible to analyse the differences between the three DWA conditions on a more objective basis. If the unconscious processing leads to more optimal representation of complex information then a tendency for this group to produce more correct answers should be found in these tests.

## Method

### *Participants*

The participants were 72 undergraduate students (41 female and 31 male;  $M = 21.86$  years,  $SD = 3.11$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Each participant received 1500 HUF (approximately 5 GBP) for participation in a 45 minute session comprising several unrelated experiments; this study made up the second half of the session. The testing was conducted in three separate sessions, and individuals were randomised to each condition within each session. About 25 participants took part in one session where they were tested in the same classroom at separate computers.

### *Materials and Procedure*

The participants were seated approximately 60 cm from the computer monitor and were presented with instructions on the screen. The test software was programmed in

*Microsoft Visual Basic 2008*, running under *Microsoft Windows XP* operating systems on a set of identical desktop computers. Responses were collected via the keyboard.

The experiment consisted of three tasks in the following order: *Housemate Rating Test*, *Number Mean Estimation Test*, and the *Bar Length Estimation Test*.

*Housemate Rating Test.* Participants were informed that they were taking part in a decision making experiment during which they would be presented with descriptions of three potential housemates (László, István, Zoltán), after which they would be asked to rate each housemate. Stimuli were those used by Dijksterhuis (2004; Experiment 3), translated into Hungarian including any necessary cultural adjustments (Appendix G). Prior to the main task, half of the participants in each group were required to rate the subjective importance of twelve attribute dimensions for a housemate (e.g., cooking skills) on a 7-point Likert scale from 1 (very unimportant) to 7 (very important).

36 sentences were constructed, each describing a single attribute of one housemate on one of the twelve dimensions. Each described the housemate as either positive (e.g., “*László is very friendly*”) or negative (e.g., “*István is not very tidy*”) on one dimension. Housemate names and attributes were counterbalanced across participants. For each participant the most attractive housemate (hereafter Housemate A) had 8 positive and 4 negative attributes; the least attractive housemate (Housemate C) had the reverse attribute on each of these dimensions, giving 4 positive and 8 negative attributes. Finally, Housemate B had 6 positive and 6 negative attributes. The sentences were presented in a random order for 3000 ms each with 500 ms blank screen between each sentence.

Following presentation of the sentences, participants either rated the housemates immediately (Immediate Decision condition), or after a four minute interval. In the Conscious Thought condition, the names of the three potential housemates were presented on the screen and participants were encouraged to use the four minutes as thinking time. In the

Unconscious Thought condition, participants were required to perform a 1-back task during the four minute interval. In this task, a random sequence of the letters A, B, and C appeared on the screen, each letter shown for 1900 ms with an 800 ms ISI. Participants were instructed to decide if the letter was the same as the previous one, indicating their response by pressing one of two keys on the keyboard (X for same, M for different).

Participants rated their impression of each potential housemate using three identical on-screen 7-point Likert scales, ranging from 1 (extremely negative) to 7 (extremely positive). For half of the participants the names of the housemates were arranged in A-B-C order (as in Dijksterhuis, 2004); for other participants the names were presented in C-B-A order. After four minutes, during which they were presented with the *Number Mean Estimation Test*, all participants rated the subjective importance of twelve attribute dimensions for a housemate, as described above (half of the participants were re-rating these dimensions).

Finally, participants were asked to report how much they had relied on memories of specific attributes whilst rating the housemates. This was done using a numerical response reported on a scale from 0 (pure intuition/guess) to 10 (pure memory).

*Number Mean Estimation Test.* This test was structurally equivalent to the *Housemate task* with the modification that instead of descriptive attributes the participants were presented with one digit numbers (0-9). They received the following instructions:

*“In the following task you will be presented with blue and red numbers. During the task you should attend to both the colours and the values of the numbers. After each number, press key X if the number has different colour from the previously presented number. If the two numbers had the same colours and the new number is bigger then press key M, otherwise do*

not press any keys. Start the task from the second number presented. Later on you will have to evaluate these numbers according to their colours and values.”<sup>11</sup>

The numbers were presented on the screen in one of two fixed orders. The fixed orders were designed to detect a bias to overweight the recently presented numbers (*recency bias*) in *List A* and the primarily presented numbers (*primacy bias*) in *List B* (Figure 41) to allow us to test the effect of presentation order. A random half of the participants in each group (Conscious Thought, Unconscious Thought, Immediate Decision) were presented with the numbers in the order of *List A*, the other half of each group were presented in the order of *List B*. Our hypothesis was that the worse the performance on a particular list, the more that subgroup was affected by the biasing nature of the presentation order used in that list.

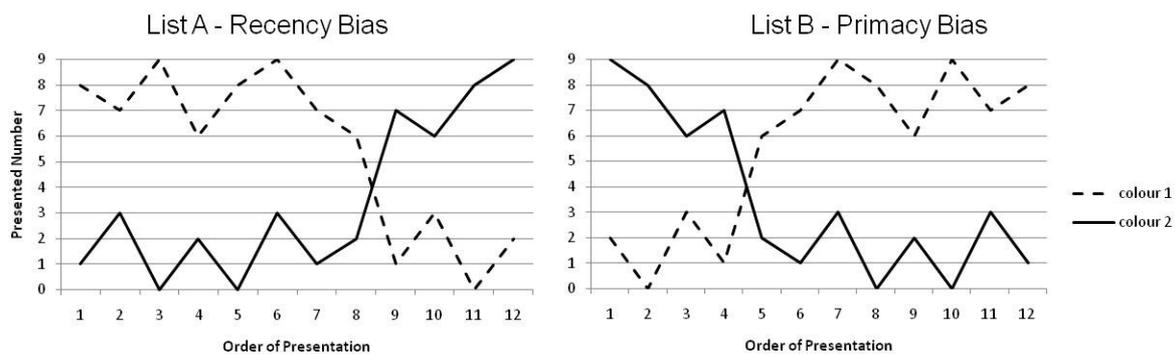


Figure 41. The order of presentation of the numbers to detect recency bias (*List A*) and primacy bias (*List B*). For those who received *List A* the recently presented numbers would impair the performance, while in *List B* a primacy effect would be misleading.

The colours were counterbalanced across the two groups of numbers. For a random half of the participants the blue numbers were larger, for the other half the red numbers were larger<sup>12</sup>.

<sup>11</sup> Translation of the original Hungarian instructions.

<sup>12</sup> A comparison of the difference scores showed no evidence that the colour of the numbers had an effect on evaluating their means,  $t(128) = 1.55, p = .123, d = .08$ .

Each number stayed on the screen for 2100 ms and was followed with a 400 ms pause. For the Conscious and the Unconscious Thought groups the delay time after the presentation of the list was 2 minutes, during which the Conscious Thought group was instructed to think about the mean value of the presented numbers by colours. During an equivalent interval the Unconscious Thought group was presented with the same n-back task as they were in the *Housemate Rating Test*. The Immediate Decision group had to make decisions after the presentation without any delay.

In the decision making phase the participants had to adjust one slider on the screen for each colour to estimate the average value of the presented numbers between 0 and 9. They were also asked to report their confidence in their ranking of the means of the two coloured numbers in a scale ranging from 1 to 100 where the higher numbers represented more confidence.

*Bar length estimation test.* This third task was structurally identical to the *Number Mean Estimation Test* with the modification that instead of abstract symbols (numbers) the stimuli were visual features: horizontal bars. The values of the numbers were represented in the length of the bars. The bar length were  $100 \text{ pixel} + y \times 25 \text{ pixels}$  where  $y$  was identical with the numbers in *List A* and *List B* in the *Number Mean Estimation Test*. The bars were presented in two new colours: green and yellow (counterbalanced). During presentation of the bars, the participants had to press key X if the current bar had different colour from the previous bar, if the colours of the two bars were same and the second bar was longer then they had to press key M, otherwise they did not have to press any keys. The aim of this instruction was for the participants to concentrate on both the colours and the length of the stimuli during the presentation. In the decision making part the participants had to estimate the mean length of the bars in two colours by adjusting two coloured sliders on the screen. In all other features the design of this task was identical to the *Number Mean Estimation Test*.

## Results

*Housemate Rating Test*

*Attitude rating.* Figure 42 shows the participants' ratings of the potential housemates, which were analysed using an ANOVA contrasting mean ratings values across the within-subject factor of Housemate, and between-subject factors of condition and gender. There was a clear preference between housemates, with higher ratings for housemates with more positive attributes,  $F(1.89, 130.44) = 54.09$ ,  $MSE = 3.35$ ,  $p < .001$ ,  $\eta^2_p = .44$  (Figure 42). Further analysis confirmed that each group showed independent evidence of differential preference, smallest  $F(98.11, 155.89) = 14.48$ ,  $MSE = 3.43$ ,  $p < .001$ ,  $\eta^2_p = .39$ , rating Housemate A significantly more positively than Housemate B, smallest  $t(23) = 2.25$ ,  $p = .03$ ,  $d = .46$ .

There was no evidence of any influence of the different experimental conditions, or gender, on these ratings:  $F_s < 1$  for all effects and interactions.

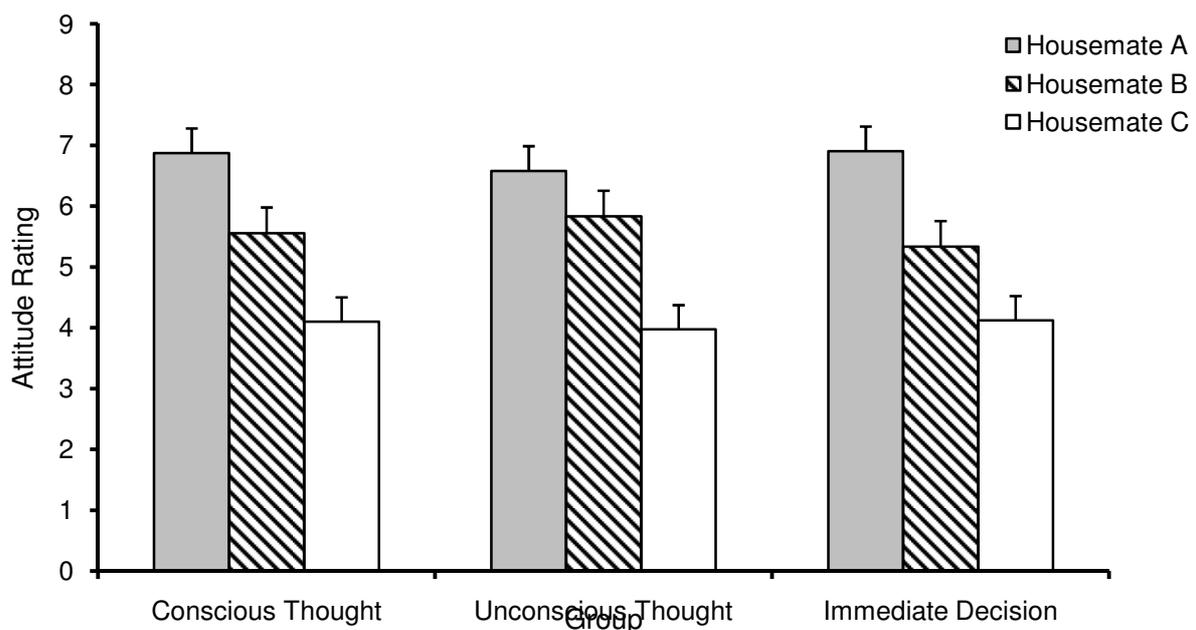


Figure 42. Mean attitude rating scores of each Housemate per groups. Error bars represent SEDs.

*Congruency with Personal Preference.* Following Dijksterhuis's (2004) procedure, a weighting index was calculated from the final ratings of the twelve dimensions for each participant. This is the sum of the subjective ratings of the eight dimensions on which Housemate A was described more attractively than was Housemate C, minus the sum of ratings of the four remaining dimensions (where Housemate C was described more positively than was Housemate A). This index thus reflects the degree to which Housemate A should be (subjectively) preferred to Housemate C for that individual; a low value indicates that the participant regards the few positive attributes of Housemate C, or the few negative attributes of Housemate A, as important.

This index was used by Dijksterhuis (2004) to evaluate the quality of the housemate judgments: insofar as participants rate Housemates A and C according to their subjective preferences, across participants the index should positively correlate with the degree of preference for Housemate A compared to Housemate C. Excluding those participants who 'incorrectly' rated Housemate A as less attractive than Housemate C<sup>13</sup> (four in the Conscious Thought condition, five in each of the other conditions), the correlations in the current study were as follows: Conscious Thought group  $r(21) = .29, p = .101$ ; Unconscious Thought group  $r(20) = .79, p < .001$ ; Immediate Decision group  $r(20) = .02, p = .481$ . The correlation was significantly higher in the Unconscious Thought than in the Conscious Thought condition ( $z = 2.29$  based on the difference between two Fisher-transformed  $r$  coefficients; (Howell, 2007)). These correlations follow the pattern reported by Dijksterhuis (2004).

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<sup>13</sup> The excluded participants were inconsistent with their decisions according to the logic of the original work (Dijksterhuis, 2004) since each participant's subjective weighting would have indicated preferring Housemate A over Housemate C. Nevertheless, the inclusion of the incorrect decision makers would give the following results: Conscious Thought group  $r(24) = .36, p = .080$ ; Unconscious Thought group  $r(24) = .254, p = .232$ , Immediate Decision group  $r(23) = .09, p = .685$ .

