The effect of value on long-term associative memory

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Abstract

It is often impossible to remember everything we encounter. Strategically remembering more valuable information has been demonstrated to be beneficial in optimizing working memory and long-term memory. This thesis explored the conditions under which this value-directed remembering effect could extend to associative memory (i.e., memory for details associated with an item), and explored the possible mechanisms underlying this effect. Chapter 2 explored whether value effects on associative memory (i.e., item-colour binding) would be more reliable when the binding condition between item and associative information is optimised. Across four experiments, it was demonstrated that value effects could be observed on colour memory when colour information is well-integrated with items (i.e., using appropriate study stimuli and encoding instructions), while also confirming previous findings that value indeed has little effect on colour memory when the binding condition is inadequate. Chapter 3 examined the role of attention in this effect. While divided attention (DA) during the encoding phase decreased overall level of performance, it did not impact the ability to strategically encode and briefly maintain high value item-colour bindings. This was consistently observed using the sequential and the simultaneous presentation formats, suggesting selective encoding requires little attentional resources. DA did, however, impair persistence of value effects when items were presented sequentially. Chapter 4 explored the possible encoding strategies that might be driving this value effect. Overall memory performance and the value effect under the no-strategy-instruction condition more closely resembled that using an instructed verbal rehearsal strategy than using an elaborative rehearsal strategy,

suggesting maintenance rehearsal is probably the primary encoding strategy driving this effect. Taken together, findings from this thesis indicate that value effects could be observed on memory for associative information, provided it is well-integrated with items. Such effect requires little attentional resources and is probably driven by maintenance rehearsal for more valuable associations.

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Abbreviations

AD	Alzheimer's disease
ADHD	Attention deficit hyperactivity disorder
ANOVA	Analysis of variance
BF	Bayes factor
DA	Divided attention
DRM	Deese-Roediger-McDermott
EEG	Electroencephalogram
FAR	False alarm rates
FA	Full attention
FSW	Frontal slow wave
JOL	Judgment of learning
LTM	Long-term memory
MMs	Marginal means
RKG	Remember, Know, Guess
SE	Standard error
SD	Standard deviation
VTA	Ventral tegmental area
WM	Working memory
WMC	Working memory capacity

CHAPTER 1

GENERAL INTRODUCTION

In our daily life, we are often presented with a large amount of information, and it is often impossible to remember all of it, especially as not all information is equally important. To operate our limited capacity memory and attentional systems efficiently, one approach is to selectively remember the information that is more valuable or goal-relevant. Recently, this strategy has been explored in working memory (WM; Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry & Ricker, 2020; Sandry et al., 2014; 2020) and in long-term memory (LTM; Castel et al., 2002; 2013; Elliott, Blais, et al., 2020; Elliott, McClure, et al., 2020; Hennessee et al., 2017; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016; 2017; Robison & Unsworth, 2017; Stefanidi et al., 2018). However, whether participants can also apply this strategy to LTM for associative information (i.e., details associated with an item/event, such as colour, location of an item) is currently inconsistent. There is some evidence suggesting that associative memory is better for high value information than low value information (Elliott, McClure, et al., 2020; Siegel & Castel, 2018a, 2018b; Ariel et al., 2015; Griffin et al., 2019; Cohen et al., 2017; Festini et al., 2013; Hargis & Castel, 2017; Castel et al., 2007), whereas other studies find no beneficial effect of value on associative memory (Villaseñor et al., 2021; Hennessee et al., 2017; 2018). This thesis examined whether participants can selectively remember more valuable item-colour bindings in immediate and delayed memory and explored the possible mechanisms underlying this effect.

The literature review will discuss value effects in WM in young adults, and such effects in children and older adults. The possible underlying mechanisms will then be discussed, and some initial work exploring the value effect in WM using different stimulus modalities, including verbal stimuli and odour stimuli. The value effect in LTM will then be discussed, as well as several possible mechanisms supporting this effect. These include more attention allocation towards high value information, more elaborative encoding for high value information, and reward-related dopaminergic consolidation for high value information. Its relation with working memory capacity and metacognition will also be discussed.

1.1 The value effect in WM

1.1.1 The value effect in WM in young adults

WM refers to a limited capacity system for the temporary storage and processing of information required for complex cognition (Logie et al., 2021). To optimise task performance, it would be useful to use these limited resources as efficiently as possible. One way of achieving this is to strategically focus attention on the information that is more valuable or goal-relevant. Hu et al. (2014) introduced a paradigm to investigate this when exploring the interfering effect of a to-be-ignored stimulus suffix on feature binding in visual WM. In this paradigm (Hu et al., 2014, Experiment 4), four coloured shapes were presented sequentially in different locations of the screen. Participants were instructed to remember the shape-colour bindings and were informed that correctly remembering the first (or the last) item could earn more points than the other items. Following the final study item there was either a blank interval, or a suffix (i.e., a to-be-ignored item). Finally, a test probe (a colour blob or a line drawing of a shape) appeared and participants were asked to orally recall the other feature of the probed target object. The results showed that the last item was remembered better than the other items in the list, but a suffix reduced this recency effect. In addition, when assigning more points to the first or the last item in the 4-item list, memory for the items at these positions were subsequently improved, but like the recency effect, it was reduced by a suffix. It was interpreted that both central executive processes (reflected by the value effect) and perceptual attention (reflected by the recency effect) combine to determine a limited number of items into a privileged state, from where the items are more accessible but also more vulnerable to interference (Hitch et al., 2020; Hu et al., 2014).

The effect of value, since then, has been replicated across a range of studies. A further study by Hitch et al. (2018) demonstrated that the value effect was not due to the special status that the first or the end positions may have in WM, because the effect was also observed in the second and the third positions when these positions were associated with higher points. They also found that participants were able to prioritise more than one item. Allen and Ueno (2018) extended these outcomes from sequential presentation format to a simultaneous presentation context, and found that attention can be managed quite flexibly so that associating each item in an array with a different point value (1, 2, 3, 4 points) results in correspondingly graded levels of recall performance.

Instead of indicating the point value of each item via serial position as the studies mentioned above, Sandry and colleagues used the colour of the item to show its importance. The value effect was consistently observed in WM for words (Sandry et al., 2020), shapes, arrows and unfamiliar characters (Sandry & Ricker, 2020). In this paradigm, three visual stimuli were presented sequentially. One of the stimuli was shown in red, and the other two were shown in black. In the differential probe value condition, the red stimulus was worth more points than the black stimuli; in the equal probe value condition, both red and black stimuli were worth an equivalent point. During the test phase, one stimulus from the study list and one novel stimulus were presented side by side, and participants were asked to choose the old one. Each stimulus from the list was equally being tested. The results revealed shorter RTs for high value items and this was consistently observed in each serial position. Improved performance for red-coloured items was not observed in an equal probe value condition, ruling out the possibility that the value effect was due to item distinctiveness. Similar patterns were evident in memory accuracy data, although Bayesian factor analysis revealed weak evidence supporting no difference in accuracy between high and low value items at serial position two and/or serial position three. Sandry et al. (2020) also found the effect of value in LTM for words, as indicated by higher free recall accuracy for high value words than low value words in a surprise delayed test.

1.1.2 The value effect in WM in children and older adults

The value effect has also been observed in other age groups. Although older adults have poorer visual WM overall, their ability to strategically direct attention to more valuable items in WM is equivalent to younger adults (Allen et al., 2021). Children are also able to prioritise more valuable information in WM, provided that the experimental task is more meaningful and motivating for them. To be more specific, Berry et al. (2018) using a near-identical paradigm to previous studies (Hitch et al., 2018; Hu et al., 2014; Hu et al., 2016) investigated 7 to 10 year-old's ability to prioritise high value items in WM in a sequential presentation format. Across 3 experiments, large recency effects for the final item were consistently observed, but there was no evidence that children were able to prioritize the more valuable item in a 3-item sequence. A more recent study by Atkinson et al. (2019) suggested this was possibly because the task was taken from previous studies using adult participants, and the notional points system might not be sufficiently motivating for children. To make the points system more meaningful and make the task more age-appropriate, Atkinson et al. (2019) introduced children a friendly alien named Zorg. Children were told that Zorg's planet had been invaded by evil aliens and were asked if they would help zap them. To zap the aliens, they needed energy points, which could be collected by playing memory games (i.e., the experimental task). In the differential probe value condition, they were told that correct recall of the first item would earn them four energy points, and that correct recall of any other item would earn them one energy point. In the equal probe value condition, they were told that correct recall of any item would earn them one energy point. After every 10 trials, children were shown a progress bar and were reminded of the probe value instructions. At the end of the session, they were told they had accumulated enough energy points to zap the evil aliens and also received a prize. By placing the memory task in the context of a story, it was found that children aged 7 to 10 years do indeed show a memory boost for high value items. This ability was consistently observed using both sequential and simultaneous presentation of items. However, it should be noted that the observed value effects were still smaller than those typically observed in young adults (Atkinson et al., 2019).

1.1.3 Mechanisms of the value effect in WM

It has been suggested that value effects may reflect high value items being prioritised in the FoA (Hitch et al., 2020). Although both verbal rehearsal and attentional refreshing (Camos et al., 2009) can be used to support prioritisation in the FoA (Hitch et al., 2020; Sandry et al., 2014), attentional refreshing may play a more important role, as value effects are observed when concurrent articulation tasks are adopted to prevent verbal rehearsal (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014). In addition, presenting a visual suffix (i.e., a to-be-ignored item) at the end of each study list has reduced the value effect, especially when the suffix is similar to the study items (Allen & Ueno, 2018, Hitch et al., 2018; Hu et al., 2014). This may suggest that the prioritised item is refreshed in its original visual format and thus is vulnerable to interference from a visual stimulus suffix.

Prioritising high value information in the FoA might depend on the availability of sufficient general executive resources (Hitch et al., 2018; Hu et al., 2014; 2016). For example, in Hu et al. (2016), a concurrent activity involving high or low cognitive load was required during the value effect task. High cognitive load was achieved by counting backward from a multi-digit number. Low cognitive load was achieved by repeating of a single multi-digit number. Both tasks involve similar verbal output and therefore reduce the opportunity to use verbal rehearsal to similar extent, with the critical difference being that counting places a considerably higher load on the central executive (Hitch et al., 2020). It was found that value effects were reduced or abolished with the higher cognitive load, suggesting prioritising high value information relies on the limited-capacity resources of the central executive. Supporting this view, as mentioned above, children aged 7 to 10 years showed a smaller value effect relative to younger adults, possibly because of the immaturity of executive resources (Atkinson et al., 2019).

Inconsistent with this view, however, older adults typically suffer from reduced executive resources (Craik & Byrd, 1982; Craik & McDowd, 1987), but they have equivalent ability to younger adults of prioritising more valuable items in WM, although their overall memory indeed declined (Allen et al., 2021).

1.1.4 Exploring value effects in WM using different stimulus modalities

The studies mentioned above all examined the effect of value in visual WM. Work is starting to explore this effect on other forms of stimuli. For example, Sandry et al. (2014) found that visually presented verbal stimuli (i.e., letters) associated with higher value could be retrieved faster and more accurately. Similarly, Atkinson et al. (2020) presented participants with audio clips of digit sequences and asked them to recall the digits in the correct order. One digit from the sequence was worth more points than the other digits. Recall was enhanced for higher value items. This was the case even when rehearsal and executive resources were disrupted by dual-tasks (i.e., repeat “Monday, July” or backward counting from that date), although this may have been achieved by neglecting other lower value items in the sequence (Atkinson et al., 2020).

The verbal domain contrasts to the visual domain in terms of the reliance on general executive resources. It is interesting to explore whether other domains may be similarly or differentially impacted by value of information. For example, Johnson and Allen (2021, Experiment 2) have explored whether participants can direct their attention in WM for colour-odour bindings. In this study, participants were presented with 3 different odorants, each in a different coloured cube. At test, they received one of the previous 3 odorants which was presented in a neutral white coloured cube, and were asked to verbally recall the colour of the cube in which the odorant was originally presented. In the value condition, the first odour-colour binding was worth more points; in the control condition, the 3 odour-colour bindings were equally important. The results showed that compared to the control condition, participants were able to reallocate their attention based on stimulus value. This was reflected by a small increase in accuracy at position 1 (high value) and a reduction in accuracy for positions 2 and 3 (low value). However, this value effect was smaller than those observed previously for shape-colour bindings (Atkinson, Berry, et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016).

One reason for the reduced value effect could be that it might be difficult to attentionally refresh an odour as is the case in visual domain (Sandry & Ricker, 2020; Sandry et al., 2020; Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016). While attentional refreshing is assumed to be a domain-general process (Souza et al., 2018) and consistent with this view the value effect observed in verbal domain has been suggested to be driven by attentional refreshing (Atkinson et al., 2020), in Atkinson et al. (2020), it is unclear whether high value verbal digits are refreshed in the original verbal format or is refreshed in a recoded visual format. It would be worthwhile for future work to continue to explore whether stimuli from different sensory domains might similarly benefit from value-directed remembering (Allen, 2020). This may also help to understand whether attentional refreshing, a critical proposed mechanism supporting the value effect, is a domain-general process (Souza et al., 2018) or is limited to several specific domains.

1.2 The value effect in LTM

1.2.1 Improved LTM for more valuable information

Analogous research has also been conducted in the LTM field, using the term value-directed remembering (termed as the value effect in this thesis). This was introduced by Castel et al. (2002) when exploring ageing and the ability to control memory processes. Previous research using a directed forgetting paradigm has found that older adults have less control over memory, as reflected by recalling fewer words that has been instructed to remember and more words that has been instructed to forget relative to younger adults (Zacks et al., 1996). However, Castel et al. (2002) using the value-directed remembering paradigm have found equivalent control abilities between younger and older adults. In this study, participants were given lists of 12 words, with each word randomly paired with a different value, ranging from 1 to 12. They were told that their task was to try to remember the words and the goal was to keep the point score as high as possible. Following recall of each list, participants were informed of their score.