One acknowledged potential weakness of the Dijksterhuis (2004) study was that ratings for each dimension were elicited after the rating of housemates, and thus may have been influenced by the first rating process. In the present study, half of the participants in each group gave additional ratings of the attribute dimensions before the task, a manipulation that had no detectable influence on the rating of the three housemates  $F_s < 1$ . Using a weighting index calculated from the pre-task ratings only gave the same ordinal pattern of correlations among those who rated Housemate A more favourably than Housemate C: Conscious Thought group  $r(12) = -.09, p = .402$ ; Unconscious Thought group  $r(13) = .83, p < .001$ ; Immediate Decision group  $r(13) = .09, p = .391$ ; Unconscious Thought group correlation was significantly higher again than that in the Conscious Thought group,  $z = 2.26$ .

In summary, among those participants who discriminated between Housemates A and C, the magnitude of preference shown by participants in the Unconscious Thought condition more closely reflects individual subjective priorities than it does in the Conscious Thought condition.

*Conscious Status of Decision Knowledge.* The conscious status of structural knowledge used for the housemate judgments was analysed in the same manner as the subjective weighting index, by correlating the reported rate of reliance on memory with the degree of preference for Housemate A over C. This analysis revealed that superior performance (greater difference in attractiveness rating) was generally associated with greater reported use of explicit memory: Conscious Thought group,  $r(15) = .40, p = .137$ ; and Unconscious Thought group,  $r(16) = .57, p = .022$ ; Immediate Decision group,  $r(17) = .25, p = .341$ <sup>14</sup>. The observed correlation in the Unconscious Thought group contradicts the UTT account that suggests that enhanced performance by these participants is due to their greater use of unconscious knowledge.

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<sup>14</sup> The correlational coefficient of the Conscious Thought group and the Unconscious Thought group was not different ( $z = 0.56$  based on the difference between two Fisher-transformed  $r$  coefficients).

*Presentation order effect.* A further analysis was performed to assess the claim that the diverted attention condition would produce ratings based on a more optimal integration of information. Optimal use of information must result in ratings that are uninfluenced by factors such as the order in which positive and negative attributes were presented. As presentation order was randomised, the influence of order can be evaluated by assessing, for each participant, the degree to which the positive attributes of a particular housemate occurred early or late in the sequence.

The few negative attributes of Housemate A may occur predominantly in the early or late part of the sequence; a similar pattern may arise for the few positive attributes of Housemate C. For each participant, a regression line was calculated for predicting the valence of the twelve attributes (positive = 1 or negative = 0) from their position within the 36 item sequence. Positive slopes thus reflect presentation orders where the positive attributes were predominantly late in the sequence, and whereas a negative slope reflects the reverse.

Table 8 shows that the attractiveness ratings of both Housemates A and C were negatively correlated with the degree of slope in the attribute sequence. The table shows test statistics for null hypotheses of zero correlation combined across housemates for all groups (calculated from the mean of the Fisher's transformed correlation coefficients; Howell, 2007). There was a significant negative correlation overall, indicating that earlier presentation of the positive attributes produced higher attractiveness ratings. This tendency to overweight the information presented earlier was statistically significant for participants within the Unconscious Thought group. These data thus provide no support for the prediction that the Unconscious Thought manipulation produces a more optimal weighting of the attributes.

Table 8

*Slope - Performance Correlation Coefficients for Housemate A and Housemate C*

	Housemate A	Housemate C	Combined
Conscious	$r(24) = -.16$	$r(24) = -.05$	$Z_r = -.69$
Unconscious	$r(24) = -.39$	$r(24) = -.50^*$	$Z_r = -3.11^{**}$
Immediate	$r(24) = -.14$	$r(24) = .05$	$Z_r = -.29$
Combined	$Z_r = -1.89$	$Z_r = -1.45$	$Z_r = -2.36^*$

*Note.* Combined values represent standardised sum of the Fisher's transformed correlation coefficients (Howell, 2007). Significance tests of zero correlation hypothesis are \*  $p < .05$ , \*\*  $p < .01$ .

*Number Mean Estimation Test*

*Group Differences.* A mixed ANOVA with Colour as within-subjects factor and Group as between-subjects factor showed that the participants within the three groups estimated the means of the two colour numbers differently,  $F(1,111) = 5.86$ ,  $p = .017$ ,  $\eta_p^2 = .05$ , and, crucially, that there was an interaction between the groups and the estimated means,  $F(2,111) = 3.15$ ,  $p = .046$ ,  $\eta_p^2 = .05$ , (Figure 43), indicating differences in performance between groups. Examination of the performance levels between the groups, measured as the difference between the colour estimates (Figure 43), revealed that the major difference was between the Conscious Thought and the Unconscious Thought groups,  $t(100) = 2.33$ ,  $p = .022$ ,  $d = .14$ , where the Conscious Thought group ( $M = 1.22$ ) outperformed the Unconscious Thought group ( $M = .11$ ) (the actual mean difference was 2 in the test).

Examining the performance of each group separately showed that, on average, the Conscious Thought group correctly ranked the average of the larger numbers higher than the average of the smaller numbers, two-tailed  $t(47) = 3.63$ ,  $p < .001$ ,  $d = .52$ , while for the

Unconscious Thought group the difference between the two ratings was not reliable,  $t(45) < 1$ . In summary, when using numbers rather than subjective preference for multi-attribute choices, this test provides evidence for the benefits of decision making based on deliberate thinking.



Figure 43. The difference between the estimation of the mean of the higher numbers and the mean of the lower numbers in the three experimental groups (the actual difference was 2). The error bars represent SEMs.

*Gender Differences.* A Group  $\times$  Presentation order  $\times$  Gender ANOVA model revealed that Gender did not have any effect on the difference scores of the number mean estimations,  $F(1,102) < 1$ . Therefore, this factor was excluded from the further analyses.

*Presentation order.* The effect of presentation order on the estimations was measured by the comparison of the performance after the differently ordered presentation sequences. The overall pattern seen in Figure 44, is similar to the previous results in that the ranking was worse overall in the ‘primacy bias’ presentation order, suggesting that early information is

overweighted. However, in a Group  $\times$  Presentation order ANOVA the effect of presentation order did not reach significance,  $F(1,124) < 1$ , (Figure 44). nor was there any Group  $\times$  Presentation order interaction,  $F(2,124) < 1$ . An additional test confirmed that presentation order had no effect upon the proportion of participants who ranked the numbers in the right order: no presentation order effect,  $\chi^2(70) = .58, p = .810$ .

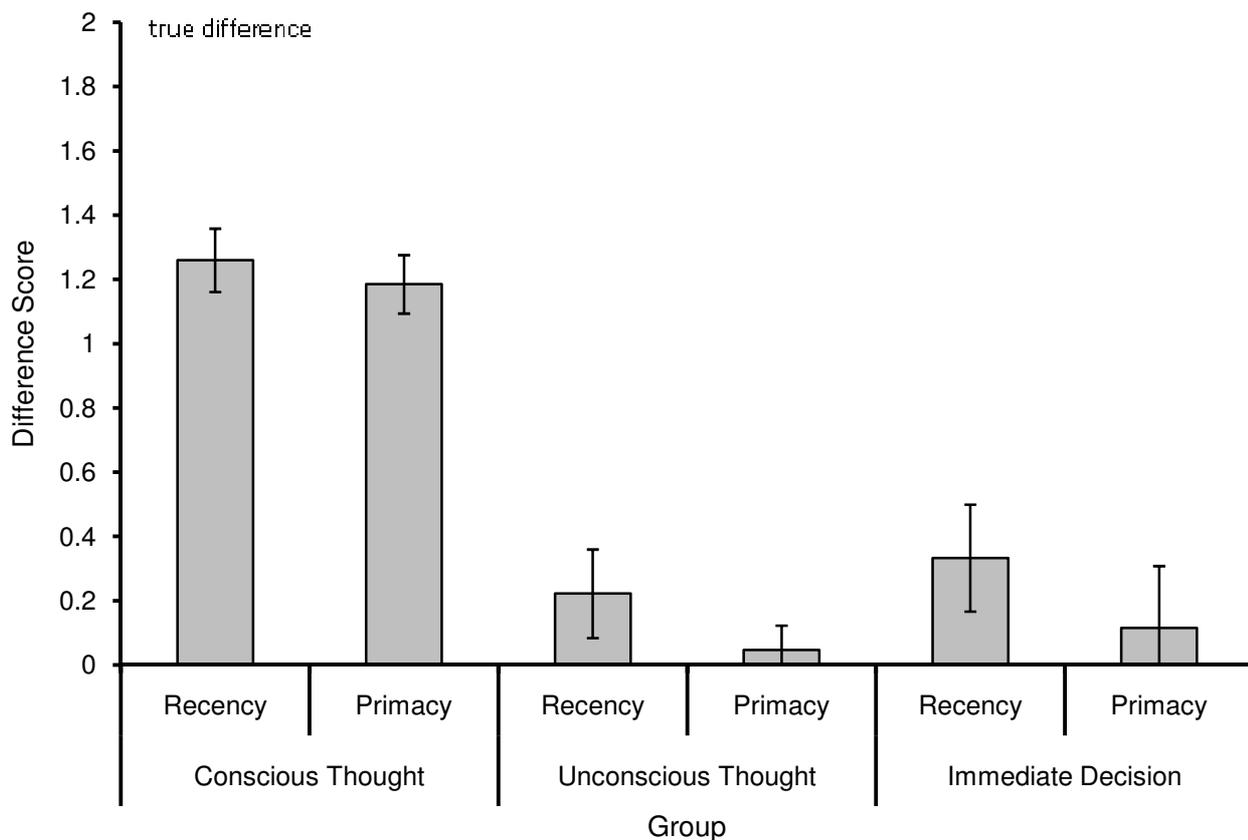


Figure 44. The effect of presentation order in the Number Mean Estimation test in the three experimental groups. The actual difference between the two colour numbers in the test was set to be 2. The participants in the Recency subgroup received the numbers in an order where overweighting the recent items could bias the performance; in the Primacy subgroup the primary items in the list were misleading. Error bars represent SEMs.

*Confidence rating.* In the second and third testing sessions a confidence measurement was taken after the ranking of the coloured numbers. In this measure the participants had to rate how confident they were about the order of the numbers they ranked. The scale ranged

between 1 and 100 where the higher numbers represented more confidence. Overall, confidence ratings did not correlate with performance  $r(129) = -.03, p = .704$ .

### *Bar Length Estimation Test*

*Performance.* A mixed ANOVA on the estimation scores, with bar colour as a within-subject factor and Group as a between-subject factor showed a difference between the estimated length of the presented bars by colour,  $F(1,87) = 79.12, p < .001, \eta^2_p = .48$ , where the mean of the estimations of the longer bar colours were, correctly, higher than the shorter bars (measured in units equivalent to the numbers in the previous task). This pattern was true for each group: Conscious Thought group,  $t(38) = 5.55, p < .001, d = .89$ ; Unconscious Thought group,  $t(37) = 5.62, p < .001, d = .91$ ; Immediate Decision group  $t(15) = 6.26, p < .001, d = 1.57$ , with no evidence of a difference between the groups  $F(2,87) = 1.43, p = .246, \eta^2_p = .03$  (Figure 45).

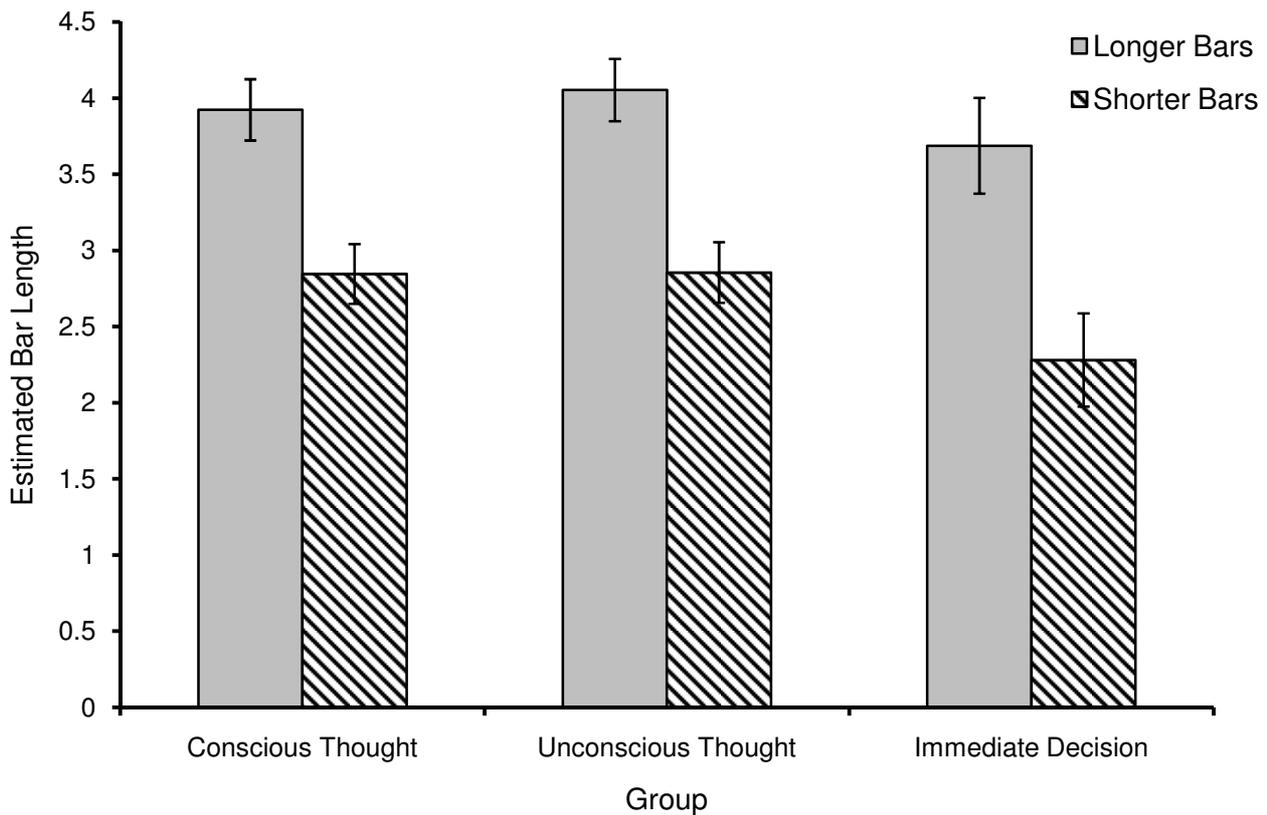


Figure 45. Estimated average bar length of the three experimental groups. The bar length were measured in units equivalent to the numbers in the previous experiment. The true average difference between the length bars was 2 units. Error bars represent SEMs.

*Gender Differences.* A Group  $\times$  Presentation order  $\times$  Gender ANOVA showed no significant effect of Gender,  $F(1, 78) = 3.02, p = .062, \eta^2_p = .04$ .

*Presentation order.* The effect of presentation order on the difference scores for estimations did not reach significance,  $F(1, 87) = 3.18, p = .078, \eta^2_p = .04$  (Figure 46), nor was there any Group  $\times$  Presentation-order interaction,  $F < 1$ . Inspection of Figure 46 indicates that the effect is numerically largest in the Conscious and the Unconscious groups (the groups with delay between the presentation and the rating), and a post-hoc analysis of presentation order across these groups suggested an effect,  $F(1, 73) = 6.57, p = .012, \eta^2_p = .08$ . Whilst this result cannot be regarded as conventionally significant, due to the lack of overall effect or interaction, this pattern suggests that a delay between the presentation and the decision making phase may encourage overweighting the recently presented bars.

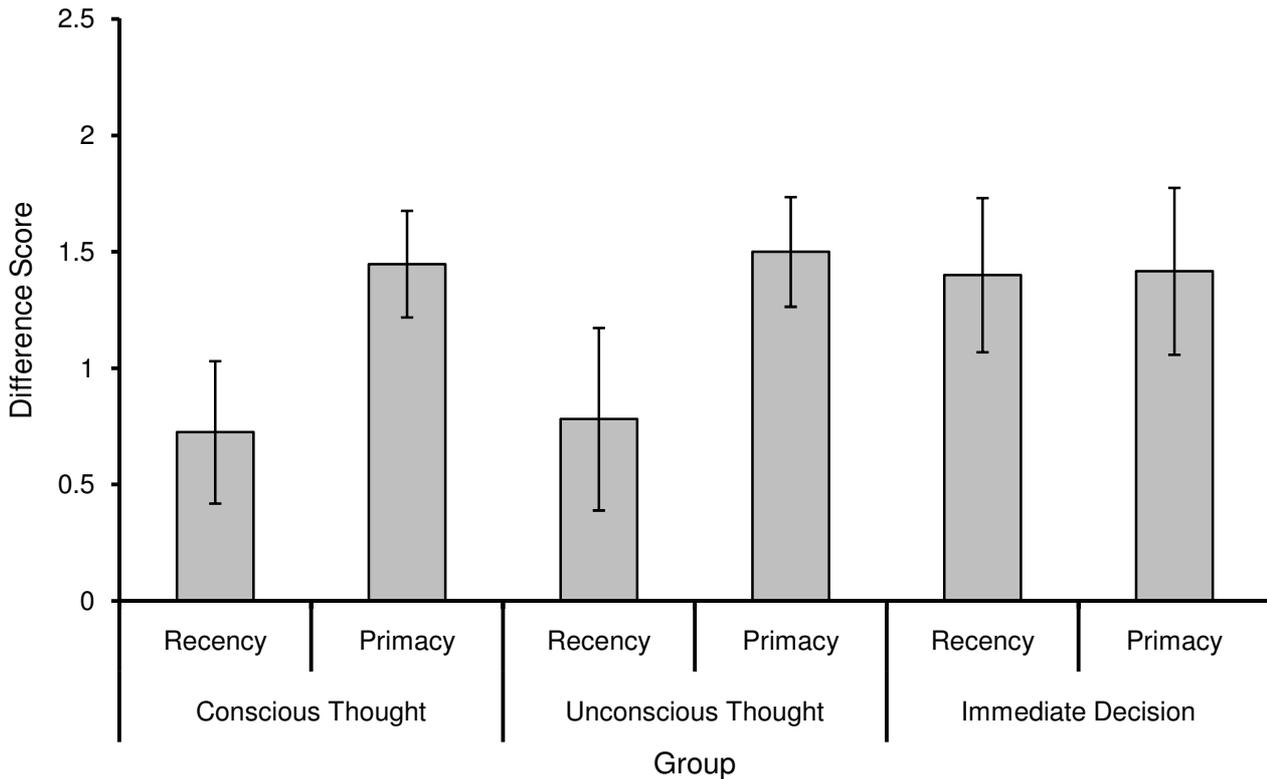


Figure 46. The effect of presentation order in the bar length estimation in the three experimental groups. The actual difference between the two colour bars in the test was set to be 2 units. Error bars represent SEMs.

*Confidence rating.* In the second and third testing sessions a confidence measurement was used after the ranking of the colour bars. In this measure the participants had to rate how confident they were in the order of the numbers they ranked. The scale ranged between 1 and 100 where the higher numbers represented more confidence. Overall, the confidence ratings did not correlate with the performance,  $r(72) = -.08$ ,  $p = .460$ .

## Discussion

This experiment consisted of a replication of a test of the deliberation without attention paradigm and two further tests designed such that the final rating of the stimuli can be more objectively assessed. This study tested two major claims of the UTT. The first question addressed here focused on whether the distracted attention group performs better in a complex judgment task. The second aim was to test whether the performance of the

distracted attention group is due to the more optimal weighting mechanisms of unconscious thought.

The *Housemate Rating Test* failed to replicate the original finding (Dijksterhuis, 2004) that the Unconscious Thought group performs better in the task in terms of rating, however, the pattern of stronger correlation between preference and rated subjective dimension weights was replicated.

All three groups performed well on the task, no difference was found between their performances in this measure. In accord with the earlier study, and with the prediction of the UTT, the preferences of the Unconscious Thought group correlated with their ratings of the importance of the attribute dimensions.

The measure of reliance on memory showed, however, that the more the members of the Unconscious Thought group relied on memory, the better performance they showed. Had unconscious knowledge been responsible for the greater correlation with the subjective index, the results would have shown the opposite, that is that more reliance on intuition would have been found among those who performed better. This pattern of results, however, indicates that if the Unconscious Group was better in any way, then there is no basis to assume that this was the result of unconscious thoughts, but rather from conscious reflection.

The results refute the second assumption as well, since there is no evidence that the diverted attention group relied on more optimal weighing mechanisms. Rather, this group showed sensitivity to presentation order, the earliest-presented attributes got overweighed, suggesting a primacy bias, or early impression formation.

The *Number Mean Estimation Test* was designed to reduce the subjectivity of the evaluation of the performance. The ranking of the numbers of the two colours was best

achieved by the Conscious Thought group, and the other two groups did not perform reliably above chance level. It seems that the good performance was due to the conscious deliberation time that was provided to the first group. According to UTT, unconscious thought is able to weigh the objects of choice more optimally, which implies that it would lead here to an approximately good estimation. On the other hand, one could argue that numbers are too abstract to be processed unconsciously. The UTT and previous empirical reports assume, however, that the unconscious can deal with numbers, not in an arithmetic level, but it can integrate the numerical information into rough estimations (Betsch, Plessner, Schwieren, & Gutig, 2001; Dijksterhuis & Nordgren, 2006).

The *Bar Length Estimation Test* presented a different pattern of results. Here, all three groups performed equally well on the estimation test. It is difficult to determine from the data whether the difficulty or the nature of the task was different from the number task to allow this result. It is possible that the perceptual nature of this task is an important factor since it showed a strong recency of presentation effect, in contrast to the overweighting of early information observed in the other tests. Once again, the Unconscious Thought group did not perform better than the Conscious Thought group.

In summary, the three tests provided no support for the predictions of the UTT. The only measure in which the Unconscious Thought group came out better was the correlation of the housemate rating and the subjective importance of the attribute dimensions. A crucial finding of this study showed, however, that the performance of the diverted attention group strongly correlated with their reliance on memory. In addition, the judgments of the Unconscious Thought group reflected a presentation order bias. It is plausible to think, therefore, that the diverted attention condition triggered unconscious processing, nor did it lead to more optimal weighting of the objects of choice.

#### Experiment 4.2: Modified Deliberation-Without-Attention Test Study

It is important to notice that the lack of difference between the groups in the *Housemate Rating Test* and the *Bar Length Estimation Test* in the previous experiment along with the effect of presentation order in these tests may imply that the participants have made their rating during the presentation phase, more similarly to online judgment tasks (Hastie & B. Park, 1986). Along with all of the 16 experiments included within Acker's (2008) meta-analysis, participants were aware of the task demands before the presentation of the attributes.

Thus, it is possible that the experimental manipulation did not affect performance because the participants had already made their decisions before the manipulation occurred. Consistent with this possibility, Lassiter et al (2009) have shown that the Deliberation without Attention (DWA) effect is abolished if participants are instructed to memorise information, rather than to form a global impression during the presentation phase.

In this next experiment, the participants were neither asked to form an impression, nor were they informed about the latter task demands at the beginning of the experiment. If the available information is processed more optimally through unconscious thought, then in this design, the decisions can be made only during the manipulation period, and so we should expect a stronger manifestation of unconscious processing.

## Method

### *Participants*

The participants were 56 predominantly undergraduate students (32 female and 24 male;  $M = 21.44$  years,  $SD = 5.93$  years) of Eötvös Loránd University, Budapest, Hungary and all were native speakers of Hungarian. Each participant received 1000 HUF (approximately 5 GBP) for participation in a 45-minute session comprising several unrelated experiments; this study made up the second half of the session.

### *Materials and Procedure*

This experiment consisted only of the *Housemate Rating Test*. The procedure of this test differed from the previous procedures in only one feature. Before the presentation of the stimuli sentences the participants were not informed that their task after the presentation would be to rank the objects. To ensure that the participants processed the necessary information, they were told to read the presented sentences carefully as they would need to use them in a later part of the test.

## Results

*Attitude rating.* Just as in the previous experiment, an ANOVA with Housemate and Gender as within-subject factors and Group as between-subject factors revealed that the participants showed clear preference between the housemates,  $F(2, 100) = 15.80$ ,  $p < .001$ ,  $\eta^2_p = .24$ , (Figure 47). There was no reliable effect of Gender on these ratings,  $F(1, 50) = 2.23$ ,  $p = .147$ ,  $\eta^2_p = .04$ . There was no evidence of any influence of the different experimental conditions on the groups,  $F(2, 50) < 1$ . Further analysis confirmed that each group showed independent evidence of differential preference, smallest  $F(2, 36) = 4.50$ ,  $p = .018$ ,  $\eta^2_p = .20$ .

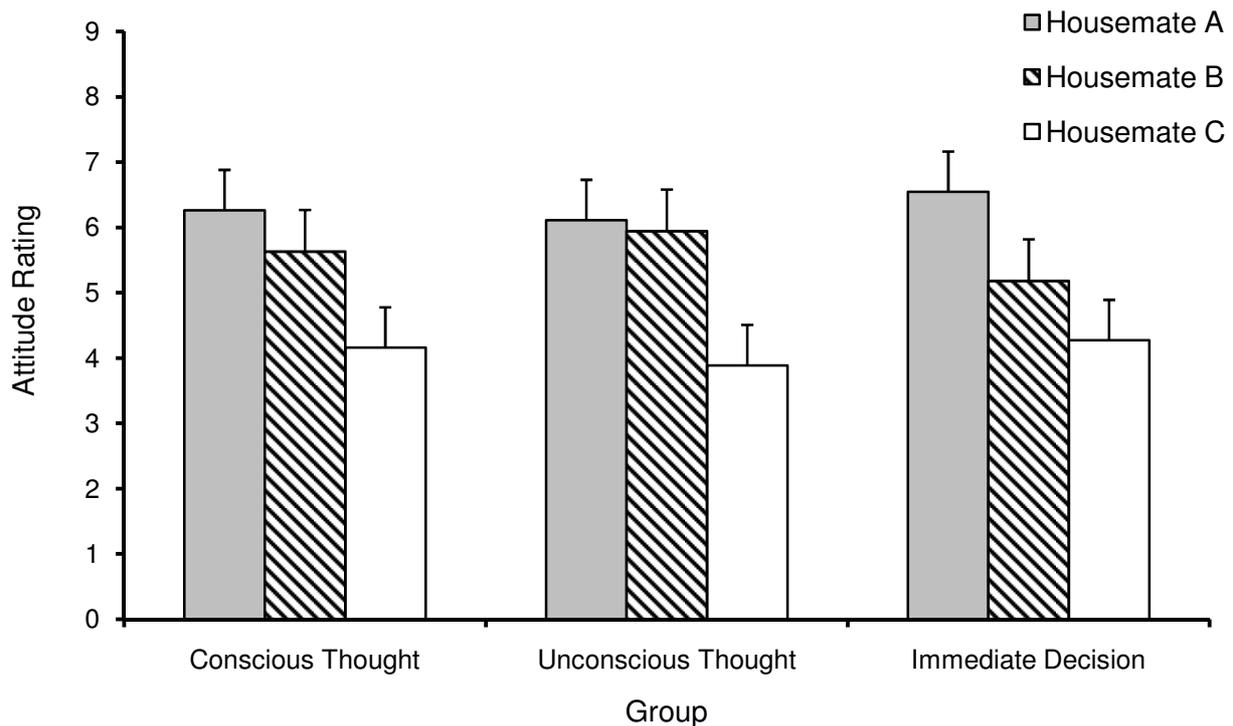


Figure 47. Mean attitude rating scores of each Housemate per groups. Error bars represent SEDs.