The degree of selectivity was measured by using a selectivity index (Watkins & Bloom, 1999). This selectivity index is based on the participant's sum score, relative to chance and ideal performance. The participant's score is the sum of the points that were paired with the recalled items; the ideal score is the sum of the highest points at that level of recall. Chance score is calculated as multiplying the average value of all the points by the number of words recalled. For example, if a participant recalled four words, and the points associated with the words were 12, 10, 9, and 8, the participant's score is 12 +10 + 9 + 8. The ideal score is 12 + 11 + 10 + 9. The chance score is 6.5 (average of the points from 1 to 12) × 4 (the number of words recalled).

$$\text{selectivity index} = \frac{\text{participant's score} - \text{chance score}}{\text{ideal score} - \text{chance score}}$$

Across four experiments, it was consistently found that older adults achieved significantly higher levels of selectivity, despite their recalling fewer words than did younger adults. This may be because younger adults recalled a greater number of words (relative to the older adults) and this diluted their selectivity index. In addition, older adults were likely to use primary memory to prioritise more valuable words. When primary memory was substantially eliminated by using delayed recall, older and younger adults' selectivity was equivalent. Older adults' strategic reliance on primary memory is especially evident using the self-regulated learning paradigm, in which study time and the choice to restudy words are under participant's control during the study session (Castel et al., 2013). It was found that relative to younger adults, older adults allocated a greater amount of study time to the higher value words and capitalized on recency effects by studying high value items often and also immediately before the test. As a result, older adults showed comparable levels of selectivity, despite recalling fewer words, relative to younger adults. Taken together, these studies suggest that both younger and older adults are able to selectively study more important information to optimise performance.

Studies using recognition memory tasks have also observed the value effect, and it is further found that high value information is remembered with better memory quality. Two distinct processes have been hypothesized to contribute to recognition memory, recollection/remembering and familiarity/knowing (e.g., Gardiner, 1988; Tulving, 1985; Yonelinas, 2002). Recollection is being able to consciously recollect a previous experience or event, typically including the memory of various details related with this episode. Familiarity is being able to recognize the information but without consciously recollecting related details. Results from value effect studies adopting the remember/know (R/K) paradigm have shown that value typically enhances recollection, with little or no impact on familiarity (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018).

A more objective way of measuring memory quality, relative to the self-reported R/K paradigm, is to test memory for details associated with item information. These contextual details/sources refer to all kinds of information that collectively specify the conditions under which a memory is formed, including the temporal, spatial, and social context of an event, the media, and modalities through which the event is perceived (Johnson et al., 1993; Naveh-Benjamin, 2000). Previous studies have revealed substantial evidence for the distinction between item and associative memory (Clark & Shiffrin, 1992; Hockley, 1991, 1992; Hockley & Cristi, 1996; Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995), such as a larger detrimental effect from ageing for associative than item memory (Castel & Craik, 2003; Cowan et al., 2006; Naveh-Benjamin, 2000; Naveh-Benjamin et al., 2004; Naveh-Benjamin et al., 2003; Old & Naveh-Benjamin, 2008; Overman & Becker, 2009), and distinct medial temporal lobe support for associative and item memory (Davachi, 2006; Davachi et al., 2003; Glisky et al., 1995).

Research exploring the effect of value on associative memory has revealed inconsistent results. Some studies found that higher value items were associated with better associative memory. For example, in Siegel and Castel (2018a), younger and older adults were presented with items worth different point values in a visuospatial display (either sequentially or simultaneously). They were instructed to remember the location of the items for a later test, with the goal of maximizing their score. Although age-related visuospatial memory deficits were still present, older adults showed equivalent ability as younger adults of selectively encoding high value item-location binding, regardless of presentation format. The effect of value on item-location memory has also been observed in other studies (Elliott, McClure, et al., 2020; Siegel & Castel, 2018b; Siegel et al., 2021), and also on other types of associative memory, including memory for word pairs (Ariel et al., 2015; Griffin et al., 2019), memory for word plurality status (Cohen et al., 2017), and memory for the point-values associated with the words (Castel et al., 2007, but see Hennessee et al., 2017).

Other studies, in contrast, revealed no beneficial effect of value on associative memory. For instance, Villaseñor et al. (2021) investigated how value influences different aspects of memory, including item memory and memory for contextual details. The paradigm was similar to the typical value effect studies. An important difference is that more contextual details were included, such that words were presented in either red or green font and in Comic Sans or Times New Roman. In addition, while the word appeared on the computer screen, it was simultaneously presented auditorily in either a feminine or masculine voice. During recognition, for words judged as “old,” participants were asked to report the number of details (i.e., no details, few details, a lot of details) they could retrieve (subjective context memory), and the voice gender in which the words were presented (objective context memory). Results showed better item memory and subjective context memory for higher value relative to lower value information, but value had no effect on objective context memory. Similarly, Hennessee et al. (2017; 2018) only found value effects on item memory but not on memory for the colour of words.

While the effect of value on associative memory is inconsistent, its effect on item memory is quite consistent and robust under a variety of different conditions. It has been observed in the sequential presentation context and also in the simultaneous context, with the latter demonstrated a larger effect (Middlebrooks & Castel, 2018). Time constraints have no apparent impact on the value effect, such that shortening presentation time for each word (from 5s to 1s) decreased memory overall but it did not impact the ability to selectively study more valuable words (Middlebrooks, Murayama, et al., 2016). The value effect is also evident in tasks that are more analogous to real-world situations. For example, it has been shown that both younger and older adult are able to better remember allergens with high severity (Middlebrooks, McGillivray, et al., 2016), medication interactions with severe outcomes (Friedman et al., 2015; Hargis & Castel, 2018), and personal information (i.e., face, name and occupation) with higher social value (i.e., they are more likely to interact with in the future; Festini et al., 2013; Hargis & Castel, 2017).

The ability to strategically encode high value information has been demonstrated to be evident across the lifespan. Castel, Humphreys, et al. (2011) employed the value effect task across six distinct age groups: children (5–9 years of age), adolescents (10–17 years of age), younger adults (18–23 years of age), middle-aged adults (45–64 years of age), younger-older adults (young-old; 65–79 years of age), and older-older adults (old-old; 80–96 years of age). Participants were asked to study and recall words worth different point values. They were told that the goal of the task was to earn as many points as possible. To ensure children were aware that higher point values were more important, they were told that the more points that they earned, the more stickers they could earn. After they had finished recalling items from each list, participants were informed of the point total earned for that list. The results showed that memory capacity improved from childhood to adolescence, with memory peaking in the younger adults and then systematically decreasing across middle age to older-older adults. Memory selectivity, in contrast, appeared to follow a different developmental trajectory. Overall, participants' recall was sensitive to point value, with higher value words being better remembered than lower value words, but different age groups differed in the degree of selectivity. Selectivity did not improve significantly from children to adolescents, but there was considerable improvement in young adults and it remained stable across middle-aged adults and younger-older adults. It then declined slightly in the older-older adults group. The authors speculated that children, adolescents, as well as the oldest adults have decreased selectivity possibly due to declines in frontal lobe function and lack of sufficient metacognitive monitoring (Castel, Humphreys, et al., 2011).

1.2.2 Mechanisms of the value effect in LTM

Several mechanisms have been proposed to explain the value effect in LTM. These include more attention allocation towards high value information, more elaborative encoding for high value information, and reward-related dopaminergic consolidation for high value information. Other studies have explored its relationship with working memory capacity and metacognition.

1.2.2.1 The role of attention

One important mechanism which underlies the value effect is that participants may strategically allocate more attention towards higher value information (e.g., Castel et al., 2002). Supporting this view, research using eye tracking methodology has found that participants' pupils dilated more (i.e., an indication of the amount of attentional effort devoted to a given item) when studying high relative to low value words, and these were associated with better memory for high value words (Miller et al., 2019). In addition, participants with attentional impairments such as Alzheimer's disease or ADHD show decreased value effects relative to healthy controls (Castel et al., 2009; Castel, Lee, et al., 2011), suggesting sufficient attentional resources are critical for being strategic when prioritising more valuable information. When such attentional resources are taxed by an unrelated dual task, one might expect that the value effect would be reduced or abolished. To explore this question, several studies have been conducted using the dual-task paradigm, but the results remain inconsistent.

Elliott and Brewer (2019) examined how various dual-tasks at encoding alter the effect of value. Participants encoded words that were assigned either high or low point values in multiple study-test phases. Participants were instructed that they could earn the point values by successfully recognizing the words in an upcoming recognition memory task. Their goal was to maximize their score. The value effect was observed, such that high value words were recognized more accurately than low value words. Importantly, performing an unrelated dual task (i.e., random number generation or tone detection, but not articulatory suppression) abolished/reduced the value effect. In contrast, other studies found that although tone detection dual tasks decreased participants' overall memory performance, their ability to selectively remember more valuable information was not impaired. This was observed on memory for words (Middlebrooks et al., 2017) and on memory for item-location associations (Siegel and

Castel, 2018b). A more recent study demonstrated that whether a dual task would impact the effect of value depends on the extent to which this dual task shares the same processing resources with the primary task (Siegel et al., 2021). Specifically, for an item-location binding memory task (a visual-spatial task), if the dual task (audio-nonspatial, audio-spatial task, or visual-nonspatial tasks) did not share the exact same processing resources to the primary task, only memory accuracy was reduced; memory selectivity was intact. If the dual task (a visual-spatial task) shared the same processing resources with the primary task, both memory accuracy and memory selectivity were impaired.

To summarise, there is evidence to suggest that high value information is prioritised through more attention allocation. While some studies have found that value effects could be maintained even when attentional resources are taxed, these results may reflect a flexible attention reallocation process, such that participants are able to allocate part of their attentional resources to the unrelated dual task and reallocate the remaining resources based on item value.

1.2.2.2 Elaborative encoding

Another critical mechanism that has been suggested is the application of elaborative encoding for higher value information. This can be observed from participants' self-report that they use more effective strategies (i.e., imagery mediators, keyword mediators, sentence generation, or relational processing) when learning high value word pairs (Ariel et al., 2015). Evidence has also been found using a modified Deese-Roediger-McDermott (DRM) paradigm (Bui et al., 2013), in which each DRM list (i.e., semantically related words) was paired with low, medium, or high point values. During recognition, some lure words (i.e., related with study words but never presented) were presented to probe the extent of relational processing. Across three experiments, it has been demonstrated that higher value can enhance true memory but also increase false memory, suggesting the value effect reflects the ability to successfully engage in relational processing (Bui et al., 2013). Consistent with this view, Hennessee et al. (2019) speculated that if differences in memory performance between high and low value items were due to differences in elaborative encoding, instructing participants to use the same elaborative encoding strategy for all items should reduce the value effect. Indeed, relative to no instruction and instruction to use rote rehearsal, elaborative encoding eliminated/nearly eliminated the value effects. Further evidence comes from studies using fMRI. Memory selectivity is associated with greater differences between high and low value words during presentation in the activation of semantic processing brain regions (e.g., left inferior frontal gyrus and left posterior lateral temporal cortex; Cohen et al., 2014, 2016), suggesting deep semantic processing is an important mechanism underlying the value effect.

There is also some indirect evidence supporting the elaborative encoding mechanism. For example, using the R/K paradigm, value effects have been consistently observed on R responses but it is unstable on K responses (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018). Previous studies indicate that R and K responses reflect different encoding processes such that elaborative rehearsal affects R but not K and maintenance rehearsal affects K but not R (Gardiner, 1988; Gardiner et al., 1994). These findings may suggest that the value effect observed on R responses is owing to elaborative encoding for high value items.

In addition, a more recent study using an incidental encoding paradigm found that semantic processing rather than perceptual processing benefited from higher value (Swirsky et al., 2020). In this study, participants were presented with two objects side-by-side. In one condition (semantic processing), they were asked “are these objects from the same category”; in the other condition (perceptual processing), they were asked “are these objects identical to one another”. The object pairs were associated with different point values and correct response to the questions would earn the corresponding point values. A surprise recognition test revealed that there was a reward-related boost in recognition for objects encoded semantically but not perceptually, supporting the elaborative encoding mechanism.

However, since the study mentioned above used an incidental approach, it cannot rule out the possibility that participants could intentionally repeat high value information multiple times in the typical value effect paradigm. This possibility, nevertheless, has been refuted by Stefanidi et al. (2018). In Stefanidi et al. (2018), the value effect was observed using delayed free recall when items paired with different point values appeared in an ascending order (1 to 10; Stefanidi et al., 2018). This is taken as evidence to refute the hypothesis that rehearsal is the sole driving force for the value effect, because if that is the case, higher value items should have less rehearsal time, and thus worse memory, than lower value items (Stefanidi et al., 2018). The authors speculated that value potentially facilitates encoding in a variety of ways, such as elaborative encoding and reward learning.

1.2.2.3 Reward-related dopaminergic consolidation

Another possible mechanism is that high value cues may activate dopaminergic projections from the ventral tegmental area (VTA) and the amygdala to the striatum and the hippocampus (Bromberg-Martin et al., 2010; Lisman & Grace, 2005; Shohamy & Adcock, 2010), and this in turn enhances hippocampal dependent memory consolidation (Wittmann et al., 2005). These findings are based on studies using monetary rewards rather than point values (they differ from each other to some extent, and this will be introduced later), but results from more recent studies using point values also support the dopaminergic memory consolidation process. For example, using EEG with a typical value effect paradigm, Elliott, Blais, et al. (2020) explored which of two hypothesized processes (elaborative encoding vs. reward-related memory consolidation process) underlies the value effect. They investigated two distinct components, the P3 component and the late frontal slow wave (FSW). The P3 component is thought to index dopamine-driven reward processing (Sato et al., 2005; Walsh & Anderson, 2012) or attentional resource allocation (Elliott, Blais, et al., 2020; Isreal et al., 1980; Wickens et al., 1983). The FSW component is thought to index executive processes and elaborative encoding (Elliott, Blais, et al., 2020; Fabiani et al., 1990; Mangels et al., 2001; Weyerts et al., 1997). It was found that the P3 component scaled linearly with participants' sensitivity to value whereas the FSW component was not sensitive to value. The authors concluded that the value effect on recognition memory is primarily driven by attention allocation arising from midbrain dopaminergic signalling, with no evidence supporting the elaborative encoding mechanism. However, since the P3 component could be a reflection of dopaminergic reward processing (Sato et al., 2005;

Walsh & Anderson, 2012) or a reflection of attentional allocation (Isreal et al., 1980; Wickens et al., 1983), it is difficult to disentangle these two processes. Use of fMRI techniques, in contrast, could detect reward-related brain regions and verify the role of dopaminergic processing. Using fMRI, Cohen et al. (2014, 2016) found greater activity in reward-sensitive regions (midbrain and ventral striatal reward regions) on high value information than on low value information across participants, suggesting dopaminergic reward system also plays a part in value effects.