Comparing this experiment with the previous study, by including a factor of Experiment within the ANOVA model showed that, overall, the absence of the pre-presentation information of the aim of the experiment had a small, but significant effect on the average rating of the housemates,  $F(1, 125) = 5.678$ ,  $p = .019$ ,  $\eta^2_p = .04$ .

*Congruency with Personal Preference.* In this study the importance of the dimension was assessed only after the decision making phase to prevent any premature insight into the aim of the presentation. To evaluate the quality of the housemate the previously described subjective weighting index (Dijksterhuis, 2004) was correlated with the degree of preference for Housemate A to Housemate C. Excluding those participants who ‘incorrectly’ rated Housemate A as less attractive than Housemate C (six in the Unconscious Thought condition, five in each of the other conditions), the correlations in the current study were as follows: Conscious Thought group:  $r(14) = .21$ ,  $p = .469$ ; Unconscious Thought group:  $r(12) = -.16$ ,  $p$

= .625; Immediate Decision group:  $r(17) = .10$ ,  $p = .709$ . The correlation in the Unconscious Thought group in this experiment was significantly weaker than in the previous experiment ( $z = -3.59$  based on the difference between two Fisher-transformed  $r$  coefficients).

*Conscious Status of Decision Knowledge.* The conscious status of structural knowledge used for the housemate judgments was analysed in the same manner as in the previous study, by correlating the reported rate of reliance on memory with the degree of preference for Housemate A over C. This analysis revealed that superior performance (greater difference in attractiveness rating, as defined by Dijksterhuis, 2004) was generally associated with greater reported use of explicit memory,  $r(59) = .32$ ,  $p = .015$ . However, whilst still positive, this correlation for the Unconscious Thought group was not significant this time,  $r(12) = .12$ ,  $p = .705$ , all the three groups reported to rely more on memory than guess (Figure 48). Rating from 0 (pure guess) to 10 (pure memory) the mean values were the following: Conscious Thought group  $M = 6.63$ ; Unconscious Thought group  $M = 6.33$ ; Immediate Decision group  $M = 6.36$ . The groups reported to rely on memory equally,  $F(2, 58) < 1$ .

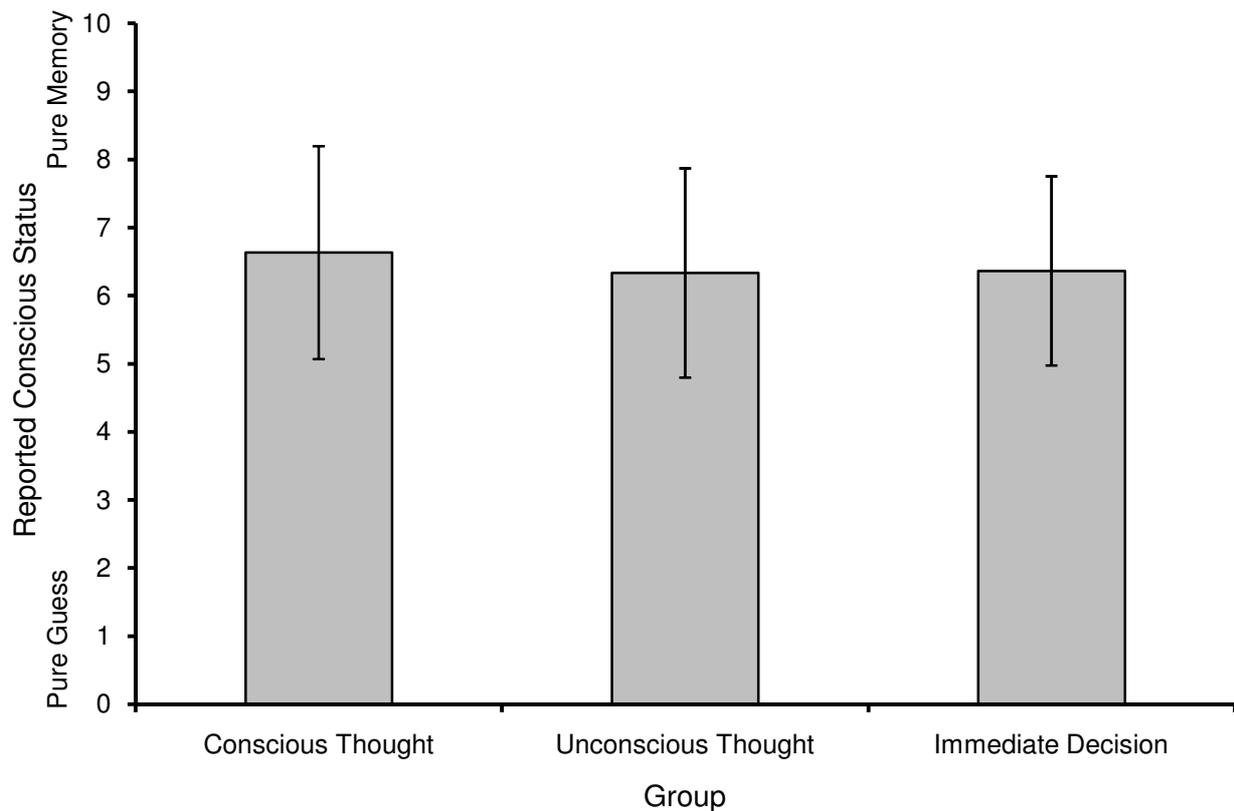


Figure 48. Reported conscious status of decision knowledge. The bars represent the mean values of how much the participants in each group reported relying on memory vs. guess when rating the potential housemates. The error bars represent SEMs.

*Presentation order effect.* Similarly to the previous experiment, in order to assess the influence of the presentation order on the rating of the potential housemates correlational coefficients were calculated between the regression line slope values and performance. The values of the slopes reflect the degree to which the positive attributes of a particular housemate occurred early or late in the sequence.

Table 9 shows test statistics for null hypotheses of zero correlation combined across housemates for all groups (calculated from the mean of the Fisher's transformed correlation coefficients). The individual correlation coefficients and the combined standardised sum values indicate that the attractiveness ratings of both Housemates A and C did not correlate significantly with the degree of slope in the attribute sequence. This absence of significant

correlations provides no evidence that the presentation order had a (linear) effect on the attractiveness ratings. We can conclude from these results that the presence of the pre-presentation instructions in the typical procedure of this test may be, in part, able to induce presentation order bias, perhaps by making participants engage in early impression formation.

Table 9

*Slope - Performance Correlation Coefficients for Housemate A and Housemate C*

	Housemate A	Housemate C	Combined
Conscious Thinking	$r(19) = -.13$	$r(19) = -.21$	$Zr = -.15$
Unconscious Thinking	$r(18) = .33$	$r(18) = .21$	$Zr = .24$
Immediate Decision	$r(22) = .03$	$r(22) = -.17$	$Zr = -.06$
Combined	$Zr = .11$	$Zr = -.07$	$Zr = .03$

*Note.* Combined values represent the standardised sum of the Fisher's transformed correlation coefficients (Howell, 2007). None of the values are significant.

## Discussion

In this final experiment the participants were presented with a modified version of the *Housemate Rating Task* where they were not aware of the task of rating the potential housemates before the beginning of the conditions. The crucial question was to see how much of the decisions in the previous experiments could have been a result of impressions formed already during the presentation. It was reasoned that the lack of a DWA effect in the previous experiments could have been the result of this early impression formation and the present design should allow more manifestation to the unconscious processing in the diverted attention condition.

Comparing the three groups on their rating about the three housemates, no difference was found. If, following the practice of the original study (Dijksterhuis, 2004), we regard the differential rating of the best and the second best housemates as a pivotal measurement in this test, then we could conclude that the four minutes delay inserted between the presentation of the attributes and the decision making had no beneficial effect on the performance of the participants; neither the Conscious nor the Unconscious Thought group could reliably differentiate between the best and the second best housemates. This result also suggests that the better performance of the groups in the previous experiment can be attributed to the fact that they had the opportunity to make their ratings online, during the presentation.

A further difference from the previous experiment is that among those participants who rated Housemates A above Housemate C, the magnitude of preference did not reflect their reported subjective priorities particularly closely; for the Unconscious Thought group, there was a significant change from the previous study. In accord with the results of the housemate rating, these results show a detrimental effect of the withdrawal of the instruction to form impression from before the presentation of the attributes.

The assessment of conscious status of decision knowledge showed that all the three groups thought to make their decisions more on the basis of memory than guess. Crucially, there was no difference between the groups on this measure, the Unconscious Thought group reported relying on memory just as highly as the other groups. This result indicates that after the modification of the design of the test we have no more evidence to claim that the diverted attention condition facilitated unconscious processing.

Finally, in this modified design the performance on the housemate rating did not correlate with the presentation order of the positive attitudes of the housemates. This absence of correlations suggests that the presentation order did not have an (linear) effect on the attractiveness ratings. We can conclude from these results that the presence of the pre-presentation instructions in the typical procedure of this test, such as *Experiment 4.1*, induces a presentation order bias due to early impression formation.

This experiment was motivated by two questions. The first question was whether preventing the participants from early impression formation would lead to different results from the previous experiment. Secondly, if the conditions have greater influence on the group performance in this design, then would the effect of the unconscious processing be better observed? The data indicated that the prevention of the opportunity of early impression formation had a detrimental effect on the test performance relative to the previous experiments, suggesting that the early test partly measured online judgment formation rather than processing during the post presentation delay. The analysis also showed that the diverted attention condition relied more on memory than intuition during the judgment task, not differently from the other groups.

In conclusion, this control study did not provide evidence for the predictions of the UTT. Rather it suggests that the DWA testing paradigm in its typical design measures the memory effects of an online judgment task.

## Chapter Discussion

The findings of the experiments in this chapter challenge the conclusions of Dijksterhuis (2004) in several aspects. Firstly, there was no evidence found that the Unconscious Thought condition produces detectable improvement in choice performance. This finding accords with recent attempts to replicate this phenomenon. Newell and colleagues (Newell, Wong, Cheung, & Rakow, 2008) failed to replicate previous evidence in support of UTT in a series of studies; Acker (2008) reported a meta-analysis showing only a modest benefit for choices following unconscious thought conditions in all the published data using this paradigm (mean effect size  $g = .251$ ).

As reported by Dijksterhuis (2004), the rated attractiveness of a housemate reflected each participant's subjective preference for the set of attributes most closely in the Unconscious Thought condition. This replicates a tendency which Dijksterhuis regarded as evidence for the benefits of unconscious thought. However, more detailed investigation of these data challenge the conclusions of Dijksterhuis (2004) in several ways.

Firstly, if unconscious thought is advantageous, it follows that a greater use of unconscious knowledge will result in superior performance. However, performance within the Unconscious Thought condition was positively correlated with greater reported reliance on specific memories of attributes: the members of this group who performed best were those who responded on the basis of conscious, explicit memory.

Secondly, according to the Weighting Principle of the UTT, advantageous decisions following unconscious thought arise because such processing combines a large amount of information in an unbiased manner. It would follow that participants in the Unconscious Thought condition would be less influenced by serial position effects in presentation. Analysis of serial position effects revealed that attributes at the beginning of the presentation had more impact on ratings than those presented later. Crucially, no evidence was found that

the effects of serial position were reduced in the Unconscious Thought condition. The analysis of serial position suggests that, for all groups, attributes early in the series have a greater influence on the final ratings.

Along with all of the 16 experiments included within Acker's (2008) meta-analysis, participants were aware of the task demands before the presentation of the attributes. As such, this pattern suggests that participants based their ratings on judgements formed online during presentation (Hastie & B. Park, 1986). The data of the second experiment supported this conjecture: without pre-presentation information about the latter judgment task the participants performed differently from the previous findings. These findings question to what degree the DWA effect described by Dijksterhuis (2004) was a result of online judgments and how much was it a manifestation of the different modes of thought.

One criterion for regarding judgment as intuitive is that the structural knowledge upon which it relies is unconscious (Dienes, 2008). The results of this study suggest that the diverted attention paradigm used by Dijksterhuis and colleagues does not produce 'intuitive' ratings in the manner claimed. Rather, it seems that explicit knowledge is the main modulator of performance in this test, regardless of the DWA manipulation. The Number Mean Estimation task showed with more objectively assessable stimuli that allowing time for the conscious thought leads to convincingly better judgments.

Given that the diverted attention condition does not seem to produce more intuitive judgments, it is not immediately clear how the divided attention manipulation might produce the modest enhancements in performance suggested by a recent meta-analysis (Acker, 2008), or the improved correspondence to individual preference found in the current study. An explanation for these effects may be found in Newell and colleagues' (2008) demonstration that the distraction manipulation leads to explicit recollection of *fewer* attributes.

It is likely that participants are more probable to recall those attributes that are either of subjective importance, or those consistent with their online impression. If so, the items most likely to be forgotten following the distraction are those which are subjectively rated as unimportant or inconsistent with the general impression. Thus a recollection of fewer items will produce a greater difference in ratings, similar to the 'less-is-more' effect reported by Goldstein and Gigerenzer (2002). This argument is very similar to that proposed to account for the DWA effect in a similar paradigm by Rey and colleagues (Rey et al., 2009).

In summary, this investigation extends the argument presented by other recent works disputing laboratory demonstrations of beneficial unconscious thinking. The DWA manipulation results in performance that is no less associated with reliance on explicit, consciously available memory, and no less influenced by presentation order. Group differences in this paradigm, therefore, do not arise from the type of unconscious processing proposed by UTT.

## VI. GENERAL DISCUSSION

This thesis began with questions about the role of awareness and attention in human learning and decision making. The 11 experiments, which were conducted to explore certain aspects of these topics, have approached them through different avenues. Tests of awareness were an integral part of the designs of each of these experiments, and the role of attention was analysed either indirectly (Chapter II), or directly (Chapter, III, IV, V) in the data obtained.

The first attempt to find support for a dissociation between learning processes began with the investigation of the interaction of conscious and unconscious learning. It was reasoned that if separate learning processes exist, then they could be observed through their interaction. Although it is often assumed of these processes that they cannot be easily distinguished through the use of behavioural tasks (e.g., Destrebecqz & Peigneux, 2006), an effect of interaction was still expected to serve as an indication of the presence of more than one source of processing.

The second series of experiments in Chapter III investigated the question of unconscious learning in an incidental learning design. Based on previous studies which claimed that learning takes place without the focus of attention (e.g., Lambert, 2003), these studies tested whether the contingency between cues and target locations would lead to implicit learning if the stimuli are within the visual field, and those incidentally predictive cues which are not part of the primary task are presented peripherally.

In Chapter IV, a new learning task, SALT, was introduced to separate the effect of attention and awareness. The question investigated was whether learning occurs when attention is focussed on individual stimuli, but awareness does not link the stimuli together. With the *disguising technique* of SALT (for details see Chapter IV), it was also tested

whether the knowledge of an explicit rule prevents learning about further possible associations if this rule is proved to be predictive.

In the final empirical chapter, Chapter V, the role of awareness in a decision-making task was analysed using the DWA paradigm. While diverted attention has been assumed to induce unconscious processing of information in complex decisions (Dijksterhuis et al., 2006), the conscious status of this deliberation has not been directly investigated before. Two new versions of this decision making test were needed to allow the analysis to clearly separate the effects of diverted attention and conscious deliberation.

Before drawing conclusions from this research on the role of attention and awareness in learning and decision making, a few crucial methodological and theoretical questions will be addressed. Following this, some alternative interpretations of implicit learning and the ‘smart unconscious’ are discussed. After an attempt to form an integrated conclusion based on the empirical findings of this work, further thoughts are added with a view to fostering new questions for the understanding of human learning and decision making.

### *Tests of Awareness*

In each of the experiments in this thesis, special attention was drawn to the various tests of awareness. A systematic application of these assessment methods across different studies provides a good opportunity to compare their merits and weaknesses. In the discussions of each chapter it was emphasised that the logic of implicit learning research is often based on tacit assumptions. At this point, it is possible to shed light on these assumptions and discuss their validity.

Two questions arise when the empirical tests of awareness in the implicit learning paradigm are considered: (1) how sensitive these tests are; and (2) if these tests all measure the same phenomenon.

*Verbal Reports.* As was mentioned in the introduction to Chapter III, since awareness is a first-person phenomenon verbal reports are the most obvious means to explore whether people are conscious about a given piece of knowledge. Originally, an implicit form of learning was claimed on the basis of the inability to report the rules of the tasks where above-chance performance was observed (e.g., Knowlton, Squire, & M. A. Gluck, 1994; Nissen & Bullemer, 1987; A. S. Reber, 1967; Miller, 1939). Posner defined this logic very clearly when he distinguished ‘detecting’ from ‘orienting’: “*By detecting I will mean that a stimulus has reached a level of the nervous system at which it is now possible for the subject to report its presence by arbitrary responses that the experimenter may assign. These may be verbal (“I see it”) or manual (pressing a key). Detecting means to be aware or conscious of the stimulus.*” (1980, p. 4). While there is no doubt that when people are able to verbalise a rule then they are conscious of it, to claim the opposite, i.e. that the people are unconscious of the rule when they are unable to report it, is more questionable.

The first problem is that the test has to be *sensitive* enough to allow for identification of all relevant information that may be held responsible for the observed effect on performance (Shanks & St. John, 1994). The verbal report would not be sensitive enough for example if the participant did not understand the question correctly, or if the person was aware of the information yet remained unable to express it verbally. To put perceptual experience into abstract words undeniably places a heavy burden on the reporter. Further reasons why some conscious knowledge can remain undetected by verbal report may be the uncertainty of the participant about fragmented knowledge or retrieval failure due to the context of retrieval being different from the context of encoding (Shanks & St. John, 1994).

For instance, the context of an SRT task is a forced choice motor control situation, which is radically different from the context of a verbal interrogation or a paper questionnaire. This difference might be sufficient to result in cases where, despite performance due to fragmented (but explicit) knowledge, participants are subsequently not able to verbalise this knowledge, thus creating an artefact of implicit learning.

Secondly, the test has to satisfy the *information criterion* as well (Shanks & St. John, 1994), according to which the knowledge measured by the test of awareness has to tap into the same knowledge that was responsible for the learning. To satisfy this criterion is perhaps more challenging since there is generally no objective way of knowing what rule or information the person used in completing the task. Taking the example of the SRT task again, the participants are usually asked about those first- or second-order conditionals which were used in the construction of the test. However, the use of zero-order information (e.g., sequence element frequencies) can also lead to observable RT performance (Destrebecqz & Peigneux, 2006). Similarly in the AGL task, the reports of the participants about permissible and nonpermissible letter pairs were not categorised as correct conscious knowledge. However, this knowledge is sufficient to produce above-chance performance on the task (Perruchet, 2008).

Eriksen (1960) lists some further desiderata of the verbal reports. The participant must be motivated to respond with the care and precision that is required, and some adequate system or scaling of these reports is needed to categorise the accuracy of these reports.

Experience with verbal reports in the present work justifies almost all of these concerns. The participants found it often challenging to verbalise their experience, despite other tests of awareness indicating that some of the information was under conscious, strategic control. From another aspect, occasionally the participants did not notice or could

not verbalise the sequence in the task, but later they communicated some regularities (e.g., location pair frequencies) that they had noticed during the task. The most frequent problem with verbal reports in these experiments was the lack of motivation to give a precise account of their task strategies. After the somewhat tedious and potentially exhausting RT tasks, participants were perhaps rarely motivated to prolong the experimenting time by giving detailed reports.

Considering these limitations, some researchers have arrived at the conclusion that verbal reports can only prove that someone is aware of something; it cannot be proved that they are not (e.g., Stadler, 1989). The application of verbal reports, which goes back to Cartesian traditions, was criticised from a philosophical perspective as well. Dennett (2003), for example, did not accept an individual's report as authoritative. In contrast, his heterophenomenology regarded these accounts, as any other data about the conscious state, as needing further verification.

### *Subjective Measures*

Despite the substantial criticism of verbal reports as reliable indicators of awareness, there are still considerable arguments in favour of using subjective measures. As already discussed in Chapter III, if consciousness can be regarded as the flexible access of mental contents (e.g., Baars, 1997), then the inability to access this content serves as evidence that this content was not completely conscious. To investigate these claims, the *zero-correlation criterion* and *guessing criterion* (Dienes, 2008), which directly rely on these premises to infer unconscious knowledge, were repeatedly employed in the present experiments. Note that these measures provide an operational definition of implicit learning: the learning is implicit when the knowledge is above the objective threshold for performance, but is below the subjective threshold for report (Cheesman & Merikle, 1984; Dienes & D. Berry, 1997). It was argued that the PDW test (Persaud et al., 2007) is the same as other subjective measures in

that it relies on a confidence judgment of the person's knowledge (Seth, Dienes, Cleeremans, Overgaard, & Pessoa, 2008). In this sense, despite the use of an objective wagering task, this measure, like other subjective measures, relies on *metaknowledge*.

These tests have been employed several times to assess awareness in implicit learning tasks (e.g., Dienes & Scott, 2005; Shanks & Johnstone, 1999). The results of these studies showed that after excluding those participants who reported some knowledge after the task, the remaining participants, those who believed that they were guessing, still performed above chance. Furthermore, the confidence level did not always correspond with the measured performance. Can these results be counted as direct evidence for the presence of unconscious knowledge?

Reingold and Merikle (1988) cautioned the researchers to note that the participants' interpretation of the task may bias these measures. Floor effects (which may mask a relationship between confidence and performance) can occur for several reasons; for example, the interpretation of 'guessing' may vary between participants. Some participants may overestimate the experimenter's expectation of reporting 'knowing' as compared to 'guessing'. The use of a confidence scale can bypass this problem since it is analysed in a correlational way (Dienes, 2008). A different problem, however, should be considered with regard to confidence scales. Instead of the continuous (50-100%) scale, Tunney and Shanks (2005; 2003) used Kunimoto and colleagues' (2001) binary (high vs. low) scale and found that the continuous confidence scale is not sensitive enough to lower levels of awareness, although no satisfactory explanation was proposed for why the binary confidence scales are more powerful<sup>15</sup>. This effect could possibly be explained by the phenomenon of *decision*

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<sup>15</sup> According to previous findings (e.g., Zimmerman, 1993), under certain distributions, binary rescaling of a measure may be more sensitive than the raw data – for heavy-tailed distributions yes/no scaling may be more sensitive than continuous measures.

*fatigue* (Vohs, 2006). A growing body of research indicates that making choices may be regarded as relying upon a depleting resource (e.g., Baumeister, 2002). Making choices requires a form of ‘mental effort’ taxing this limited resource which is required to make self-controlled choices, resulting in impaired self-control (Vohs et al., 2008). If deciding on a scale of 50-100% is more depleting than making binary choices then it is possible that the participants may lose their capacity to make adequately accurate choices on the scales of repeated trials.

In general, the results of the present work left the interpretations of these selected awareness tests in disagreement. Therefore, there is reason to think that the measures failed to meet at least one of Eriksen’s (1960) desiderata: it was probably an unrealistic expectation that the participants would always exercise sufficiently careful introspection about their confidence on a 50-100% scale to distinguish between all possible confidence levels, or would precisely weight the monetary risk of their wagering in each of the 64 trials of the PDP task.

There are further doubts about the validity of the PDW. One essential problem with the PDW is that, in theory, it could be solved implicitly as well. According to the PDW view, higher wagering on the correct than the incorrect trials indicates the presence of consciousness. Propagators of a ‘smart unconscious’ (e.g., Dijksterhuis et al., 2006), however, could argue that optimal wagering can be the result of decisions made by unconscious thought. On the other hand, since the absence of higher betting on correct trials could always be the result of risk aversion, the PDW task cannot conclusively indicate the absence of conscious processing either. This conjecture was supported here by the finding that risk-aversion (assessed by questionnaire) was related to the amount the participants were willing to wager.

In the experiments in Chapter V the amount of money wagered in the Uninformed group correlated strongly and positively with the level of reported risk aversion. However, for the Informed group, although the correlations were mostly non-significant, for all the six types of cues the correlations were negative. Remarkably, the same pattern was found for the confidence ratings as well. Whatever the explanation for this pattern may be, the level of risk aversion seems to have a strong effect on the PDW and the confidence judgments.

It is interesting to mention that, as a recent review indicated (Seth et al., 2008), no hitherto published work has applied both subjective measures and post-decision wagering in the same learning task, and as such their relationship has not been shown. These measures were systematically employed in *Experiments 2.1, 2.2, 2.4, 3.1, and 3.2* of the present work. The tests seemed to have similar sensitivity, none of them having detected the presence of conscious knowledge in Chapter III, and all of them showing conscious knowledge (for the Informed group) in Chapter IV. Both the confidence measure and the PDW seemed to be similarly sensitive to risk aversion. These findings support the argument that these tests are similarly dependent upon the metaknowledge of the participant.

#### *Process Dissociation Procedure*

The PDP appeared to be the most sensitive test of awareness among the experiments in this thesis. Learning was detected by the PDP measures whenever it was indicated by another measure, and in *Experiment 2.2*, it was the only test that could measure learning in the task. The RT measures, the confidence measure, the guessing criterion and the PDW were unable to detect learning in that experiment. One could argue that this pattern of results may serve as evidence for the presence of unconscious knowledge. In this case, however, the PDP showed below-chance exclusion performance, which is usually interpreted as a sign of the presence of explicit control (e.g., Wilkinson & Shanks, 2004).

Some authors (Q. Fu et al., 2008; Norman et al., 2006), however, have argued before that even below-chance performance in the exclusion condition does not necessitate the presence of conscious structural knowledge. That is, the sense of *feeling-of-knowing* is enough for correct exclusion. As was described earlier, this feeling of knowing may be based on implicit sources as well (Koriat, 2000), providing an example of conscious judgment knowledge without conscious structural knowledge. The data of *Experiment 2.2* does not support this conjecture. One quarter of the participants reported in the verbal reports that they were aware of having perceived any regularity in the test.

The Uninformed group *Experiment 3.1* again presented a case where only the PDP, but none of the other measures, provided evidence of learning. What could explain this difference in sensitivity between the PDP and the subjective measures? Perhaps the fact that the PDP is an objective test of awareness which does not require meta-knowledge or judgment about the presence of knowledge could explain this difference. Making decisions based on introspection may call for more mental effort than the participants are willing to make for the duration of the experimentation. The presence of these requirements may place an extra burden on the sensitivity in the subjective measures.

In summary, it can be argued that each of the tests have weaknesses and limitations in assessing awareness. As Reingold argues “*no proposed measure of conscious awareness, should be considered valid on an a priori basis*” (2004, p. 118). According to Reingold and Merikle (1988), a valid measure must fulfil both the *exclusiveness* and the *exhaustiveness* criteria. In other words they should be sensitive to all relevant conscious knowledge, and to only this knowledge. As can be seen, none of the tests discussed here satisfy these requirements without serious doubts. A combined application of these tests, as the present experiments exemplified, can provide a more sensitive, however far from perfect, tool for assessing the presence of conscious knowledge.