It is worth noting that while value effects studies using point values bear some similarities with the studies using monetary rewards, in terms of enhanced memory for more valuable information and the underlying mesolimbic dopaminergic system, they also differ in several aspects. For example, the value effect is typically tested and observed immediately or with a short delay after encoding (e.g., 5 minutes, Castel et al., 2002; Hennessee et al., 2017; Middlebrooks & Castel, 2018; Siegel & Castel, 2018a), whereas previous work using monetary rewards suggest that the memory enhancement are most apparent after a long delay (e.g., over 24 hours, Murayama & Kuhbandner, 2011; Spaniol et al., 2013). In addition, when the monetary reward/point value cue is presented before the encoding item, high monetary cue induces increased reward-related brain activation during the cue period, and this is associated with better subsequent memory for the item followed that cue (e.g., Adcock et al., 2006; Park and Rugg, 2010; Bollinger et al., 2010; Addante et al., 2015). In contrast, in the value effect, value-related differences in the brain response to the cue were not associated with the degree to which value affected memory selectivity (Cohen et al., 2014, 2016).

1.2.2.4 Relation with WMC

WM is a limited capacity system for the temporary storage and processing of information required for complex cognition (Logie et al., 2021). Selective encoding in the value effect task involves strategically allocating limited attentional resources to items, with a goal of maximizing point score (Castel et al., 2009). Therefore, efficient selective encoding might be related to individual differences in working memory capacity (WMC; Castel et al., 2009). Several studies have been conducted to explore this question, though the results are inconsistent. Some studies observed a weak and unstable correlation between selectivity and WMC (Castel et al., 2009; Griffin et al., 2019), some studies found no correlation (Elliott, McClure, et al., 2020; Miller et al., 2019), and others found that selectivity is largely mediated by individual differences in WMC (Hayes et al., 2013; Robison & Unsworth, 2017).

Specifically, Castel et al. (2009) compared the value effect in younger adults, older adults and Alzheimer's disease (AD) group. They found no difference in selectivity (as reflected by selectivity index) for younger and older adults, but the AD group showed lower selectivity than the other groups. The correlation between WMC and the selectivity index was significant in older adults, and was marginally so in AD group, but was not significant in younger adults. In fact, the observed correlation between WMC and the selectivity index in older adults was fairly weak ($r = 0.22$), suggesting that there are strategic processes involved in selective encoding that are not shared with complex span tasks (i.e., reading span and operation span tasks; Castel et al., 2009). Similarly, Griffin et al. (2019) found that while WMC was correlated with selectivity, such that higher-span participants were better able to prioritise higher value words, the correlation (r = 0.19) was small. In addition, they did not replicate this finding in Experiment 2a and 2b in which the only differences compared to Experiment 1a and 1b were that the word pairs were semantically unrelated rather than related, and that the task was composed of several study-test cycles, rather than a single long list. Consistent with Experiment 2a and 2b in Griffin et al. (2019), Miller et al. (2019, Experiment 2) found that WMC and memory selectivity was unrelated. Likewise, Elliott, McClure, et al. (2020) found that episodic memory, WMC, and value effects represented three distinct constructs. Episodic memory, but not WMC, was predictive of value effects. These studies indicate that the ability to strategically prioritise more valuable information is largely independent of WMC.

Other studies, in contrast, found that individuals with higher WMC are more likely to engage selective encoding strategies to improve memory performance. Using a slightly different paradigm to the studies mentioned above, in which the items were presented sequentially and each was presented for a fixed duration (e.g., 2s), Robison and Unsworth (2017) implemented a self-regulated paradigm. All the items were presented simultaneously, allowing participants to choose how to allocate their study time. The authors found that individuals with higher WMC showed greater selectivity (Experiment 2). Furthermore, instructing participants to use an effective strategy (i.e., ignoring lower value items) at the beginning of the task attenuated the correlation between WMC and selectivity. It was concluded that individuals with lower WMC were less efficient than individuals with higher WMC at optimising memory performance because they were less likely to ignore lower value items. It should be noted, however, that the correlation between selectivity and WMC was not observed in Experiment 1 from this study.

Another study suggesting that WMC can support the ability to selectively encode information is by Hayes et al. (2013). In this study, there are several critical methodological differences to the previously described studies. Firstly, to increase the task demands, the typical value effect task was modified to include negatively valued items, such that point values were ranged from −6 to +12. Thus, participants must limit the processing of negative-value words. Secondly, the WM tasks used in this study were different to those used in the studies mentioned above. In those studies, WM tasks included the reading span task, the operation span task and the symmetry span task (or two of them). In Hayes et al. (2013), the WM tasks were the operation span task and the Stroop span task. Hayes et al. (2013) revealed that selectivity was largely mediated by individual differences in WMC. However, this might be driven by the inhibition process shared by the value effect task and the Stroop span task. Indeed, using the typical value effect paradigm (no negative value), it has been consistently found that older adults have equivalent control abilities to younger adults (e.g., Castel et al., 2002; 2013; Siegel & Castel, 2018a). However, in this study, younger adults demonstrated superior selectivity relative to older adults. This stemmed from older adults' inability to inhibit recalling negative value items, while also not being able to recall as many high items as younger adults. Therefore, it appears that different encoding processes might have been engaged when negative point values are included in the value effect paradigm, and the ability to prioritise more valuable information under this paradigm is related to WMC.

To summarise, when selective encoding does not involve inhibitory process, there is more evidence supporting no correlation or minimal correlation between value effects and WMC.

1.2.2.5 Relation with metacognition

Another ability that might be related to the value effect is metacognition. Metacognition is defined as thoughts, beliefs, and other cognitive processes devoted to monitoring and controlling one’s own cognitions (Hertzog & Dunlosky, 2011). Previous studies found that while older adults show decreased memory capacity, their ability to selectivity remember more valuable information is as good as younger adults (Ariel et al., 2015; Castel et al., 2002; 2013; Siegel & Castel, 2018a). This might be because in contrast to well-documented episodic memory deficits that occur with ageing (Hasher, 2006; Hess, 2005), metacognitive processes associated with memory appear to experience little to no age-related decline (Castel et al., 2012; Hertzog & Dunlosky, 2011).

Recently, work has started to explore the relation between metacognition and value effects. For example, Siegel and Castel (2019) examined metacognition for memory selectivity in younger and older adults. Prior to the presentation of each word list, participants were asked to predict how many words they would recall on the upcoming list. Older adults recalled less words overall, and their ability to predict their memory capacity were less accurate than younger adults. However, with increased task experience, they became more accurate in predicting the number of words they would later recall and became more selective towards high value information. This suggests that older adults are able to use metacognition about their memory capacity to adjust their goal-relevant strategies by allocating attention towards high value information (Siegel & Castel, 2019). Similarly, using the judgment of learning (JOL) and judgment of importance paradigm (i.e., making judgments as to how important it is to remember an item), Murphy and colleagues found that participants' metacognition and later recall were influenced by the value of the to-be-learned words. Participants rated valuable words as more likely and more important to be remembered, and were subsequently selective for high value information in their recall, demonstrating accurate metacognition and metacognitive awareness of their selectivity (Murphy et al., 2021; Murphy & Castel, 2021).

In summary, while research on the relation between selectivity and metacognition is limited so far, the existing evidence suggests a positive correlation between the two abilities. It would be interesting for future studies to continue to explore how different metacognitive processes (e.g., during acquisition, retention, and retrieval) may impact value effects, and how these processes could be improved to optimise memory performance.

1.3 Thesis outline

The aim of this thesis is to examine whether individuals can selectively prioritise more valuable associative information in immediate and delayed memory, and to explore the possible mechanisms that underlie this effect. Prior work has well-documented that in the situations where it is impossible/difficult to remember all the information that is present in the environment, individuals can strategically prioritise more valuable information, as reflected by improved memory for high compared to low value information. This has been observed in WM for shape-colour bindings (Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry & Ricker, 2020; Sandry et al., 2014; 2020), and in LTM for words (Castel et al., 2002; 2013; Elliott, Blais, et al., 2020; Elliott, McClure, et al., 2020; Hennessee et al., 2017;

Middlebrooks & Castel, 2018; Middlebrooks et al., 2016; 2017; Robison & Unsworth, 2017; Stefanidi et al., 2018). However, studies in associative LTM have yielded inconsistent results (Ariel et al., 2015; Castel et al., 2007; Cohen et al., 2017; Elliott, McClure, et al., 2020; Festini et al., 2013; Griffin et al., 2019; Hargis & Castel, 2017; Siegel & Castel, 2018a, 2018b; Villaseñor et al., 2021; Hennessee et al., 2017; 2018). A possible reason for this inconsistency is that the effect of value on associative memory may have been mediated by the binding condition between item and associative information. This thesis therefore examined whether the value effect could be observed (depending on the experiment) in immediate memory and/or LTM for item-colour binding when the binding condition between item and colour was optimised. It also explored the role of attention and strategy type in this effect. The exploration of the mechanisms is not only helpful in understanding of the value effect on item-colour binding memory specifically, but also helpful in understanding value effects more general. For instance, it will provide more evidence regarding the inconsistent findings of the impact of attention on value effects (Atkinson et al., 2020; Elliott & Brewer, 2019; Hu et al., 2016; Middlebrooks et al., 2017; Siegel & Castel, 2018b), and extend the limited research on the encoding strategies driving this effect (Hennessee et al., 2019).

1.3.1 Chapter 2: The effect of value on long-term memory for item-colour binding

Previous studies have found inconsistent results regarding the value effect on associative memory. One reason could be that it depends on the binding condition between item and associative information. Based on prior work which found no evidence of the impact of value on memory for word colour with incidental learning of colour information (Hennessee et al., 2017; 2018), two factors were identified that might influence the binding between item and colour information, and therefore increase the likelihood of value effects emerging on associative as well as item memory. The first was the type of item used as a to-be-remembered stimulus set (images vs. words). The second is the nature of the encoding phase when encoding item–colour associations (intentional vs. incidental). This chapter examined whether the effect of value would be observed on colour memory when the binding condition between item and colour was optimised. In addition, previous studies have employed immediate or short retention intervals (typically 5 minutes) between the study and the test phase. To our knowledge, no study has investigated the persistence of value effects using point values over more extended delay periods. Therefore, this chapter also examined the longevity of any beneficial effects of value that are observed.

There are four experiments in this chapter. Experiment 1 explored whether the value effect would be observed on colour memory when using coloured images (with incidental learning of colour information as in previous studies). Experiment 2 again explored this question by using intentional learning of word colour (using word stimulus set as in previous studies). In both experiments, memory was tested twice, with a 5-minute short delay and a 24-hour long delay. Experiment 3a and Experiment 3b sought to replicate the findings of Experiment 2 under intentional word–colour encoding conditions (Experiment 3b), while also confirming whether value effects on word–colour associative memory are indeed less reliable following incidental encoding of colour (Experiment 3a) in the present paradigm.

1.3.2 Chapter 3: The role of attention in the value effect on item-colour binding memory

Chapter 3 aimed to explore the role of attention in the value effect in immediate and delayed memory for item-colour binding. To reduce available attentional resources, the dual task paradigm was adopted. If divided attention reduces the value effect on colour memory, this would suggest that strategically remembering more valuable item-colour bindings is dependent on attentional resources; if divided attention does not reduce the value effect, this would suggest that selectively remembering more valuable item-colour binding requires little attentional resources.

This chapter included four experiments, all conducted online using Pavlovia or Gorilla Experiment builder. Experiment 4 used a similar paradigm to Experiment 2, in which a long study list was followed by a filler task before a recognition test. Experiment 5 used a paradigm developed from prior research (e.g., Castel et al., 2008; Middlebrooks et al., 2017), in which it separated the long study list into several study-immediate test trials and provided participants with feedback regarding how many points they earned in each trial. Experiment 6 and Experiment 7 made a further adjustment based on Experiment 5, such that items were presented in one of the 25 locations within 5 × 5 grids (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021). Items were presented sequentially in Experiment 6 and simultaneously in Experiment 7. In all the experiments, participants completed half of the study trials with full attention (in one block), and the other half with divided attention. In the latter condition, participants conducted the value effect task while performing an unrelated tone detection task.

1.3.3 Chapter 4: The role of strategy type in the value effect on item-colour binding memory

Previous studies suggest that an important mechanism underlying the value effect is that high value items are engaged with via elaborative encoding (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). The aim of this chapter was to explore what types of encoding strategies might underlie the value effect on item-colour binding memory. Before performing the value effect task, participants were instructed either to use verbal rehearsal to remember the item and its colour, to build an association between each item and its colour, or received no specific strategy. Several assumptions were adopted regarding the different strategy conditions and possible patterns of performance. It is assumed that the no-instruction condition gives a view of what participants normally do. It is also assumed that if a strategy condition produces outcomes that resemble the no-instruction condition, in terms of overall performance levels and value effects, this indicates this instructed strategy to be the predominant strategy underlying the value effect; if a strategy condition improves or decreases overall performance relative to the no-instruction condition, or changes the value effect (i.e., an interaction between value and strategy), this suggests it is not the dominant approach normally. Two experiments were conducted in this chapter, with simultaneous presentation in Experiment 8 and sequential presentation in Experiment 9.

CHAPTER 2

THE EFFECT OF VALUE ON LONG-TERM MEMORY FOR ITEM-COLOUR BINDING

2.1 Introduction

A growing body of research suggests that assigning high point value to some items can give them priority for retention and retrieval in WM (e.g., Hitch et al., 2018; Hu et al., 2014; 2016) , and in LTM (e.g., Castel et al., 2002; 2013). This has been demonstrated using different measurements of memory, including free recall (Castel et al., 2002; Cohen et al., 2017; Stefanidi et al., 2018), cued recall (Allen & Ueno, 2018; Atkinson et al., 2018; Griffin et al., 2019; Schwartz et al., 2020), and recognition (Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Sandry et al., 2014). Furthermore, high value information is typically remembered with better memory quality, as reflected by greater self-report of recollection/remembering (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018).