## *The Logic of Implicit Learning Research*

### *The 'Learning-plus-Retrieval' Approach*

It is clear, however, that all these tests of awareness are designed to serve as evidence for implicit learning in a peculiar way. In a typical implicit learning task, learning occurs at a particular moment in time (Time 1) then sometime after that learning, but more often after some different task phases, the conscious status of the acquired knowledge is assessed (Time 2). This methodological scenario relies on a tacit assumption that the conscious status of the retrieval at Time 2 is equatable with the conscious status of the process at Time 1. Implicit learning, therefore, seems to be a concept that is defined by the unconscious status of the process of learning, but measured by the lack of conscious status of the retrieval of memory. To accept this measurement it is necessary to weight the logic of its argument.

When, 15 years ago, Berry (1994) summarised the 25 years of implicit learning research suggested that implicit learning should be defined and measured exclusively by the process of learning since it may or may not result in unconscious knowledge. Others also pointed out that the term 'implicit memory' should be used to refer to the case when the retrieval episode occurs without awareness, but the characterisation of 'implicit learning' should be based on the assessment of conscious intention and awareness during knowledge acquisition only (e.g., Frensch, 1998; Stadler & Roediger III, 1998). While they proposed that the intentionality or the automatic nature of the learning process should be the focus of investigation, others (e.g., Jimenez, 1997) argued that "*intention cannot be safely assessed without reference to the conscious knowledge upon which it depends*" (Jimenez, 1997, p. 14). It seems, therefore, that it is impossible to demonstrate implicit learning without the assessment of the conscious status of the acquired knowledge. Does this limitation make implicit learning a conundrum?

Some authors believe that it does not. Jiménez (1997), for example, laid down an explicit logic that arguably leaves room for knowledge-based implicit learning research. He proposed that *“if we accept the assumption that intention to learn about some given regularities can not directly produce unconscious knowledge about these regularities, then implicit learning may indirectly be established through the demonstration of the acquisition of some unconscious knowledge”* (p. 14).

In his conceptual and methodological review, Jiménez (1997) described three methodological scenarios for demonstrating implicit learning based on knowledge assessment. Firstly, a pure measure of unconscious knowledge could serve as the best behavioural index. Most authors agree, however, that such a measure does not exist. Consciousness cannot be “switched off”, thus explicit knowledge can always affect the behavioural measures of unconscious knowledge (e.g., Curran & Keele, 1993). According to the second scenario, a pure measure of awareness could be utilised by ‘subtracting’ the effect of consciousness from a behavioural measure contaminated by both processes (e.g., Jacoby, 1991). It has been argued, however, that the objective tests of awareness, where the participants are encouraged to access their knowledge for the test, would inevitably be contaminated by unconscious knowledge (e.g., Shanks & Johnstone, 1998). As was discussed earlier, even the exclusion phase of the PDP is not an uncontroversial measure of explicit knowledge (Q. Fu et al., 2008; Norman et al., 2006). The objective tests of awareness are not exclusive measures of conscious knowledge in this sense (Reingold & Merikle, 1988). The subjective measures, such as the verbal report or subjective confidence, are also criticised from the aspect that they are not exhaustive measures (Shanks & Johnstone, 1998; Perruchet & Pacteau, 1990). As was described previously, there are several reasons to believe that the verbal reports are insensitive in detecting the conscious knowledge of the participant. The

confidence measures, the guessing criterion, or the PDW are also vulnerable to biases such as risk aversion, misinterpretation or undermotivation.

Not finding satisfactory pure measures of unconscious or conscious knowledge, Jiménez (1997) proposed a third possibility in which “*the idea that one can identify pure measures of awareness should be abandoned in favor of the search for some minimal operational definition of this term*”. He suggested accepting certain measures to be a priori relevant to the conscious or unconscious. In his example, intentional, controlled responding could be exclusively ascribed to consciousness, and thus be utilised for an operational definition. By this, however, he has inevitably returned to the second scenario that he previously rejected. Other researchers, who similarly found the ‘process pure’ models implausible (Destrebecqz & Peigneux, 2006; Perruchet et al., 2006; Sun et al., 2001a), suggested a model with simultaneous involvement of the different processes with varying contributions from each. The danger of this approach is that the model can become unfalsifiable. If the presence of explicit knowledge is not evidence against the presence of unconscious knowledge then unconscious knowledge remains an irrefutable concept.

In summary, the ‘learning-plus-retrieval’ approach of implicit learning relies on the assumption that we can straightforwardly infer from the analysis of the retrieval of certain knowledge at Time 2, to the acquisition of the same knowledge at Time 1. As was demonstrated, this definition requires the acceptance of the assumption that conscious learning cannot lead to unconscious knowledge. This argument, however, could be refuted by independent evidence of unconscious knowledge about conscious learning. One could argue that the pattern of results in *Experiment 2.2* is one of those cases. There the performance on the exclusion condition of the PDP showed below-chance performance, arguably demonstrating conscious control, or explicit knowledge about the stimuli. Despite this strong effect of conscious control ( $d = .68$ ), none of the subjective measures reflected the presence of

explicit knowledge. A conclusion based only on the results of the confidence measure, the guessing criterion and the PDW should suggest evidence for implicit learning. The performance on the exclusion condition and the fact that 25% of the participants reported noticing regularities, however, contradict this logic. In conclusion, the essential problem with the usage of such tests of awareness is that logically the absence of evidence can never serve as evidence of absence. The absence of evidence for conscious knowledge in the assessment tests cannot unquestionably ascertain the presence of unconscious knowledge per se. The 'pure measure' models, therefore, are not promising avenues for the research of learning processes. The 'simultaneous involvement' models are probably more plausible, but valid retrieval-based assessments of each contribution are even less conceivable.

#### *The 'Learning-Only' Approach*

A promising direction for research of 'simultaneous involvement' models, however, is the analysis of process interaction. Instead of aiming for studying the processes in isolation, the models of interaction try to go beyond the controversies by taking into account both learning processes (Sun et al., 2001b; Sun et al., 2005; Cleeremans & Jimenez, 1998). Although they used retrieval-based assessment of knowledge status as well, the first three experiments in this work (Chapter II) were dedicated to this approach. It was reasoned that if separate learning processes exist then they could be observed through their interaction. Although it is assumed of these processes that they cannot be easily separated in behavioural tasks (e.g., Destrebecqz & Peigneux, 2006), it has been argued that an observable interaction could serve as an independent criterion for isolating the effect of implicit learning (Jimenez & Mendez, 2001).

The design of *Experiments 1.1-1.3* attempted to 'prime' the implicit and explicit types of processing both independently and in combination. The results of *Experiment 1.1* allowed for the interpretation that the interaction of the two systems resulted in a summated performance;

that is, the preliminary engagement of the two systems within the same task (but different sequences) may have added up in a beneficial way. This interpretation, however, was not supported by any of the tests of awareness, nor was it replicated in the following *Experiment 1.2* and *Experiment 1.3*. Crucially, the explicit knowledge of the participants alone could provide an explanation for all of the effects of learning. This lack of interaction could be interpreted as evidence against the two systems model. However, an alternative explanation for this failure to find an effect always remains that the ‘priming’ technique utilised in this study was not suitable to enhance a particular style of processing or that the test was not sensitive enough for measuring the interaction of these processes.

A further way to examine the process of learning can be based on the assumed properties of the learning processes. One possible definition of implicit learning implies that it is automatic and does not require attention.

There is no universally accepted set of criteria for automaticity. The requirements are usually lack of control, obligatoriness, effortlessness, poor memory, unconsciousness, or unconditionality (Frensch, 1998; Hasher & Zacks, 1984; Logan, 1988), where obligatoriness and effortlessness are probably the key properties (Frensch, 1998). The effortlessness refers to the claim that the process does not require ‘mental energy’. The obligatoriness means that under certain circumstances the process is always initiated.

The effortlessness criterion seemed to be easily applied to experimental tests. The most obvious empirical way to investigate the effortlessness of a learning process is to test whether it is subject to interference in a dual-task manipulation (e.g., Nissen & Bullemer, 1987). Starting from the origin of the SRT paradigm (Nissen & Bullemer, 1987) this question has been repeatedly tested. The studies, which used mostly tone-counting as a secondary task, replicated Nissen and Bullemer’s (1997) finding that the dual task interferes with sequence

learning (A. Cohen, Ivry, & Keele, 1990; Curran & Keele, 1993; Frensch et al., 1994; Frensch & Miner, 1994; Stadler, 1995). Stadler (1995) and Frensch and his colleagues (1994) suggested that the tone-counting may interfere with the organisation of sequence knowledge. Therefore, performance on the SRT task may be affected even if the learning was implicit. In short, the resource attention load in concurrent tasks reduces the capacities of control functions in sequence learning (e.g., Shanks et al., 2005). Therefore, it is, again, possibly not the most promising methodology to explore effortless implicit learning.

The other possible consequence of implicitness is that the learning does not require attention. This hypothesis was tested from two perspectives in this thesis. In Chapter III it was explored whether unconscious learning occurs in an incidental learning design. Based on previous studies, which claimed that learning takes place without attentional focus on the stimuli (e.g., Lambert, 2003), studies in this chapter tested whether the contingency between cues and target locations would lead to implicit learning if the cues are not part of the task and are presented peripherally within the visual field.

In *Experiment 2.1* and *Experiment 2.2* the participants were not informed about the cue-target relationships and, in general, learning did not occur. The only hint of a learning effect in *Experiment 2.2* could be explained by explicit knowledge. *Experiment 2.3* served as a control condition where the predictive cues were not presented in the design. In *Experiment 2.4* the participants were encouraged to find and use the cue-target relationships and as a result a greater effect of learning was measured, though just in the PDP test. In general, no effect of learning was found that would suggest that learning happened without attention. The results were again explainable without assuming any unconscious learning processes.

The results of the experiments in Chapter III provided new support for the models of learning that claim that perception is not sufficient for implicit learning to occur, but that the

stimuli must be selected by attention (e.g., Mackintosh, 1975). The studies in the subsequent Chapter IV approached the question of implicit learning from a new angle. Many empirical researchers would agree that selective attention on the stimuli is necessary for learning to occur (e.g., Jimenez & Mendez, 1999; Pacton & Perruchet, 2008). What the ‘learning without attention’ description of implicit learning refers to in this case is that learning can happen without conscious attention on the *association* between the stimuli (Pacton & Perruchet, 2008).

Chapter IV discussed some models (e.g., Logan & Etherton, 1994) in which learning of the association between the stimuli is an obligatory consequence of the selective processing of their co-occurrence. Frensch and Miner (1994), for example, described a framework for implicit learning where learning involves all the covariational environmental information that is simultaneously active in the short term memory. In this sense, the concurrent or consecutive activation of predictably associated information would lead to implicit learning. It should be noted that a classic implicit learning interpretation of performance on the basic design of the SRT paradigm tacitly relies on this assumption.

In Chapter IV, a new learning task, SALT, was introduced to separate the effect of attention and awareness. This task addresses the question of whether learning occurs when selective attention occurs, but awareness of a relationship does not bind the stimuli together. *Experiment 3.1* and *Experiment 3.2* approached the question from different angles. In the first experiment the predictive cues were introduced to the participants as parts of an independent dual task by which attention was drawn to the predictive cues 500 ms before the appearance of the target locations. The second experiment additionally ensured that the representation of the cues and associated target locations were concurrently active, thus allowing them to be linked together by an automatic process.

The level of awareness of the relationship between the stimuli was manipulated in two ways. First, the two groups in each experiment differed in whether they received explicit information about the hidden associations or not. Second, the Informed group was informed about only half of the predictive features, and remained uninformed about the other half. Detection rates on the Dual Task confirmed that the participants attended to and processed all the relevant features of the stimuli, but the between-groups comparison and the within-subjects analysis of the behavioural data, along with the post-experimental knowledge tests, showed no evidence for learning without contingent explicit information.

As the main conclusion, these studies do not support the view that learning is an obligatory consequence of selective attention. Rather, learning was observed only when attention was drawn to the associations between the stimuli, emphasising the central role of attention in learning.

Overall, none of the nine experiments which were dedicated to questions of implicit learning in this thesis produced evidence for the existence of more than one kind of learning process. Of course, the fact that no support was found for dissociable implicit learning processes in these experiments does not exclude the possibility of its existence. Even if implicit learning is a real phenomenon, the data suggest, however, that its effects are either very weak, or not obligatory in human behaviour.

### *The Critique of Unconscious*

If the support is so weak and the methodology is so problematic so far as finding evidence for the existence of unconscious learning is concerned, then why do we seem to find this dichotomy so intuitively sensible? Almost 50 years ago, Charles Eriksen (1960) summarised the research of the time on discrimination and learning without awareness. His conclusions offered a warning:

*“Perhaps our tendency to uncritically accept experiments on unconscious phenomena may be due to our firm belief in the existence of the unconscious. [...] There would seem to be little doubt that a considerable amount of human behaviour occurs without awareness of the behaviour at the time of its occurrence but it is to be noted that this does not logically require that behaviour is learned without awareness.”* (p. 297).

Could the support for dissociating learning processes be the result of this type of flawed logic? 50 years later, the arguments that suggest this remain convincing. Those who argued for dual systems of memory (e.g., Graf & Schacter, 1985; Schacter, 1987), or learning (e.g., Dienes & Perner, 1999; Frensch et al., 1998; Willingham et al., 1989) often based their argument on the observed dissociation between the measures of the performance on the learning task and the tests of awareness. Those participants who do not provide evidence of knowledge on the test of awareness, but nevertheless perform above baseline on the learning task, have been counted as examples of the implicit phenomenon.