However, inconsistent results have been observed regarding value effects on associative memory. Some studies found that higher value items were associated with better associative memory, such as memory for item-location binding (Siegel & Castel, 2018a, 2018b), memory for word pairs (Ariel et al., 2015) and memory for word plurality status (Cohen et al., 2017). Others studies revealed no beneficial effect of value on associative memory, such as memory for the voice gender in which words were presented (Villaseñor et al., 2021) or memory for the colour of visually presented words (Hennessee et al., 2017; 2018). For example, in Hennessee et al. (2017), a series of words were presented in different colours, with each one associated with a point-value. Participants were informed that they could earn the point-value associated with the word if they correctly recognized the word at a later test. They were not asked to memorize the point-value or word colour. At test, participants performed an old-new recognition test and for the items they had recognized as old, they indicated the point-value and the colour each word was initially associated with. Memory for high value words was better than that for low value words. However, value was not found to affect memory for colour or memory for point-value. When further examining whether associative memory would interact with memory type (recollection or familiarity), it was found that colour memory accuracy was lower in high value recollected items, compared with low value recollected items.

Though a reduction of associative memory in high value items may seem counterintuitive, previous studies have revealed behavioural and neural dissociation between memory for item and memory for contextual details (Davachi, 2006; Davachi et al., 2003; Glisky et al., 1995; Old & Naveh-Benjamin, 2008; Spencer & Raz, 1995). In some cases, item memory and associative memory appear to function in a consistent pattern, whereby item memory improves alongside enhanced associative memory. For example, it is well documented that emotional information is often better remembered than neutral information (e.g., Hamann, 2001, for a review). This emotional memory enhancement effect also extends to associative memory, such as memory for visual details of objects (i.e., perceptual features, such as colour, shape, size, and orientation) and memory for colour of words (e.g., Doerksen & Shimamura, 2001; Kensinger & Corkin, 2003; Kensinger et al., 2006). In others, item memory and associative memory act in a trade-off pattern in which the memory enhancement for item information emerges at the expense of memory for associated details (e.g., Kensinger et al., 2005). For instance, when individuals are confronted with a complex visual scene, memory for the emotional component is enhanced, whereas memory for the peripheral details (e.g., another object nearby or the background of the central object) is reduced (e.g., Kensinger et al., 2005).

One possible reason for the different patterns may depend on the effectiveness or strength of binding between item and associative information. In the examples mentioned above, the associative details enhanced together with an item (e.g., visual details of an object) might be categorized as intrinsic features (Godden & Baddeley, 1980). They could be easily integrated and automatically processed when the stimulus is perceived and comprehended. In contrast, conditions eliciting a trade-off pattern may involve extrinsic features (e.g., background of the central object), which are irrelevant to the processing of the stimulus itself and thus more likely to be omitted from further encoding.

By this view, positive value effects on associative memory may stem from more effective binding between item and associative information, either due to the type of features being examined or the explicit instruction to remember both item and associative information (Ariel et al., 2015; Cohen et al., 2017; Siegel & Castel, 2018a, 2018b). The absence of value effects on associative memory may be because of less effective feature bindings due to no explicit instruction to remember associative information (Hennessee et al., 2017; 2018; Villaseñor et al., 2021). Therefore, it is possible that value effects have not been observed on LTM for colour information because of the dissociation of word and word colour under the incidental learning conditions implemented in studies to date (Hennessee et al., 2017; 2018). Prior research demonstrates distinct processing of word and word colour (Brown et al., 2002) and memory for word colour is poor under incidental learning conditions (Park & Mason, 1982; Park & Puglisi, 1985; Uncapher et al., 2006). Indeed, evidence that value enhances visual WM has typically so far been observed on colour-shape binding measures in which colour information is made an integral part of the item (Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; see Hitch, Allen, & Baddeley, 2020, for a review).

Therefore, the first goal of the current study is to establish whether value will enhance LTM for item colour under types of binding condition where the association between item and colour may be more likely to be encoded and retained in memory. Two factors were identified that may influence this binding condition. The first was the type of item used as a to-be-remembered stimulus set. Images, relative to words, appear to support effective integration with colour information (Park & Puglisi, 1985) and so may offer an effective context in which value may be applied to enhance associative memory. The second was the intention to learn associative information. Previous studies demonstrated that associative memory was significantly improved when participants were instructed to intentionally remember both the item and the associative information, relative to remembering the item information only (Chalfonte & Johnson, 1996; Hockley & Cristi, 1996; Light & Berger, 1974; Light et al., 1975). By optimising item-colour binding conditions via using images (Experiment 1) or intentional learning of word colour (Experiment 2), it was expected to see value effects on colour memory.

Also of interest is the longevity of any beneficial effects of value that are observed. A common feature of previous studies is that they have employed immediate or short retention intervals (typically 5 minutes) between the study and the test phase. To our knowledge, no study has investigated the persistence of value effects using point-values over more extended delay periods. This could improve understanding of the mechanisms of such effects. For example, Murayama and colleagues have suggested that a reward-related (possibly dopaminergic) memory consolidation process operates over longer periods of time, increasing the effects of monetary value on memory performance (e.g., Murayama & Kitagami, 2014; Murayama & Kuhbandner, 2011). Items that are assigned a higher value may also receive more active attentional processing during encoding (Allen, 2019), creating a stronger representation that is less susceptible to loss over time (either through decay or interference) and thus relatively more accessible than low value items at longer delays. It is not always the case, however, that memory enhancement effects increase in magnitude over time. For example, the superiority of semantic encoding usually diminishes over a 24-hour or longer delay (e.g., McDaniel & Masson, 1977; Morris et al., 1977; Thapar & McDermott, 2001). Therefore, a second goal of the current study was to explore how the effect of value changes over delays of a few minutes, and 24 hours.

Four experiments were conducted in this chapter. Experiment 1 used images as the stimulus set to explore the effect of value on colour memory. Experiment 2 reverted to a word list paradigm as in previous studies (Hennessee et al., 2017; 2018), but explicitly instructed participants to remember word and word colour intentionally. In both experiments, memory was tested twice, with a 5-minute short delay and a 24-hour long delay. Finally, the use of two different point values (i.e., 1 point for low value and 10 points for high value) in Experiment 1 and 2 may have made it relatively easier for participants to distinguish between high and low value items and enable a more effective focus on high value items, compared to previous studies (Hennessee et al., 2017; 2018) that used six different point values (i.e., 1, 2 and 3 point for low value and 10, 11 and 12 points for high value). Therefore, Experiment 3a and Experiment 3b (online experiments) sought to replicate the findings of Experiment 2 under intentional word-colour encoding conditions (Experiment 3b), while also confirming whether value effects on word-colour associative memory are indeed less reliable following incidental encoding of colour in the present paradigm (Experiment 3a).

2.2 Experiment 1

To date, examination of value effects on item-colour memory have focused on words as a stimulus set, with Hennessee et al. (2017) finding no evidence that value can improve memory for colour of words. This may reflect the irrelevance of the colour to the task at the encoding phase, and the possibility that word meaning is more salient and important than its visual appearance. Encoding of visual images, however, might allow the effective integration of item and colour information, meaning that colour is more reliably included as part of the memory representation that is created when participants prioritize high value items. Indeed, prior research has shown that memory for colour of pictures was substantially better than memory for colour of words (Park & Puglisi, 1985). Experiment 1, therefore, used coloured pictures as to-be-remembered stimuli. It was expected to see a memory enhancement for colour from high value items. It was also of interest whether this effect would change over time. Thus, a short-term delayed test (approximately 5 minutes after encoding) and a long-term delayed test (approximately 24 hours later) were conducted.

2.2.1 Method

2.2.1.1 Design

The experiment used a 2 (value: high, low) × 2 (retention interval: short, long) within-subject design. Forty-four items were paired with high values (10 points), the other forty-four items were paired with low values (1 point). Following the study phase, the items were tested after a short delay (approximately 5 minutes), and the same items were tested after a long delay (approximately 24 hours). Dependent variables were item memory, RKG response, colour memory and point-value memory.

2.2.1.2 Participants

To obtain a medium effect of value (η^2_p = 0.06), G*Power (Faul et al., 2009) indicated a minimum sample size of 24 (with alpha = .05 and power at 0.8). Thirty undergraduate students (23 females; mean age = 20.7 years; range = 18-27 years) recruited from the University of Leeds participated in this experiment. All participants were native English speakers, and none reported a history of neurological disorders. Participants had normal colour vision and correct or corrected-to-normal vision. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSC-462, Date of ethics approval: 15/11/2018).

2.2.1.3 Materials

The stimuli were 176 neutral line drawings of daily objects taken from Snodgrass and Vanderwart (1980) and Cycowicz et al. (1997; see Appendix A for the stimuli). Eighty-eight of them were randomly selected during the study phase, with half of them paired with a 1-point value and the other half paired with a 10-point value. Each line drawing was filled with one of the four colours: red, yellow, blue and green. They did not strongly associate with a particular colour (e.g., a butterfly). The remaining 88 images were used as foils during the recognition phase. The images assigned to each participant and the point value and colour assigned to each image were randomized for each individual participant.

2.2.1.4 Procedure

The experiment consisted of one study phase and two test phases. The study phase and the first test phase were conducted in an experimental lab using PsychoPy 3.0.5 (Peirce, 2007). The second test phase was conducted online using Qualtrics survey software (https://www.qualtrics.com). At study, participants were told that they would be presented with a series of images, each associated with a point-value they could earn later for recognition and their goal was to maximize the score. Participants were not told to memorize the point-value or the colour of the images. All 88 study images were presented individually for 3s with a 0.5s fixation cross interval (see Figure 2.1). Next, participants completed a brief distractor task (24 simple multiplication and division problems) to reduce mental rehearsal, during a 5-minute delay interval. Before completing the recognition test, participants were instructed regarding the difference between remember (R), know (K) and guess (G) using an adapted form of Gardiner et al. (1998) instructions (see Appendix C for instructions).

At test, participants viewed a randomized sequence of 88 previously presented images and 88 new images, without colour. They were asked to report whether they had seen each of them previously by pressing keys on a keyboard (1 = Yes, 2 = No). If they chose ‘Yes’, they were asked to further make an R, K, G judgment (1 = Remember, 2 = Know, 3 = Guess) and report the colour (1 = Red, 2 = Yellow, 3 = Blue, 4 = Green, 5 = Not Sure) and the point-value (1 = 1 point, 2 = 10 points, 3 = Not Sure) of the item; if they chose ‘No’, no further judgments were required for this image. The next image then appeared and the cycle was repeated (see Figure 2.1 for an example). The “not sure” option is offered to reduce potential contamination by guessing on the associative memory, as has been implemented in previous studies (e.g., Duarte et al., 2008; Gottlieb et al., 2010; Morcom et al., 2007). All responses were self-paced. Participants were informed that after approximately 24 hours, they would be emailed a link for the second part of the study (with no mention of the retest). Twenty-two hours after participating in the experiment, participants received the link and were asked to complete this phase within 4 hours in a quiet area with minimal distractions. The test procedure and the foil set were the same as in the short delay test, with the exception that the items were presented in a different order relative to the short delay test, though the order was the same for all the participants at this test.

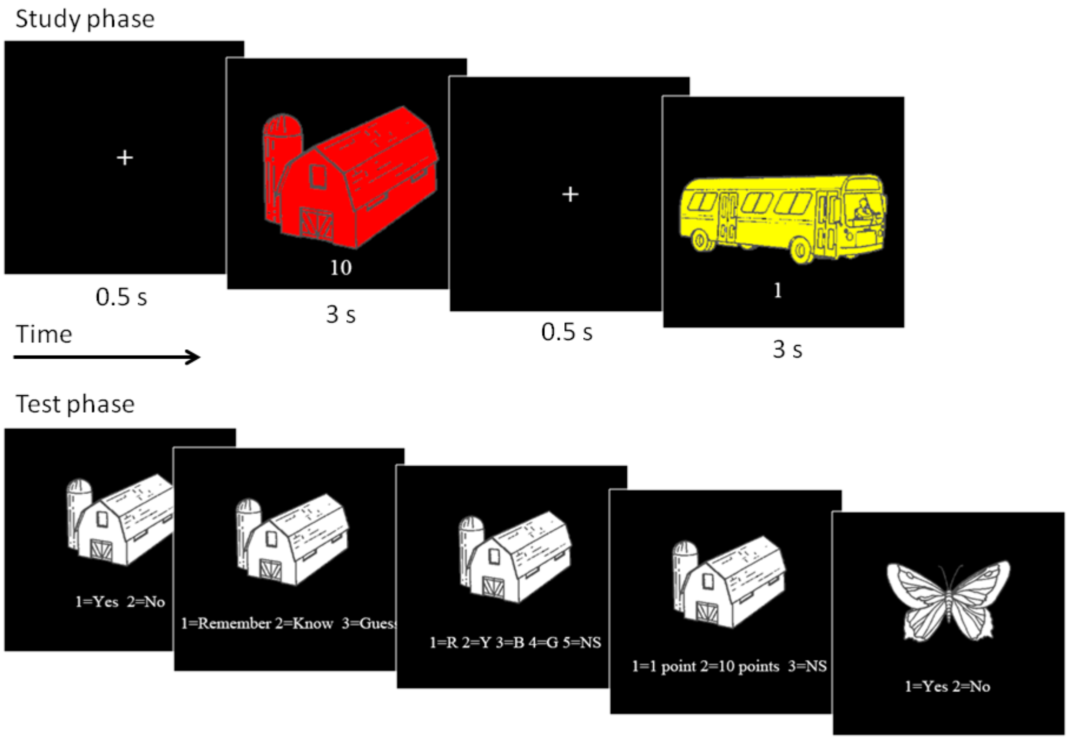

Figure 2. 1 Study and test procedures in Experiment 1

2.2.1.5 Data analysis

Both frequentist and Bayesian analysis were conducted on the data. Where frequentist analysis indicated significant interactions, these were followed up with frequentist and Bayesian t-tests. When outcomes from the two forms of analyses are not strongly convergent, we primarily draw on results from frequentist analysis for interpretation, while noting the divergent Bayesian outcomes as cautionary qualifiers. Bayesian analysis allows one to consider the likelihood of the data under both the null and alternative hypotheses, and these probabilities are compared via the Bayes Factor (BF). BF_{10} describes how many times more likely the alternative hypothesis is than the null hypothesis, while BF_{01} describes how many times more likely the null hypothesis is than the alternative hypothesis (Jarosz & Wiley, 2014; Mulder & Wagenmakers, 2016). This analysis was conducted in JASP 0.9.0.1 (JASPTeam, 2018).

2.2.2 Results

Most participants completed the 24-hour delayed test within an acceptable time frame (with one night's sleep; N = 23, mean time = 25h3m, range = 21m58m-31h31 m). Three participants failed to complete the test. Four participants took more than two days to complete the test (i.e., 50h24m, 71h9m, 193h21m, 202h48m), but their memory patterns were similar to the others and including their data did not change the results, so analyses were based on data from 27 participants.

2.2.2.1 Item memory and RKG responses

Remember (R), Know (K) and Guess (G) responses were calculated as the mean proportion of old items that were attributed to the R, K and G options. Mean hit rates, false alarm rates, *d'*, R, K and G responses as a function of value and retention interval are displayed in Table 2.1. A 2 (value: high, low) × 2 (retention interval: short, long) repeated measures analysis of variance (ANOVA) revealed a main effect of value on item memory [Hit rates, $F(1, 26) = 57.57$, $p < .001$, $\eta^2_p = 0.69$, $BF_{10} > 1000$; *d'*, $F(1, 26) = 58.31$, $p < .001$, $\eta^2_p = 0.69$, $BF_{10} > 1000$], such that memory for high value items (marginal means (*MMs*) = 0.68 , standard error (*SE*) = 0.03) was better than low value items (*MMs* = 0.50 , *SE* = 0.03). A main effect of retention interval was also found [Hit rates, $F(1, 26) = 9.21$, $p < .01$, $\eta^2_p = 0.26$, $BF_{10} = 41.66$; *d'*, $F(1, 26) = 87.60$, $p < .001$, $\eta^2_p = 0.77$, $BF_{10} > 1000$], with higher accuracy at the short delay (*MMs* = 0.63 , *SE* = 0.03) than the long delay (*MMs* = 0.55 , *SE* = 0.03). The interaction between value and retention interval was not significant [Hit rates, $F(1, 26) = 1.89$, $p = .18$, $\eta^2_p = 0.07$, $BF_{10} = 0.32$; *d'*, $F(1, 26) = 1.88$, $p = .18$, $\eta^2_p = 0.07$, $BF_{10} = 0.34$]. Bayesian analysis indicated that the most likely model included main effects of value and retention interval (BF_{10} >

1000 relative to the null model with random effects of participant only).

For R responses, repeated measures ANOVA revealed a main effect of value [$F(1, 26) = 35.47$, $p < .001$, $\eta^2_p = 0.58$, $BF_{10} > 1000$], with higher proportion for high value items (*MMs* = 0.35 , *SE* = 0.03) relative to low value items (MMs = 0.21 , SE = 0.03). The effect of retention interval was also significant [$F(1, 26) = 13.10$, $p = .001$, $\eta^2_p = 0.34$, $BF_{10} = 288.10$], with higher proportion at the short delay (*MMs* = 0.32 , *SE* = 0.03) than the long delay (*MMs* = 0.24 , *SE* = 0.03). There was no interaction between value and retention interval, $F(1, 26) = 1.43$, $p = .24$, $\eta^2_p = 0.05$, $BF_{10} = 0.29$. BF analysis revealed that the most likely model of R responses included main effects of value and retention interval ($BF_{10} > 1000$ relative to the null model with random effects of participant only). For K responses, a main effect of value was found [$F(1, 26) = 6.95$, $p < .05$, $\eta^2_p = 0.21$, $BF_{10} = 8.15$], with higher proportion for high value items (*MMs* = 0.24 , *SE* = 0.03) than low value items (*MMs* = 0.19 , *SE* = 0.03). No significant difference was found between short delay test and long delay test, $F(1, 26) = 0.34$, $p = .57$, $\eta^2_p = 0.01$, $BF_{10} = 0.25$. No interaction emerged between value and retention interval, $F(1, 26) = 0.62$, $p = .44$, $\eta^2_p = 0.02$, $BF_{10} = 0.31$. BF analysis suggested that the most likely model of K response included a main effect of value ($BF_{10} = 7.77$ relative to the null model with random effects of participant only). No significant effects were found on G responses ($F \leq 1.19$, $p \geq .29$, $\eta^2_p \leq 0.04$, $BF_{10} \leq 0.30$).

Table 2. 1 Mean Hit Rates, False Alarm Rates (FAR), *d'*, Remember (R), Know (K), Guess (G) responses and point-value memory as a function of value and retention interval in Experiment 1

	Short delay		Long delay	
	High value	Low value	High value	Low value
Hit rates	0.73(0.03)	0.53(0.03)	0.64(0.03)	0.47(0.03)
FAR	0.09(0.01)		0.20(0.03)	
d'	2.17(0.16)	1.59(0.16)	1.40(0.14)	0.91(0.13)
R	0.40(0.04)	0.24(0.03)	0.30(0.04)	0.17(0.02)
K	0.24(0.03)	0.18(0.02)	0.24(0.03)	0.20(0.03)
G	0.09(0.02)	0.11(0.02)	0.10(0.02)	0.10(0.01)
Point-value	0.51(0.04)	0.52(0.05)	0.46(0.04)	0.36(0.05)

Note. Standard errors presented in parentheses.

2.2.2.2 Associative memory

During the test phase, if participants had recognized an old item, they were required to further choose the colour (red, yellow, blue, green or not sure) and the point-value (1 point, 10 point or not sure) that the item was originally associated with. The "not sure" option was offered to reduce potential contamination by guessing on associative memory. Correct associative memory was calculated as the mean proportion of correctly recognized items that were attributed to the correct associative information (Durbin et al., 2017; Johnson et al., 1996; Mather et al., 1999).

Colour memory performance as a function of value and retention interval is displayed in Figure 2.2[1]. A 2 (value: high, low) × 2 (retention interval: short, long)

[1] Chance level for colour memory and point-value memory was not .25 and .50 respectively, because a 'not sure' option was provided to reduce guessing. When 'not sure' responses were excluded, colour memory (short delay: M_{high} = 0.53, M_{low} = 0.44; long delay: M_{high} = 0.49, M_{low} = 0.38) and point-value memory (short delay: M_{high} = 0.67, M_{low} = 0.71; long delay: M_{high} = 0.68, M_{low} = 0.54) were above chance level.

repeated measures ANOVA for colour memory was conducted. This revealed a main effect of value on colour memory [$F(1, 26) = 23.32$, $p < .001$, $\eta^2_p = 0.47$, $BF_{10} > 1000$], such that memory accuracy was higher for high value items (*MMs* = 0.30 , *SE* = 0.03) than low value items (*MMs* = 0.20 , *SE* = 0.03). A main effect of retention interval also emerged [$F(1, 26) = 13.99$, $p = .001$, $\eta^2_p = 0.35$, $BF_{10} = 47.07$], with higher accuracy at the short delay (*MMs* = 0.28 , *SE* = 0.03) than the long delay (*MMs* = 0.22 , *SE* = 0.03). There was no interaction between value and retention interval [$F(1, 26) = 0.03$, $p = .86$, $\eta^2_p = 0.001$, $BF_{10} = 0.27$]. BF analysis showed that the most likely model included main effects of value and retention interval ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

Point-value memory performance as a function of value and retention interval is displayed in Table 2.1. A 2 × 2 repeated measures ANOVA for point-value memory revealed no main effect of value [$F(1, 26) = 0.75$, $p = .39$, $\eta^2_p = 0.03$, $BF_{10} = 0.43$]. A main effect of retention interval emerged [$F(1, 26) = 21.10$, $p < .001$, $\eta^2_p = 0.45$, $BF_{10} = 12.52$], with higher accuracy at the short delay (*MMs* = 0.51 , *SE* = 0.04) than the long delay (*MMs* = 0.41 , *SE* = 0.04). There was an interaction between value and retention interval [$F(1, 26) = 14.02$, $p < .001$, $\eta^2_p = 0.35$, $BF_{10} = 0.86$], although it was not supported by BF analysis. Pairwise comparisons found no difference between high and low value items at the short delayed test [$t(26) = -0.18$, $p = .86$, Cohen's $d = -0.04$, $BF_{10} = 0.21$], nor at the long delay test [$t(26) = 1.89$, $p = .07$, $d = 0.36$, $BF_{10} = 0.95$]. BF analysis indicated that the most likely model included a main effect of retention interval ($BF_{10} = 11.14$ relative to the null model with random effects of participant only).

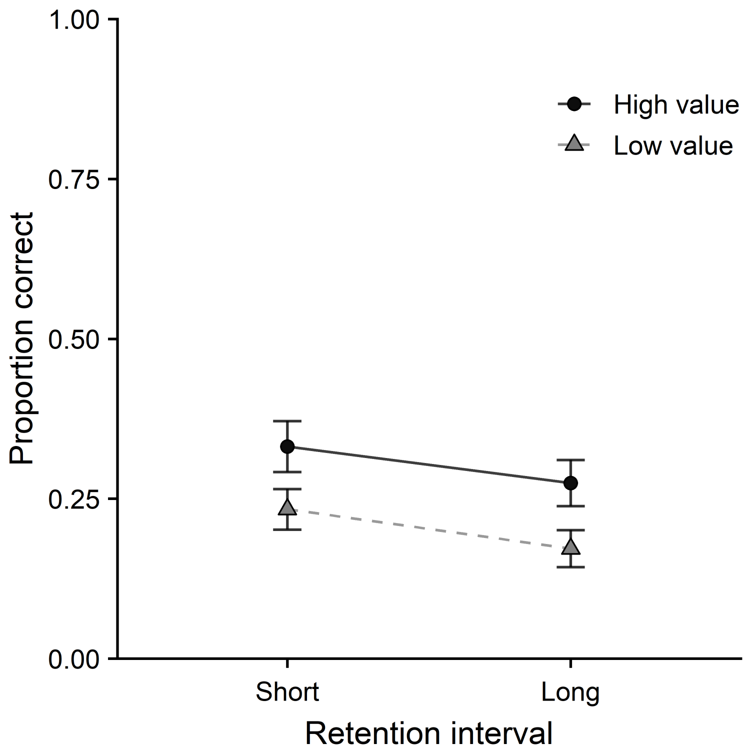

Figure 2. 2 Colour memory performance as a function of value and retention interval in Experiment 1. Note. Error bars represent one standard error of the mean.

2.2.3 Discussion

Consistent with previous findings, Experiment 1 found that high value items were better remembered than low value items (Castel et al., 2002; 2007; Castel, Humphreys, et al., 2011; Castel et al., 2013), along with greater recollection report (as indicated by rates of R; Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018). It was also found that value improved familiarity of the items (as indicated by rates of K), although previous findings regarding the effect of value on this type of memory is somewhat inconsistent (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018). Moreover, while there was some evidence of forgetting between the different retention intervals (from 5 minutes to 24 hours), the effects of value remained robust and persisted over time.

Of particular interest was the effect of value on associative memory. As predicted, a memory improvement for colour information was observed for high value items. This contrasts with previous work finding no positive effect of value on word-colour associations (Hennessee et al., 2017; 2018), indicating that value effects vary depending on the material used and the implications this has for the binding between item and associative information. In addition, although longer delay impaired colour memory overall, indicating some forgetting over time, the colour memory boost from high value was not differentially impacted, suggesting that this effect persists over time. On memory for point-value, no difference was found between high and low value conditions, either at the short delay or the long delay. This is consistent with previous findings (e.g., Hennessee et al., 2017) and is not unexpected as the use of coloured images might only optimize the binding between items and colours, though further work is required to confirm the reliability of this finding.

Experiment 1 established that value can positively influence item-colour associative memory under incidental encoding conditions when images are used as the stimulus set. We then moved on to examine whether word-colour associative memory might also show a value effect when an intentional encoding condition was instead adopted.

2.3 Experiment 2

Previous research indicates that emphasis on associative information during encoding is critical for memory performance in the binding between item and associative information. When participants were only instructed to encode item information, associative memory was poor; when they were instructed to intentionally encode both item and associative information, associative memory could be greatly improved

(Chalfonte & Johnson, 1996; Hockley & Cristi, 1996; Light & Berger, 1974; Light et al., 1975). Therefore, the absence of positive value effects on colour memory in previous research may reflect an inadequate integration of item and colour during encoding when word colour is encoded incidentally (Hennessee et al., 2017; 2018). Experiment 2 thus examined whether value effects would emerge on colour memory when participants were asked to intentionally memorize both the word and its colour. With word colour an integral, explicit element in the encoding phase, it was predicted that value benefits would generalize from the item to its associated colour, and therefore that both memory for words and word colour would improve for items assigned with high values. Following Experiment 1, this should be observable at both the short delay and the long delay tests.

2.3.1 Method

2.3.1.1 Design

As with Experiment 1, the experiment used a 2 (value: high, low) × 2 (retention interval: short, long) within-subject design. Dependent variables were item memory, RKG response, colour memory and point-value memory.

2.3.1.2 Participants

Thirty undergraduate students (25 females; mean age = 19.80 years; range = 18–30 years) from the University of Leeds took part in the experiment. All participants were native English speakers and had correct or corrected-to-normal vision. None reported a history of neurological disorders or being colour-blind. Participants gave informed consent in accordance with the guidelines set by the University of Leeds's Psychology

Ethics Committee (Ethics reference number: PSC-462, Date of ethics approval: 15/11/2018).