However, this repeatedly observed pattern of results does not necessarily lead to the conclusion of different systems being responsible for the dissociation of the measures. According to a simpler view of memory (Shanks, 2005; Shanks & Perruchet, 2002), the data can be easily explained by a one-system model. This model consists of two assumptions (1) the different items in the memory test are associated with one source of knowledge, familiarity, which is represented in the model by some variable memory strength  $f$ . The model also assumes that (2) the different measures access this source with independent errors, described by another random variable,  $e$ .

The SRT task with a subsequent recognition test can serve as a good example. In the recognition test the participants are presented with (previously learned) old sequences and new sequences. As the familiarity of the old sequence increased during the training,  $f$ , which

is modelled as a random variable, would have on average higher values for the old sequence than for the new sequence. However, as for some participants the value of  $e$  associated to the recognition measures of the new sequence will be (by chance) larger than the value of  $e$  of the old sequence, this may produce a case where the recognition of the old sequence is at or below the level of recognition of the new sequence.

In the RT measures of the same participants, however, the greater familiarity values of the old sequence would provide, on average, a measure of learning since the value of  $e$  in the two tests are independent (i.e., the specific recognition errors  $e$ , which underestimate the familiarity of the old sequence, or overestimating that of the new sequence in a particular case would, on average, disappear in another test). Hence, this model can account for the frequently observed dissociation, in selected individuals, between the two tests without implying two sources of knowledge.

A similar single system model of implicit learning of Destrebecqz and Cleeremans (2001, 2003) proposed that during learning the representations become stronger and of better quality. When these representations are strong enough to produce behavioural change, but not good enough to become clearly conscious, then they give rise to the phenomenon of implicit learning. Although the models are similar, only the second supports the idea of implicit learning as a truly measurable effect. Interestingly though, neither of these models necessitate a role for consciousness in learning (for an argument see Q. Fu et al., 2008).

In conclusion, the impression of independent sources of knowledge may be an artefact of the data. This work started with the statement that the assumption of one system is arguably more parsimonious than the assumption of multiple systems. No empirical evidence has been found in this work, or in a review of the literature, for unconscious learning. This lack of evidence suggests that, until more convincing evidence for dissociating learning or

memory systems arrives, single system models are good candidates for explaining the behavioural data.

Does the assumption of unconscious cognition represent too great a surplus in our theories about the human mind? May it be disadvantageous to rely on theories of unconscious in our daily life? The final study in this thesis suggests that there might be a case for this. In the implicit learning literature, the early models of a smart unconscious, which is capable of discovering and encoding every covariation or abstract rule in an automatic manner (e.g., D. C. Berry & Broadbent, 1984; Lewicki & Hill, 1987) have been later replaced by a more association-based passive unconscious (Frensch & Runger, 2003). In the field of decision making, however, the idea of a smart unconscious seems to persist. The UTT, which was described in detail in Chapter V, provides not just a model of decision making, but gives suggestions for everyday decisions. For example, Dijksterhuis (2004) confidently advised the reader on how to arrive at complex decisions in life:

*“When faced with complex decisions such as where to work or where to live, do not think too much consciously. Instead, after a little conscious information acquisition, avoid thinking about it consciously. Take your time and let the unconscious deal with it.”* (Dijksterhuis, 2004, p. 597)

In *Experiment 4.1* and *Experiment 4.2* the original Deliberation without Attention design was replicated to test the empirical evidence behind this wisdom. Crucially, the conscious status of the decisions was assessed to determine whether there was any evidence of unconscious structural knowledge producing conscious judgment knowledge (i.e., intuition).

The findings of these experiments challenged the conclusions of Dijksterhuis (2004) in several ways. Firstly, there was no evidence found that the Unconscious Thought condition

produces detectable improvement in terms of rating. Secondly, the results suggest that the diverted attention paradigm does not produce ‘intuitive’ ratings in the manner claimed. Rather, it seems that explicit knowledge is the main modulator of performance in this test, regardless of the DWA manipulation. The *Number Mean Estimation* task, for example, showed that with more objectively assessable stimuli, allowing time for the conscious thought leads to convincingly better judgments.

In summary, the role of awareness and attention in human learning and decision making was investigated in the 11 experiments in this thesis using a range of techniques. The endeavour to obtain evidence for learning or decision making without awareness did not find support for such a mechanism, but the investigations still yielded many interesting findings. The role of attention in the process of learning was examined from different angles. It is clear that conscious attention has a considerable effect on learning, but only when attention is drawn to the association and not just on the stimuli. The new test, SALT, is a promising tool for investigating this relationship by being able to manipulate the amount of attention on the stimuli and on the relationship independently. The Number Mean Estimation task and the Bar Length Estimation task were designed to provide an objectively assessable test of decision making with and without conscious deliberation. The failure of the DWA paradigm to measure intuition does not exclude the possibility that there may be essentially different strategies based on intuition in human decision making. Further methodological improvements may yield ways in which these strategies become testable in laboratory situations.

### *Further Thoughts*

Finally, some further thoughts are described addressing the questions of attention and awareness in the process of learning, which go beyond the scope of the empirical data of this

work and the literature reviewed. To begin with, the lack of evidence of learning without instructed attention in the SALT task indicates that no detectable learning happened between these stimuli, suggesting that attention on a relationship plays a crucial role in learning that relationship. Attention may be needed for learning not just to select the relevant features of the belonging stimuli for further processing, but also to link the stimuli together by representing their “belongingness”. Although, this might seem to be an ad hoc speculation, a substantial amount of empirical findings and theoretical positions are in accord with this consideration.

Firstly, the propositional approach to associative learning (De Houwer, 2009; Lovibond, 2003; Lovibond & Shanks, 2002; Mitchell et al., 2009) claims that even basic forms of learning are not achieved through an automatic formation of links, but are instead the result of controlled reasoning processes. According to the model, associative learning effects depend on the formations of propositions. The associations are only states of affairs, while the propositions are statements about the presence and manner of these states of affairs (De Houwer, 2009).

The formation of propositions is assumed to require controlled reasoning processes, which are described as effortful and attention-demanding processes resulting in conscious and declarative knowledge (Mitchell et al., 2009). It is noteworthy that the model leaves room for automatic processes in perception, performance, memory processes (e.g., retrieval), and emotional and physiological responses; it is only learning that cannot happen without awareness of the relationship (De Houwer, 2009). Although these claims are currently debated in the field (see Mitchell et al., 2009), a recent review of the associative learning literature found only a very limited number of previous studies that could challenge a view that all human of learning relies upon a unitary mechanism (Lovibond & Shanks, 2002).

In summary, the propositional approach of associative learning claims that this type of learning, which is arguably more basic than the one studied in implicit learning task, cannot happen without the formation of a representation of the association. Discussing the role of attention in learning Mitchell and his colleagues predicted “... *if reduced attention to the target relationship leads to a reduction in learning of that relationship, this would seem to suggest that learning is cognitively demanding and, in this sense, not automatic*” (Mitchell et al., 2009, p. 189). In fact, this is what the SALT studies showed in the present work, that reduced attention to the stimulus relationship prevented observable learning. Therefore, it seems that there are basic models of learning that are compatible with the assertion that learning is a consequence of awareness of the relationship between stimuli.

The second important empirical observation to be mentioned was described by Thorndike (1931). After presenting his participants with a sequence of pairs of words and numbers (e.g., bread 29, wall 16) he asked them not just what number came after a given word, but he also asked what word came after a given number. While within the pairs he found above-chance performance, between the pairs he measured was not better than guessing. He called it the *effect of belonging*.

*“The nature of the instruction, the way in which the pairs were read, [...] led the subjects to consider each word as belonging to the number that followed it, and each number as belonging to the word that preceded it. In this experiment, the temporal contiguity of a number with a word following it, the mere sequence without belonging, does nothing to the connection.”* (p. 24).

Later, he continued: *“Repetition of a connection is the sense of the mere sequence of the two things in time has then very, very little power, perhaps none, as a cause of learning. Belonging is necessary.”* (pp. 28-29).

Although he believed that one exception from this general finding is conditioning, his basic assumption seems to be confirmed today after many decades of research on learning.

Following the philosophy of Thorndike's 'principle of belonging' and the framework of the propositional approach, a minimalist description of learning is proposed. Starting from the finding that the effect of instructed conscious attention on learning in the SALT task was considerable, it is plausible to suggest that less attention on the association would also have resulted in observable learning. It is, therefore, not impossible that in situations where attention is greatly constrained (e.g., subliminal perception), a reduced level of attention is still able to cause observable behaviour change. In this model, attention on the predictive relationship of the stimuli (belongingness) *ignites* the process of learning. This *ignition* happens when attention drawn to an association leads to the development of a representation dedicated to this association. Depending on the degree of attention, the representation may decay with time resulting in a decrease in the amount of control, to the degree that it affects behaviour only at the level of familiarity or habit.

In this framework, without an initial realisation of 'belongingness', learning cannot happen. However, once it has 'ignited' learning, this representation does not need to remain consciously accessible to affect behaviour. For example, this model would predict that cue-outcome learning would only happen if the stimuli are encoded not just in their physical features, but also as related 'cue' and 'outcome'. If the stimuli are not identified as 'cues' and 'outcomes', cue-outcome learning would not happen. For the stimuli to become 'cues' and 'outcomes' in this case, attention must be drawn to their belongingness. This is not to say that once the stimuli are associated through this attentive process, further features of this relationship cannot be formed by rules such as described by the models of associative learning (e.g., Dickinson, 1980).

The proposed model postulates predictions only about the conditions in which learning can occur and not about the knowledge it results in. One advantage of this model is that it posits more minimalist predictions than the propositional approach. One of the hypotheses of the propositional approach, for example, predicts the learners “*who successfully learn the CS-US contingencies [will] be aware of, and be able to report, those contingencies*” (Mitchell et al., 2009, p. 188). In other words, it assumes that not just the process of learning is conscious, but the resulting knowledge is conscious as well to a reportable level.

The ‘ignition model’ allows for the case that conscious attention only initiates the learning, but the resulting knowledge of the association can affect the behaviour without further flexible access to this knowledge. Since learning can happen without further conscious control, pure experience-based learning can explain suboptimal decision making strategies (Einhorn & Hogarth, 1978). In fact, the propositional approach was criticised by Dickinson (2009), who argues that the explanation of the acquisition of nonrational behaviours is problematic in the framework since it assumes conscious reasoning behind all learning processes. The ‘realisation’ and representation of belongingness is probably a lesser assumption than conscious reasoning.

In summary, instead of postulating conscious reasoning and resulting declarative knowledge as a necessary part of all learning processes, the ignition model only proposes one additional precondition for learning. This precondition necessitates that attention is drawn not just to the associated features of the stimuli, but also to their belongingness (e.g., the stimuli being identified as ‘cues’ and ‘outcomes’). If incidental or limited attention is sufficient to generate belongingness, it may also initiate effective learning, which could possibly explain many of the findings in implicit learning research.

### *Final Conclusions*

Decades of implicit learning research have passed without resolution of the claim that explicit learning may be absent in various implicit learning settings. In this work, an attempt was made to find dissociating roles of awareness and attention in human learning and decision making. Convincing evidence was not forthcoming for models which necessitate a separate system to process unconscious learning or to make decisions. Rather, it was found that attention and explicit knowledge were able to account for all observed performance changes. There was, similarly, no support found for a ‘smart unconscious’ that deliberates on complex decisions in an optimal way. Instead, it was found that the methodology (e.g., Dijksterhuis, 2004) does not measure ‘intuition’ in the manner claimed.

Notwithstanding the vigorous efforts in the field, a review of the literature showed that the evidence for unconscious cognition in learning or decision making remains elusive. The conclusion must be that, at best, unconscious rule learning plays only negligible role in human cognition. Therefore, until more convincing evidence is acquired, it is not parsimonious to postulate a separate system for it in our models of human cognition.

Over the decades, the focus on the role of consciousness in implicit learning research presented the researchers with many methodological challenges. Some authors concluded that the problem is unsolvable, as Higham and colleagues’ pessimism about the dissociation logic exemplifies it: “... *because it is so difficult to meet the exclusiveness, information, and sensitivity criteria, it is unlikely that skeptics of unconscious processes will be convinced by experiments based on this logic.[...] enough problems have become apparent with research based on this logic over the years to consider abandoning it altogether.*” (Higham, Vokey, & Pritchard, 2000, p. 467).

Is implicit learning research, therefore, a futile endeavour of cognitive psychology? Certainly it is not. Even though the results do not necessitate the existence of dissociating learning systems, phenomena whereby learning results in stable knowledge with only weak conscious accessibility is an exciting topic of research<sup>16</sup>. Focusing more on the role of attention rather than consciousness could also lead to interesting hypotheses about learning. The ignition model aims to find the minimalist preconditions of learning, and the SALT test proposes a methodology that can modulate the magnitude and focus of attention in rule learning situations. A change in focus from ‘consciousness’ to ‘attention’ in future investigations and descriptions such as computational models, may yield considerably more advances in research on human learning and decision making.

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<sup>16</sup> For the importance of weak links as stabilisers of complex systems see Csermely (2006).

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## Appendix A

## The Paper Questionnaire Used in the Sequence Learning Study

SRT Test Questionnaire

Age: \_\_\_\_\_ Sex: **Male / Female**Handedness: **left - right**

Date: \_\_\_ / \_\_\_ / 200...

Q1.

Please, give your main impressions of the task.

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Q2.