2.3.1.3 Materials and procedure

The stimuli were 176 words selected from SUBTLEXUS (Warriner et al., 2013; see Appendix B for the words). Each contained between three and six letters and had an everyday occurrence of at least 25 times per million according to SUBTLEXUS. Word valence ranged from 4.5 to 5.5 [scale ranges from 1 (negative) to 9 (positive)] and arousal was less than 5 [scale ranges from 1 (calm) to 9 (excited)]. Half of them were randomly selected to be encoded at the study phase, with each one paired with a point-value (1 point, 10 points) and printed in one of the four colours (red, yellow, blue, green). The other half of the set was used as new items during the test phase. The procedure was the same as Experiment 1 except that participants were told to remember both the word and its colour at encoding (see Appendix D for instructions).

2.3.2 Results and discussion

Most of the participants completed the 24-hour delayed test within an acceptable time frame (with one night's sleep; N = 21, mean time = 25h1m, range = 22h31m-31h40m). Three participants did not complete the test. Six participants took over two days to complete the test (i.e., 48h17m, 52h42m, 57h46m, 65h22m, 192h54m, 211h), but including their data or not had little influence on the results, so analyses were based on data from 27 participants.

2.3.2.1 Item memory and RKG responses

Mean hit rates, false alarm rates, *d*', R, K and G responses as a function of value and retention interval are displayed in Table 2.2. A 2 (value: high, low) × 2 (retention interval: short, long) repeated measures ANOVA revealed a main effect of value on item memory [Hit rates, $F(1, 26) = 27.05$, $p < .001$, $\eta^2_p = 0.51$, $BF_{10} > 1000$; *d'*, $F(1, 26) = 25.30$, $p < .001$, $\eta^2_p = 0.49$, $BF_{10} > 1000$], whereby memory was better for high value items (*MMs* = 0.43 , *SE* = 0.03) than low value items (*MMs* = 0.29 , *SE* = 0.03). A main effect of retention interval also emerged [Hit rates, $F(1, 26) = 8.08$, $p < .01$, $\eta^2_p = 0.24$, $BF_{10} = 11.37$; *d'*, $F(1, 26) = 18.73$, $p < .001$, $\eta^2_p = 0.42$, $BF_{10} = 817.12$], with higher accuracy at the short delay (*MMs* = 0.39 , *SE* = 0.03) than the long delay (*MMs* = 0.33 , *SE* = 0.03). There was an interaction between value and retention interval [Hit rates, $F(1, 26) = 8.12$, $p < .01$, $\eta^2_p = 0.24$, $BF_{10} = 0.45$; *d'*, $F(1, 26) = 6.00$, $p < .05$, $\eta^2_p = 0.19$, $BF_{10} = 0.38$], yet BF suggested weak evidence for this, with some support for the null. Nevertheless, pairwise comparisons indicated that value improved memory at both the short delayed test [Hit rates, $t(26) = 5.32$, $p < .001$, $d = 1.02$, $BF_{10} > 1000$; *d'*, $t(26) = 5.01$, $p < .001$, $d = 0.96$, $BF_{10} = 729.39$] and the long delayed test [Hit rates, $t(26) = 4.60$, $p < .001$, $d = 0.89$, $BF_{10} = 271.12$; *d'*, $t(26) = 4.64$, $p < .001$, $d = 0.89$, $BF_{10} = 302.24$]. BF analysis revealed that the most likely model included main effects of value and retention interval ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

For R responses, a main effect of value emerged [$F(1, 26) = 23.70$, $p < .001$, $\eta^2_p = 0.48$, $BF_{10} > 1000$], with higher proportion for high value items (*MMs* = 0.22 , *SE* = 0.02) relative to low-value items (*MMs* = 0.09 , *SE* = 0.02). The effect of retention interval was not significant [$F(1, 26) = 2.08$, $p = .16$, $\eta^2_p = 0.07$, $BF_{10} = 0.41$]. There was an interaction between value and retention interval [$F(1, 26) = 8.59$, $p < .01$, $\eta^2_p = 0.25$, $BF_{10} = 0.51$], but BF suggested weak evidence for this, slightly favouring the null.

Pairwise comparisons revealed that the R response rate was higher for high value items than low value items, both at the short delay test [$t(26) = 4.78$, $p < .001$, $d = 0.92$, $BF_{10} = 423.37$] and the long delay test [$t(26) = 4.66$, $p < .001$, $d = 0.90$, $BF_{10} = 313.35$]. BF analysis indicated that the most likely model of R responses included a main effect of value ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

For K responses, the effect of value was not significant [$F(1, 26) = 1.60$, $p = .22$, $\eta^2_p = 0.06$, $BF_{10} = 0.68$]. There was a significant effect of retention interval [$F(1, 26) = 6.47$, $p < .05$, $\eta^2_p = 0.20$, $BF_{10} = 3.30$], with better memory at the short delay (*MMs* = 0.10 , *SE* = 0.02) than the long delay (*MMs* = 0.07 , *SE* = 0.02). No interaction emerged between value and retention interval, $F(1, 26) = 0.21$, $p = .65$, $\eta^2_p = 0.01$, $BF_{10} = 0.26$. BF analysis revealed that the most likely model of K response included a main effect of retention interval ($BF_{10} = 3.07$ relative to the null model with random effects of participant only). No significant effect was found on G responses ($F \leq 0.49$, $p \geq .49$, $\eta^2_p \leq 0.02$, $BF_{10} \leq 0.29$).

Table 2. 2 Mean Hit Rates, False Alarm Rates (FAR), *d'*, Remember (R), Know (K), Guess (G) responses and point-value memory as a function of value and retention interval in Experiment 2

	Short delay		Long delay	
	High value	Low value	High value	Low value
Hit rates	0.47(0.03)	0.31(0.04)	0.38(0.03)	0.27(0.04)
FAR	0.14(0.03)		0.17(0.03)	
d'	1.19(0.11)	0.65(0.09)	0.81(0.08)	0.40(0.07)
R	0.24(0.03)	0.09(0.01)	0.20(0.03)	0.09(0.02)
K	0.11(0.02)	0.10(0.02)	0.08(0.02)	0.06(0.01)
G	0.12(0.02)	0.12(0.02)	0.10(0.01)	0.11(0.02)
Point-value	0.55(0.06)	0.37(0.05)	0.47(0.05)	0.27(0.04)

Note. Standard errors presented in parentheses.

2.3.2.2 Associative memory

Colour memory as a function of value and retention interval is displayed in Figure 2.3. A 2 (value: high, low) × 2 (retention interval: short, long) repeated measures ANOVA for colour memory was conducted. This revealed a main effect of value [$F(1, 26) = 9.91$, $p < .01$, $\eta^2_p = 0.28$, $BF_{10} = 440.86$], whereby performance was better on high value items (*MMs* = 0.39 , *SE* = 0.04) than low value items (*MMs* = 0.26 , *SE* = 0.04). A main effect of retention interval was also found [$F(1, 26) = 10.89$, $p < .01$, $\eta^2_p = 0.30$, $BF_{10} = 11.15$], with higher accuracy at the short delay (*MMs* = 0.37 , *SE* = 0.04) than the long delay (*MMs* = 0.28 , *SE* = 0.04). There was no interaction between value and retention interval, $F(1, 26) = 0.01$, $p = .92$, $\eta^2_p = 0.00$, $BF_{10} = 0.27$. Bayesian analysis indicated that the most likely model included main effects of value and retention interval ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

Point-value memory as a function of value and retention interval is displayed in Table 2.2. A 2 × 2 ANOVA for point-value memory revealed a main effect of value [$F(1, 26) = 7.96$, $p < .01$, $\eta^2_p = 0.23$, $BF_{10} = 866.30$], such that accuracy was higher for high value items (*MMs* = 0.51 , *SE* = 0.05) than low value items (*MMs* = 0.32 , *SE* = 0.05). There was also a main effect of retention interval [$F(1, 26) = 21.15$, $p < .001$, $\eta^2_p = 0.45$, $BF_{10} = 1.62$], with higher accuracy at the short delay (*MMs* = 0.46 , *SE* = 0.03) than the long delay (*MMs* = 0.37 , *SE* = 0.03), though weakly supported by BF. No interaction emerged between value and retention interval [$F(1, 26) = 0.05$, $p = .82$, $\eta^2_p = 0.002$, $BF_{10} = 0.28$]. BF analysis revealed that the most likely model included main effects of value and retention interval ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

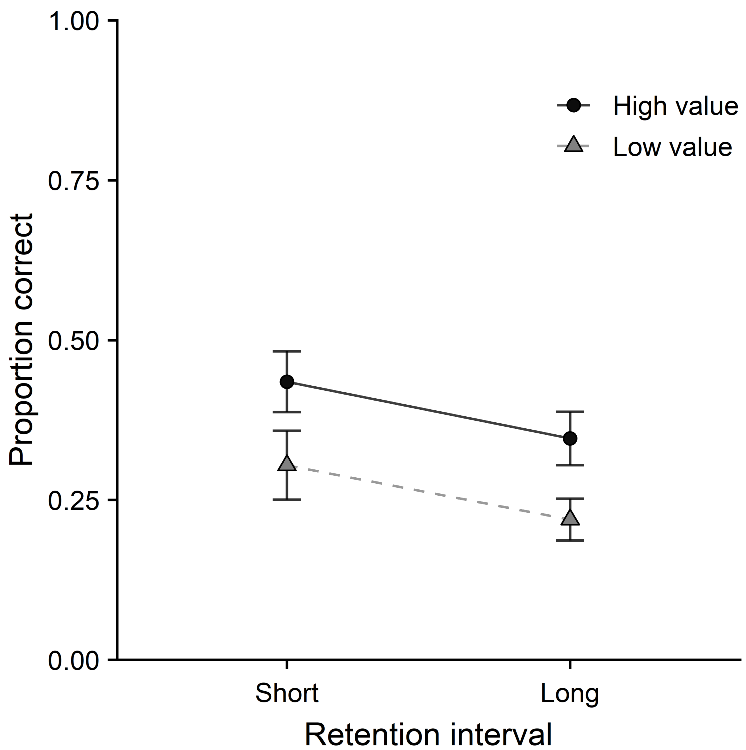

Figure 2. 3 Colour memory performance as a function of value and retention interval in Experiment 2. Note. Error bars represent one standard error of the mean.

The results of Experiment 2 generally replicated the value effects observed in Experiment 1, such that recognition and recollection of high value items were better than low value items, in both the short- and the long-delay tests. Importantly, value effect on memory for word colour was observed when participants were instructed to intentionally remember the word and word colour, and this effect was not impaired by the passage of time. Relative to incidental colour memory encoding (Hennessee et al., 2017; 2018), word-colour binding is presumably more likely to be encoded and maintained in a durable and accessible form, and thus value effects will generalize across identity and associated colour. In addition, memory for point-values associated with each word was also enhanced by value and was consistent across different retention intervals, though this result is inconsistent with that observed in Experiment 1.

2.4 Experiments 3a and 3b

Experiment 3a and 3b were conducted with the aim of replicating and extending previous findings regarding the value effects on word-colour binding. Experiment 3a instructed participants to remember the word but word colour was incidental to the encoding phase (as in Hennessee et al., 2017; 2018), while Experiment 3b instructed participants to intentionally remember both the word and the word colour (as in Experiment 2 of the current chapter). Based on previous findings, we expected to see a reliable beneficial impact of value on colour memory in Experiment 3b, but not in Experiment 3a. These two experiments were conducted online, rather than in a lab setting as in Experiment 1 and 2.

2.4.1 Method

2.4.1.1 Design

The experiment used a single factor (value: high, low) within-subject design. Sixteen items were paired with high values (10 points), and the other sixteen items were paired with low values (1 point). Dependent variables were item memory, RKG response, colour memory and point-value memory.

2.4.1.2 Participants

Thirty participants were recruited from Prolific (www.prolific.co; Palan & Schitter, 2018) in each experiment (Experiment 3a: 17 females, mean age = 24 years, range = 19–30 years; Experiment 3b: 14 females, mean age = 23.7 years, range = 19-30 years). All participants were native English speakers and had correct or corrected-to-normal vision. Informed consent was obtained from participants in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSYC-111, Date of ethics approval: 19/10/2020).

2.4.1.3 Materials and procedure

The experiments were conducted online using the Gorilla Experiment Builder (www.gorilla.sc; Anwyl-Irvine et al., 2020). The materials and procedure were similar to Experiment 2. It included a study phase, a filler task, and a test phase. To maintain participant motivation and avoid attrition in an online testing environment, the experimental sessions were shortened. Sixty-four words were randomly selected from the words pool used in Experiment 2. Half of them were used as study words, the other half were used as new words during the test phase. The study words were presented in four different colours (red, yellow, blue, and green), with half paired with 1 point and the other half paired with 10 points. The study words and the new words, the parings between study words and point-values were counterbalanced across participants. During the study phase, each word was presented for 3 seconds with a 0.5 second interval. In Experiment 3a, participants were instructed that they would score either 1 point or 10 points for getting the words correct in a later memory test; in Experiment 3b, participants were instructed that they would score either 1 point or 10 points for getting the words and their colours correct in a later memory test. In both experiments, the goal was to maximize their point score. To ensure participants that maintained focus on the task during encoding, three attention-check trials were randomly presented among the study trials. Participants were instructed to press key 'z' within 3 seconds on these trials. Following the study phase, there was a filler task (6 math questions) which lasted approximately 2 minutes. Then the old words and the new words (all in white) were presented randomly, and a recognition test were conducted. For the words participants recognized as old, further RKG judgment ('Remember', 'Know', 'Guess'), colour memory test ('Red', 'Yellow', 'Blue', 'Green') and point-value memory test ('1 point', '10 points') were conducted. At the end of Experiment 3a, participants were asked whether they tried to memorize the colour of the words during the study phase.

2.4.2 Results

2.4.2.1 Experiment 3a

2.4.2.1.1 Item memory and RKG response

Mean hit rates, false alarm rates, *d*', R, K and G responses as a function of value are displayed in Table 2.3. A series of paired samples t-tests were conducted. This revealed a main effect of value on item memory [Hit rates, $t(1, 29) = 5.03$, $p < .001$, $d = 0.92$, $BF_{10} = 963.16$; *d'*, $t(1, 29) = 4.96$, $p < .001$, $d = 0.91$, $BF_{10} = 821.77$], such that memory for high value items was better than low value items. The effect of value was also significant on R responses [$t(1, 29) = 3.25$, $p < .01$, $d = 0.59$, $BF_{10} = 12.93$], whereby high value items were along with more recollection than low value items. It was marginally non-significant on K responses [$t(1, 29) = 2.03$, $p = .051$, $d = 0.37$, $BF_{10} = 1.17$], and not significant on G responses [$t(1, 29) = -0.25$, $p = .80$, $d = -0.05$, $BF_{10} = 0.20$].

2.4.2.1.2 Associative memory

Colour memory as a function of value is displayed in Figure 2.4a. Point-value memory as a function of value is displayed in Table 2.3. Paired samples t-tests revealed no main effect of value, neither on colour memory [$t(1, 29) = 1.7$, $p = .10$, $d = 0.31$, $BF_{10} = 0.70$], nor on point-value memory [$t(1, 29) = 10.89$, $p = .59$, $d = -0.10$, $BF_{10} = 0.22$]. Nine participants reported that they memorized the colours intentionally during the study phase. Removing their data also revealed no effect of value on colour memory [$t(1, 20) = 1.7$, $p = .28$, $d = 0.24$, $BF_{10} = 0.39$].

2.4.2.2 Experiment 3b

2.4.2.2.1 Item memory and RKG response

Mean hit rates, false alarm rates, *d*', R, K and G responses as a function of value are displayed in Table 2.3. The effect of value was not significant on item memory [Hit rates, $t(1, 29) = 1.61$, $p = .12$, $d = 0.29$, $BF_{10} = 0.62$; *d'*, $t(1, 29) = 1.62$, $p = .12$, $d = 0.30$, $BF_{10} = 0.62$]. There was a significant value effect on R responses [$t(1, 29) = 2.39$, $p < .05$, $d = 0.44$, $BF_{10} = 2.18$], such that memory for high value items was along with more remembering relative to low value items, although BF revealed weak evidence to support this. No effect of value was observed on K [$t(1, 29) = 0.59$, $p = .56$, $d = 0.01$, $BF_{10} = 0.23$] or G [$t(1, 29) = -1.86$, $p = .07$, $d = -0.34$, $BF_{10} = 0.89$] responses.

2.4.1.2.2 Associative memory

Colour memory as a function of value is displayed in Figure 2.4b. Point-value memory as a function of value is displayed in Table 2.3. Paired samples t-tests revealed a main effect of value on colour memory [$t(1, 29) = 2.41$, $p < .05$, $d = 0.44$, $BF_{10} = 2.29$], with better memory for high value items than low value items, although not strongly supported by BF. No effect of value was observed on point-value memory [$t(1, 29) = -1.70$, $p = .10$, $d = -0.31$, $BF_{10} = 0.70$].

Table 2. 3 Mean Hit Rates, False Alarm Rates (FAR), *d'*, Remember (R), Know (K), Guess (G) responses and point-value memory as a function of value and retention interval in Experiment 3a and Experiment 3b

	Experiment 3a		Experiment 3b	
	High value	Low value	High value	Low value
Hit rates	0.71(0.04)	0.50(0.04)	0.48(0.03)	0.42(0.03)
FAR	0.15(0.03)		0.12(0.02)	
d'	1.91(0.17)	1.27(0.13)	1.27(0.12)	1.10 (0.08)
R	0.29(0.05)	0.14(0.03)	0.22(0.03)	0.14(0.03)
K	0.30(0.04)	0.23(0.04)	0.15(0.02)	0.14(0.02)
G	0.13(0.03)	0.13(0.02)	0.11(0.02)	0.14(0.02)
Point-value	0.64(0.04)	0.67(0.05)	0.52(0.05)	0.65(0.05)

Note. Standard errors presented in parentheses.

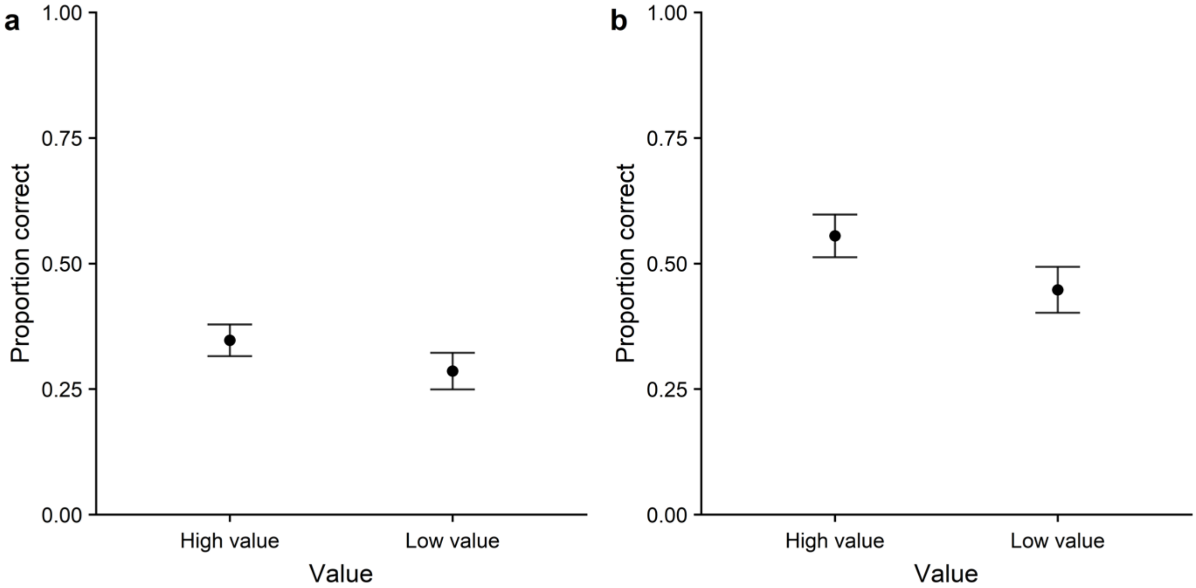

Figure 2. 4 Colour memory performance as a function of value in Experiment 3a (a) and Experiment 3b (b). Note. Error bars represent one standard error of the mean.

2.4.3 Discussion

The aim of Experiment 3a and 3b was to replicate the outcomes of Experiment 2 regarding value effects on intentional word-colour memory associations, while also demonstrating that such effects are much less reliable when using incidental colour encoding as found in previous studies (Hennessee et al., 2017; 2018). In Experiment 3a, when participants were instructed to remember words (colour was incidental), value effect on item memory was observed but there was no significant effect on colour memory, in line with previous studies in the area (Hennessee et al., 2017; 2018). In Experiment 3b, when participants were instructed to remember both the words and word colours, the value effect on colour memory re-emerged, although this was not strongly supported by BF analysis. These results verified that when the binding condition between item and colour is optimized, the influence of value could extend to colour information. On point-value memory, no value effect was observed from either experiment. These results are consistent with Experiment 1 rather than Experiment 2, suggesting the effect of value on point-value memory is somewhat unreliable.

Although the focus of the present study was on associative rather than item memory, it is worth noting that the value effect on item memory was not observed in Experiment 3b, contrasting with Experiment 2. Speculatively, one possibility could be that online participants may have invested less energy and concentration in the task than those involved in a laboratory experiment (Kraut et al., 2004), and thus may have been less likely to use deeper strategic encoding, likely an important mechanism underlying the value effect on item memory (Cohen et al., 2014; Hennessee et al., 2019). However, there is no direct evidence to support this suggestion at present; it would be valuable for future work to carefully explore the extent to which value effects emerge for both item and associative memory across different levels of manipulations such as participant engagement, attentional load, and strategic approach.

2.5 General discussion

Across four experiments, the current study explored whether value enhances memory for associative information under different conditions in which the binding between item information and associative information is optimized, and whether this value effect persists over time. By using coloured images (Experiment 1) and intentional learning of word colour (Experiment 2), it was consistently found that value improved memory for colour information and this effect persisted over a longer delay (approximately 24 hours). Experiments 3a (incidental word colour) and 3b (intentional word colour) focused on memory over short delays and confirmed that value effects on word–colour associative memory are indeed somewhat less reliable following incidental encoding of colour (Hennessee et al., 2017; 2018) relative to intentional encoding of colour (Experiment 2).

Alongside these key novel findings, the current study also replicated previous findings that item recognition and recollection were superior in high value items, relative to low value items (Castel et al., 2002; 2013; Hennessee et al., 2017; 2018), and extended these observations over longer periods of time.

There are several suggested mechanisms of value effects. First, it is possible that high value items are allocated with more attentional resources during encoding (Allen, 2019; Miller et al., 2019). Within the context of WM (Hu et al., 2016) or LTM (Elliott & Brewer, 2019), the memory advantage for high value items has been shown to be reduced by concurrent divided attention, although other studies have found that such tasks only impair overall memory and do not reduce value-directed prioritization effects (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018a, 2018b). Nevertheless, when participants are given the choice to decide what information to study and how to study it, they spend more time studying and restudying the high value items, relative to low value items (Castel et al., 2013; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017). Similarly, Miler et al. (2019) used pupillometry as an index of attention and observed increased pupillary responses during encoding of items at high relative to low value serial positions. Thus, more attentional resources may be allocated to the encoding of high value items.

A second, related, possibility is that high value items are engaged with via deeper strategic encoding. Hennessee et al. (2019) found that instructing participants to use sentence generation and mental imagery strategies across both high and low value conditions eliminated/nearly eliminated value effects on recognition, suggesting this effect is due to more elaborative encoding strategies for high value items. Similarly, Bui et al. (2013) showed that high value items were engaged with enhanced relational processing relative to low value items. These findings are consistent with participants' self-report that they use more effective strategies (i.e., imagery mediators, keyword mediators, sentence generation, or relational processing) when learning high value word pairs (Ariel et al., 2015). Thus, in the context of the current study, valuable item-colour bindings may be engaged with using strategic encoding techniques such as subvocal rehearsal (e.g., mentally repeat 'red iron') and associating items with colours (e.g., the iron is red because it is hot). Third, it may also involve a (possibly dopaminergic) memory consolidation process (Murayama & Kitagami, 2014; Murayama & Kuhbandner, 2011; Spaniol et al., 2013). Reward-related motivation is thought to activate the dopaminergic midbrain and the hippocampus (Shohamy & Adcock, 2010), and this in turn enhances hippocampal-dependent memory consolidation (Wittmann et al., 2005).

When considered in the context of prior work examining value effects on colour memory (Hennessee et al., 2017; 2018), the conditions for binding between item and colour information that were implemented in the current study appear to have optimized the likelihood of value effects generalizing across item identity and colour. One potential reason is that the specific binding conditions implemented in a task help determine whether associative information is initially registered and maintained, possibly within the FoA in WM (see e.g., Cowan, 1999; Hitch et al., 2020). Further encoding processes, for example, continued attentional and/or strategic processing, will then be implemented according to value, thus giving rise to memory benefits for item and associative information. Thus, in Experiment 1, the use of conjunctive bindings within which colour information is an integral part of each image may have resulted in colour being more likely to be encoded into and maintained within the FoA. This is consistent with the object file theory that attention to any one property of an object causes other properties of that object to be attended (Kahneman et al., 1992; Treisman & Zhang, 2006). In Experiment 2 and Experiment 3b, colour information was maintained in the FoA through a form of relational binding based on the intentional learning of words and colours. In Experiment 3a and previous studies (Hennessee et al., 2017; 2018), however, colour information might not have been maintained in the FoA through incidental learning of word colour, thus no value effect was observed on colour memory. In line with this explanation, previous positive findings regarding value effects on associative memory may reflect associative information being entered into the FoA at encoding via intentional learning, such as memory for visuospatial bindings (Siegel & Castel, 2018a, 2018b), memory for word pairs (Ariel et al., 2015) and memory for word plurality status (Cohen et al., 2017).

These value effects persist over 24 hours, indicating that rather than being transient, they are potentially robust and long-lasting. There was no evidence of that such effects increased in size, as observed in previous studies (e.g., Murayama & Kuhbandner, 2011; Spaniol et al., 2013). Among various methodological differences, there was no monetary value attached to the items in the current study, which might be an important factor in engaging enhanced dopaminergic consolidation over time. In addition, it should be noted that, in the current study, all items were tested at both the short and long delay test points. As literature on the testing effect indicates memory can be enhanced through testing and retrieval (e.g., Karpicke & Roediger, 2007; Roediger & Karpicke, 2006), value effects at the longer delay may at least partly reflect their more successful retrieval at the earlier test point. Nevertheless, it is clear that the effect of value, both on item memory and on colour memory persists after a 24-hour delay. Future studies should systematically explore the longevity of the value effect and how it might interact with intervening bouts of testing and retrieval.

Results regarding point-value memory are inconsistent in the current experiments. Better point-value memory was found for higher value items in Experiment 2, but this was not observed in Experiment 1, 3a or 3b. Indeed, previous findings regarding the value effect on point-value memory have also been inconsistent (Castel et al., 2007; Hennessee et al., 2017; 2018). Point-values inform how the participant approaches each item during the encoding phase, thus there may be a relatively weak incidental binding formed between each item and its value, but this does not always reliably survive to the test phase. It could be useful for future work to explore whether value effects on point memory also emerge when this is made an explicit part of the encoding phase, and whether this then impacts on other value effects that are observed. Indeed, it is useful to note that colour memory improved for high value items in Experiments 1 and 3b, even though participants were not reliably better at retrieving the associated values of these items. This supports the idea that value influences colour memory at least in part during the encoding phase.

One methodological difference between the current experiments and previous studies (Hennessee et al. 2017; 2018) that may be worth noting relates to the variation in the number of different point values that are allocated to items. The current experiments adopted the approach used in exploration of value effects in WM (see Hitch et al., 2020) and applied a binary high-low distinction (i.e., 1 point for low value and 10 points for high value), whereas there were six different point values (i.e., 1, 2 and 3 for low value and 10, 11 and 12 for high value) in previous studies (Hennessee et al., 2017; 2018). The dichotomous value structure used in the current study may be easier for participants to distinguish between high and low value items and reduce the complexity of the taskset, which may enable a more effective focus on high value items. Consistent with this idea, Villaseñor et al. (2021) found a value effect on a subjective (though not an objective) measure of context memory when the range of point values were reduced from 1-8 to 1-4. Thus, although Experiments 3a (incidental colour encoding) and 3b (intentional colour encoding) replicated the relative pattern of findings from Experiment 2 of the current chapter and previous studies using a binary value system, it would be worthwhile for future studies to explore the extent to which variability and complexity of value allocation might impact on changes in value effects.