To what extent did you feel that the asterisk followed a random or a predictable sequence of locations?

The locations moved to by the asterisk were...

1	2	3	4	5
totally random	mostly random	half and half	mostly predictable	totally predictable

Q3.

If you noticed any regularity in the movement of the asterisk, what are you able to say about it? When did you first notice this?

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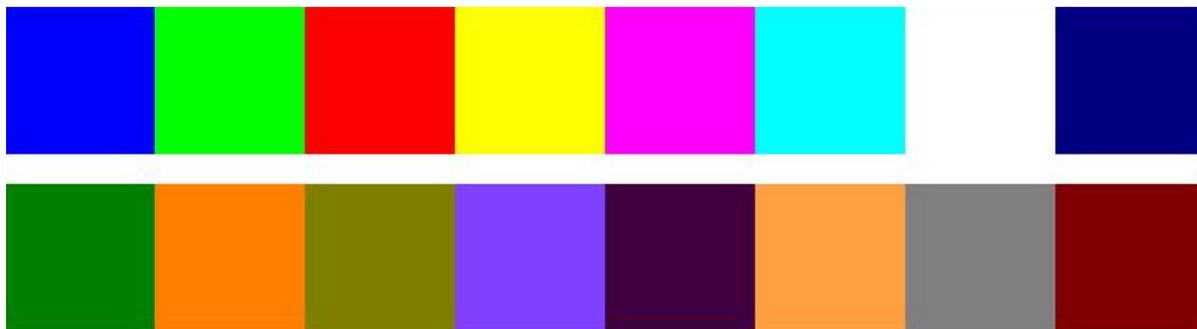
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Q4.

If you noticed any repeated sequences in the task, how many items long were those sequences?

## Appendix B

The 16 colours used in the Colour-frame Study



## Appendix C

The English Translation of the Ethical Consent

Used for the Experiments in Hungary

## STATEMENT OF CONSENT

I confirm that I participate in *Balazs Aczel, Csongor Cserep, Judit Kulcsar and Bence Lukacs's* cognitive psychological research voluntarily. I have received satisfactory information about the nature of the experiment.

I understand that my personal data will be kept confidentially and no person other than the experimenters of the study will have access to them. I agree that the my recorded experimental data will be accessible by other researcher.

I understand that I am free to withdraw at any time, without giving any reason, without consequence. Should this be the case my recorded data will be deleted.

I understand that the recorded data are only for the purpose of research and are not diagnostic. I will not request any expert's report after the experiment.

\_\_\_/\_\_\_/ ,200...., Budapest

Signature: .....

Name: \_\_\_\_\_

## The Original Hungarian Language Ethical Consent

Used in the Experimenting in Hungary

**NYILATKOZAT**

Kijelentem, hogy *Aczél Balázs és Cserép Csongor, Kulcsár Judit és Lukács Bence* kognitív pszichológiai vizsgálatában önszántamból veszek részt. A vizsgálat jellegéről annak megkezdése előtt kielégítő tájékoztatást kaptam.

Tudomásul veszem, hogy az azonosításomra alkalmas személyi adataimat a vizsgálat vezetője bizalmasan kezeli, azokba a vizsgálat lebonyolításában és feldolgozásában részt vevő személyeken kívül másoknak nem enged betekintést. Hozzájárulok ahhoz, hogy a vizsgálat során a rólam felvett, személyem azonosítására nem alkalmas adatok más kutatók számára is hozzáférhetőek legyenek.

Fenntartom a jogot arra, hogy a vizsgálat során annak folytatásától bármikor elállhassak. Ilyen esetben a rólam addig felvett adatokat törölni kell.

Tudomásul veszem, hogy a vizsgálati adatok kutatási, és nem *diagnosztikai* célokat szolgálnak, ilyen jellegű *szakvéleményre* a vizsgálatok elvégzését követően igényt nem támasztok.

Budapest, 200.../ \_\_\_/ \_\_\_ ALÁÍRÁS: .....

NÉV:

## Appendix D

## The English Translation of the Questionnaire

## Used in the Colour-frame Study

Subject number:    Age: \_\_\_\_\_    Sex: Male / Female    Date: \_\_\_ / \_\_\_ /

Q1. Please, give your main impressions of the task.

---



---

Q2. To what extent did you feel that the colour of the frame predicted the location of the asterisk?

The locations of the asterisk were...

1	2	3	4	5
totally random	mostly random	half and half	mostly predictable	totally predictable

Q3. If you noticed any regularity in the relation of the asterisk and the colours, what are you able to say about it? When did you first notice this?

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Q3. Are you more risk averse or risk seeker?

1-----2-----3-----4-----5-----6-----7  
risk averse risk seeker

Q4. What would you choose rather ...

- |                                    |    |  |
|------------------------------------|----|--|
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 15 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 20 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 25 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 30 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 35 pounds |

## The Original Hungarian Language Questionnaire

### Used in the Colour-frame Study

Ksz. szám: \_\_\_\_\_ Életkor: \_\_\_\_\_ Nem: Férfi / Nő Dátum: 2008 \_\_\_\_ / \_\_\_\_ / \_\_\_\_

K1. Röviden írd le a kísérletről szerzett benyomásod, gondolataidat.

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K2. Mennyire érezted, hogy a képernyő keretének színe bejósolta a csillag helyét?

A csillag megjelenése...

1	2	3	4	5
teljesen random	többnyire random	fele-fele	többnyire bejósolható	teljesen bejósolható

K3. Ha tapasztaltál valami rendszerességet a csillag helyét illetően, akkor mit tudsz arról mondani? Mikor tűnt fel ez először?

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K4. Magadat inkább kockázat kerülőnek, vagy kockázat keresőnek tartod?

1-----2-----3-----4-----5-----6-----7

kockázat kerülő

kockázat kereső

Q5. Mit választanál inkább...

1000 Ft-ot

vagy

50% esélyt, hogy nyerj 1500 Ft-ot

1000 Ft-ot

vagy

50% esélyt, hogy nyerj 2000 Ft-ot

1000 Ft-ot

vagy

50% esélyt, hogy nyerj 2500 Ft-ot

1000 Ft-ot

vagy

50% esélyt, hogy nyerj 3000 Ft-ot

1000 Ft-ot

vagy

50% esélyt, hogy nyerj 3500 Ft-ot

## Appendix E

## The Ethical Consent Used in Cambridge



Department of Experimental Psychology

**VOLUNTEER INFORMATION SHEET**

**Title of Project:** Reaction time and selective attention.

**Principle Investigator:** Balazs Aczel

You are being invited to take part in a research study. Before you decide it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information. Take time to decide whether or not you wish to take part. Thank you for reading this.

*What is the purpose of the study?*

The purpose of the study is to examine some of the cognitive processes involved in attention and response selection. We hope the research will help us to develop theories about how people's attention influences the way they respond.

*Do I have to take part?*

No. It is up to you to decide whether or not to take part. If you decide to participate, you will be asked to sign the consent statement at the bottom of this letter, and you will be given a copy of this information sheet and consent statement. You will be free to withdraw from the study at any time and without giving a reason.

*Who can participate?*

Study participation is restricted to individuals over age 18. Also, if you have experienced mental health problems in the past (e.g. anxiety or depression), please discuss this with a member of the research team.

*What will happen to me if I take part?*

The study will involve a single session at the Department of Experimental Psychology (Downing Site), lasting about fifty minutes. The tasks will be run on a computer, which will provide clear instructions at each point. Any questions will be answered by the experimenter who will be present throughout. You will have opportunity to practice all tasks. The task will involve pressing buttons as quickly as you can when you detect a target on the screen.

*Confidentiality – who will have access to the data?*

All data will be anonymous, identified only by a code number. Personal data (e.g. your name) will not be stored on computer, and kept only in a locked file. Only qualified members of the research team will have access to the stored computer data.

*What will happen to the study results?*

Results will be presented at academic conferences, written up in a PhD thesis and journal articles. Results are presented in terms of the average responses of groups of individuals. If any individual response data were ever presented, such data would be totally anonymous, without any means of identifying the individuals involved.

*Will video or audio tapes be used?*

No video or audio tapes will be used in this experiment.

*Withdrawal*

You may withdraw at any stage without explanation.

*Approval*

The project has received ethical approval from the Psychology Research Ethics Committee of the University of Cambridge.

**You are entirely free to withdraw from the study at any time without having to explain why.**

**If you have any questions about the study, please contact:**

**Mr Balazs Aczel, PhD Candidate, Dept of Experimental Psychology, University of Cambridge, Downing St Cambridge, CB2 3EB. Tel: 01223 333576. Email b.aczel@psychol.cam.ac.uk**

**STATEMENT OF CONSENT**

**Title of Project:** Reaction time and selective attention.

**Subject ID code** \_\_\_\_\_

**Please initial box:**

1. I confirm that I have read and understand this information sheet and I have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without consequence.

3. I agree to take part in the above study.

\_\_\_\_\_  
**Name of participant**

\_\_\_\_\_  
**Date**

\_\_\_\_\_  
**Signature**

## Appendix F

## The English Version of the Questionnaire

## Used in the SALT Study

**Age:** \_\_\_\_\_ **Sex:** Female / Male **Handedness:** left - right **date:** 2009 \_\_\_ / \_\_\_ /

Q1. Please, give your main impressions of the task.

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Q2. If you noticed any regularity in the appearance of the bigger filled circles then what was it and when did you notice it?

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Q3. Are you more risk averse or risk seeker?

risk averse 1-----2-----3-----4-----5-----6-----7 risk seeker

Q4. What would you choose rather ...

- |                                    |    |  |
|------------------------------------|----|--|
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 15 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 20 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 25 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 30 pounds |
| <input type="checkbox"/> 10 pounds | or | <input type="checkbox"/> 50% chance of winning 35 pounds |

## The Hungarian Version of the Questionnaire

## Used in the SALT Study

**Életkor:** \_\_\_\_ **Nem:** Férfi / Nő **Kezesség:** bal - jobb **Dátum:** 200.. \_\_\_\_ / \_\_\_\_ /

K1. Röviden írd le a kísérletről szerzett benyomásod, gondolataidat!

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K2. Ha tapasztaltál valami rendszerességet a nagy körlapok megjelenésében a teszt során, akkor mi volt az és mikor észlelted ezt?

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K3. Magadat inkább kockázat kerülőnek, vagy kockázat keresőnek tartod?

kockázat kerülő 1-----2-----3-----4-----5-----6-----7 kockázat kereső

K4. Mit választanál inkább...

1000 Ft-ot                      vagy                       50% esélyt, hogy nyerj 1500 Ft-ot

1000 Ft-ot                      vagy                       50% esélyt, hogy nyerj 2000 Ft-ot

1000 Ft-ot                      vagy                       50% esélyt, hogy nyerj 2500 Ft-ot

1000 Ft-ot                      vagy                       50% esélyt, hogy nyerj 3000 Ft-ot

1000 Ft-ot                      vagy                       50% esélyt, hogy nyerj 3500 Ft-ot

## Appendix G

## Stimuli Used in the Housemate Rating Test

Table G1

## English Translation of the Stimuli Used in the Housemate Rating Test

<b>Dimensions</b>	<b>Positive attributes</b>	<b>Negative attributes</b>
How important it is for you that your roommate ...	<i>Housemate X ...</i>	<i>Housemate X ...</i>
___ is friendly?	___ is very friendly.	___ is not too friendly.
___ has a good sense of humour?	___ has a good sense of humour.	___ doesn't have a good sense of humour.
___ is tidy?	___ is very tidy.	___ isn't very tidy.
___ is spontaneous?	___ is very spontaneous.	___ isn't very spontaneous.
___ is punctual?	___ is very punctual.	___ isn't very punctual.
___ has nice friends?	___ has nice friends.	___ has boring friends.
___ is a good cook?	___ is a good cook.	___ isn't a very good cook.
___ likes the same music?	___ likes the same music as you.	___ likes different music than you.
___ has experience with living in a shared house?	___ has experience with living in a shared house.	___ has no experience with living in a shared house.
___ has a high income?	___ has a high income.	___ has a low income.
___ gets good grades?	___ gets good grades.	___ doesn't get good grades.
___ studies the same topic as you?	___ studies the same topic as you.	___ studies a different topic to you.

Table G2

## The Original Hungarian Stimuli Used in the Housemate Rating Test

<b>Dimensions</b>	<b>Positive attributes</b>	<b>Negative attributes</b>
Milyen fontos Neked, hogy a lakótársad ...	<i>László/István/Zoltán ...</i>	<i>László/István/Zoltán ...</i>
___ barátságos legyen?	___ nagyon barátságos.	___ nem túl barátságos.
___ -nak jó legyen a humora?	___ jó a humora.	___ nincs jó a humora.
___ rendszerető legyen?	___ nagyon rendszerető.	___ nem nagyon rendszerető.
___ spontán legyen?	___ nagyon spontán.	___ nem nagyon spontán.
___ pontos legyen?	___ nagyon pontos.	___ gyakran késik.
___ jó fej barátai legyenek?	___ jó fej barátai vannak.	___ unalmasak a barátai.
___ jól főzzön?	___ jól főz.	___ nem túl jól főz.
___ hasonló zenéket szeressen?	___ hasonló zenéket szeret.	___ más zenéket szeret.
___ -nak legyen gyakorlata az együttlakásban?	___ -nak van gyakorlata az együttlakásban.	___ -nak nincs gyakorlata az együttlakásban.
___ -nak legyen elég pénze?	___ mindig van pénze.	___ nincs sok pénze.
___ -nak jók legyenek a jegyei?	___ jók a jegyei.	___ nem jók a jegyei.
___ ugyanazt tanulja?	___ ugyanazt tanulja.	___ más tárgyat tanul.