2.6 Conclusions

Across four experiments this chapter explored whether value enhances memory for associative information under conditions that might support a more effective process of binding between identity and colour. When colour information was well integrated with items, either through using suitable study materials (i.e., images) or through using appropriate instructions during the encoding phase (i.e., intentional learning of word colour), memory for colour information could indeed be improved when items were allocated with increased value. When colour information was poorly integrated with item information (i.e., incidental learning of word colour), no effect of value was observed on colour memory, consistent with previous findings (Hennessee et al., 2017;

2018). In addition, after approximately 24 hours, while there was some evidence of forgetting, value effects persisted over time, suggesting they are potentially robust and long-lasting. Therefore, value effects can be observed on item recognition, item recollection, and associative memory, from delays after approximately 5 minutes to 24 hours.

CHAPTER 3

THE ROLE OF ATTENTION IN THE VALUE EFFECT ON ITEM-COLOUR BINDING MEMORY

3.1 Introduction

In Chapter 2, the effect of value on colour memory was observed when the colour information is well integrated with items, either through using suitable study materials (i.e., images) or through using appropriate instructions during the encoding phase (i.e., intentional learning). However, it is unclear what cognitive processes are employed to allow more valuable associative information to be retained over less valuable information. An important mechanism is that participants may strategically allocate their attention based on item value (Allen, 2019; Castel et al., 2002). That is, they selectively focus on high value information to increase the likelihood of later remembering them. This is supported by research demonstrating that participants with attentional impairments such as Alzheimer's disease or ADHD show decreased value effects relative to healthy controls (Castel et al., 2009; Castel, Lee, et al., 2011). In addition, Miler et al. (2019) used eye tracking methodology and found that participants' pupils dilated more when studying high relative to low value words, and these changes were associated with better memory for high value words, suggesting that more attention may be allocated to the encoding of high value items.

More evidence supporting this mechanism can be drawn from value effect studies using the self-regulated paradigm, in which participants were given unrestricted choices about how to allocate study time (Ariel et al., 2015; Castel et al., 2013;

Middlebrooks & Castel, 2018; Robison & Unsworth, 2017). For example, in Castel et al. (2013)'s study, participants were shown a display of point values ranging from 1–30 on the computer screen. Participants used the computer mouse to click on a point value, and a word then appeared directly below the number. This word remained on the screen until the participant clicked on another value and then the next word was displayed. Thus, study time and the choice to study and restudy words were under the participant's control during the study session. The results showed that both younger and older adults spent more time studying and restudying high value words, relative to low value words. As a consequence, both age groups remembered more high than low valued words.

Indeed, it is well established that attention and memory, especially WM, are closely related (e.g., Allen, 2020; Awh et al., 1998; Chun et al., 2011; Gazzaley & Nobre, 2012; Oberauer, 2019). The information to which we attend is more likely to be remembered (e.g., Schmidt et al., 2002). In fact, in the domain of attention and WM, one method of directing attention to influence WM is through assigning different point-values to items. For example, Hu et al. (2014, Experiment 4) found that when assigning more points to the first or the last item in a 4-item list, memory for these items were subsequently improved. Hitch et al. (2018) generalized this effect to mid-sequence serial positions, suggesting that the effect was not due to anything special about start or end items, but an allocation of attention based on item value. They also found that attention can be flexibly managed to prioritise more than one items. A further study by Allen and Ueno (2018) extended these outcomes from serial visual memory to a simultaneous presentation context. Value-based prioritisation effects were consistently observed and participants were indeed able to prioritise multiple items. Furthermore, it was found that associating items with graded values (i.e., four items associated with 1-4 points respectively) resulted in correspondingly graded levels of recall performance, reflecting an impressively flexible attentional control process (Allen & Ueno, 2018). This process may depend on the availability of general executive resources. When such resources were taxed via a more attentionally demanding dual task, value effects were reduced or abolished (Hu et al., 2016).

Using dual tasks to divide attention during the encoding phase is a widely used methodology to examine the role of attentional executive resources in an effect. It is well established that divided attention (DA), relative to full attention (FA), at encoding has a clear detrimental effect on LTM, including measures using free recall, cued-recall, and recognition (e.g., Baddeley et al., 1984; Castellà et al., 2020; Craik et al., 1996; Naveh-Benjamin, Craik, Gavrilescu, et al., 2000; Naveh-Benjamin et al., 1998). It has also been shown that DA results in decreased associative memory, including memory for spatial location of objects (Naveh-Benjamin, 1987, 1988), memory for temporal order of words (Naveh-Benjamin, 1990), memory for frequency of words occurrence (Naveh-Benjamin & Jonides, 1986), and memory for face-name-nouns combinations (Naveh-Benjamin, Craik, Perretta, et al., 2000). Similarly, the detrimental effect of DA is also observed on WM for individual features and for feature bindings (e.g., Allen et al., 2006; Allen et al., 2014; Allen et al., 2012; Brown & Brockmole, 2010; Peterson & Naveh-Benjamin, 2017). Thus, if an effect depends on attentional resources, a suitable dual task load should diminish the availability of attentional resources and reduce or even abolish the effect. The most commonly used dual tasks designed to load on executive control resources include backward/forward counting (e.g., Allen et al., 2006;

Allen et al., 2014; Allen et al., 2012), random number generation (e.g., Clark-Foos & Marsh, 2008; Hicks & Marsh, 2000), digit monitoring (e.g., Castel & Craik, 2003; Craik et al., 2010; Kern et al., 2005; Mulligan & Hartman, 1996), and tone detection (e.g., Dell'acqua & Joucoeur, 2000; Iidaka et al., 2000; Naveh-Benjamin et al., 2006; Talmi et al., 2007).

Studies in the value effect field have already adopted the dual task paradigm to explore how attentional resources during encoding may impact the effect. However, the results remain inconsistent. Some evidence suggests that taxing attentional resources during encoding only reduces overall memory performance but does not impair the ability to selectively remember important information. For example, Middlebrooks et al. (2017) used three different tone detection tasks to divide participant's attention while participants were remembering words based on point values. The tone detection tasks differ in the extent to which attentional and WM resources may be required. In the low load task, participants were instructed to indicate via keyboard whether each tone they heard was low pitch or high pitch; in the medium load task, participants indicated via keyboard whether the two tones played during a word's presentation were the same or different; in the high load task, participants indicated via keyboard whether the current tone was the same or different as the previous tone. Although attention was stressed to different degrees (Middlebrooks et al., 2017), participant's ability to selectively remember more valuable words was not impaired.

Using a similar approach, Siegel and Castel (2018b) have explored how DA may influence the value effect on memory for item-location bindings. They speculated that, compared with item memory, memory for item-location associations requires more attentional resources (Brown & Brockmole, 2010; Elsley & Parmentier, 2009). While DA may not impact the implementation of value-based study strategies for item information (Middlebrooks et al., 2017), it may have differential effects when the cognitive load is high (i.e., item-location binding). However, the results showed that while participants in the DA conditions recalled fewer item-location associations overall, participants in all encoding conditions (both DA and FA) were equally selective, such that equivalent proportion of high value relative to low value item-location bindings was recalled. Consistent with these findings from LTM, Atkinson et al. (2020) recently found a similar pattern in auditory verbal WM. It was found that recall was enhanced for higher value items from within a sequence of digits, and a simple (disrupting verbal rehearsal only) or a complex dual task (disrupting verbal rehearsal and executive control) did not reduce the value effect. Indeed, the value effect was actually larger under articulatory suppression, relative to the FA condition, although it should be noted that participants probably abandoned the less valuable items to retain the more valuable digit (Atkinson et al., 2020). Taken together, these studies suggest that the ability to selectively remember more valuable information can be maintained even when attentional resources are taxed.

In contrast to these findings, other studies suggest that executive resources are necessary for being strategic when remembering information varying in value. For instance, Elliott and Brewer (2019) found that dual tasks like random number generation and tone-detection, but not articulatory suppression, abolished/reduced the value effect on recognition memory. Likewise, as mentioned earlier, Hu et al. (2016) found that the value effect on visual WM was substantially reduced when participants engaged in a more demanding dual task (count up from a two-digit number in steps of two), relative to a simple dual task (repeat aloud a two-digit number), suggesting a key role of the availability of attentional resources in the value effect.

Recently, Siegel et al. (2021) examined whether the ability to selectively encode information may depend on the extent to which a dual task requiring overlapping processing resources with the primary task. In this study, participants studied items in different locations in a grid (a visual-spatial task) varying in point values. In the DA condition, they also performed a dual task along with the primary task. There were four different types of dual tasks, namely an audio-nonspatial task, an audio-spatial task, a visual-nonspatial task, and a visual-spatial task. While all the dual tasks reduced memory accuracy relative to the FA condition, only the visual-spatial dual task impaired participants' selectivity in terms of memory performance. For these dual tasks that did not share the exact same processing resources as the primary visual-spatial memory task, selectivity was equivalent to the FA condition. This study suggests that the selective attentional control process is attenuated when concurrent tasks rely on overlapping processing resources (Siegel et al., 2021).

The goal of the current study was to explore the role of attention in the value effect on LTM for item-colour bindings by using the dual task paradigm. Attention is important for item-colour bindings in LTM. While shape and colour may be automatically bound and retained as integrated objects in WM, as reflected by no more memory impairment for shape-colour binding than memory for single features when attentional resources were disrupted by dual tasks (e.g., Allen et al., 2006; Allen et al., 2014; Allen et al., 2012; Johnson et al., 2008), binding of shape and colours appear to be more fragile and susceptible to interference from other items (Allen et al., 2006; Wheeler & Treisman, 2002). Allen et al. (2006, Experiment 5) found that memory accuracy on shape-colour binding was significantly lower than memory for single features with sequential rather than simultaneous presentation, especially for items earlier in the sequence. It was thought to occur as more recent bindings may interfere with those already held in visual WM from previous presentations (Allen et al., 2006). Ueno et al. (2011) further demonstrated that when study items were followed by suffixes comprising features that could potentially have formed the study items, greater disruption of retention for feature binding than for individual features was observed. It thus is likely that maintaining item-colour binding into LTM may require more attentional resources, relative to maintaining single feature information. Indeed, prior work on LTM revealed that memory for binding of item-colour was lower than memory for single features. This was consistently observed by using words and pictures (Cycowicz et al., 2001; Park & Mason, 1982), in younger and older adults (Chalfonte & Johnson, 1996). In addition, Chalfonte and Johnson (1996) also found that relative to younger adults, older adults had intact memory for item and colour features individually, but their memory for binding was impaired, suggesting item-colour binding memory is indeed more demanding.

Attention may be particularly important in the value effect on item-colour binding memory. Previous studies using coloured words have found no effect of value on memory for colour of words (Hennessee et al., 2017; 2018), whereas Chapter 2 observed the value effect on colour memory when the binding condition between item and colour information was optimized. The reason could be due to the extent to which attention was allocated to colour information. In the studies using coloured words (Hennessee et al., 2017; 2018), participants were only instructed to remember the words but not the colour of words. Thus, colour of words might have been largely neglected. In Chapter 2, we may have brought colour information into participants' FoA via intentional learning of word colour (Experiment 2) or via conjunctive binding by using coloured line drawings (Experiment 1). Experiment 3a and 3b verified the role of attention by demonstrating that value effect on word colour was only observed with intentional learning rather than incidental learning of word colour. As such, attention may be particularly important for value effect in the item-colour binding domain. If DA reduces the value effect on colour memory, this would suggest that strategically remembering more valuable item-colour bindings is dependent on attentional resources; if DA does not reduce the value effect, this would suggest that selectively remembering more valuable item-colour bindings requires little attentional resources. This study will not only improve understanding of the mechanisms underlying the value effect on item-colour binding memory, but also add more evidence regarding the inconsistent findings of the impact of DA on value effects, and help clarify whether selectivity is a relatively flexible, cost-free ability or requires attentional resources.

Four experiments were conducted in this chapter. Experiment 4 used a similar paradigm to Experiment 2, in which a long study list was followed by a filler task before a recognition test. To render the paradigm more online-friendly, Experiment 5 adopted a paradigm developed from prior research (e.g., Castel et al., 2008; Middlebrooks et al., 2017), in which it separated the long study list into several study-immediate test trials and provided participants with feedback regarding how many points they earned in each trial. Experiment 6 and Experiment 7 made a further adjustment based on Experiment 5, such that items were presented in one of the 25 locations within 5 × 5 grids (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021), either sequentially (Experiment 6) or simultaneously (Experiment 7). In all the experiments, half of the study trials were completed with FA, and the other half were completed with DA. In the latter condition, participants conducted the value effect task while performing an unrelated tone detection task.

3.2 Experiment 4

Experiment 4 aimed to examine whether DA during encoding would impact participants' ability to selectively encode more valuable item-colour bindings. If it was reduced by DA, that would be consistent with some previous findings (Elliott & Brewer, 2019; Hu et al., 2016), suggesting that strategically prioritising more valuable item-colour bindings is dependent on attentional executive resources; if DA did not reduce the value effect, that would be in line with other findings (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b), indicating that strategically remembering item-colour bindings is a flexible ability that requires little executive resources.

3.2.1 Method

3.2.1.1 Design

The experiment used a 2 (value: high, low) × 2 (attention: FA, DA) within-subject design. The FA condition and DA condition were implemented in turn in four blocks and the order of the two conditions were counterbalanced across participants (i.e., FA-

DA-FA-DA/DA-FA-DA-FA). In each block, half of the words were paired with high values and the other half were paired with low values. Dependent variables were item memory, colour memory and point-value memory.

3.2.1.2 Participants

Thirty participants were recruited from University of Leeds and from Prolific (22 females; mean age = 20.3 years; range = 18-29 years). All participants reported having correct or corrected-to-normal vision and were without colour-vision deficits. No participants reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSYC-14, Date of approval: 08/04/2020).

3.2.1.3 Materials and procedure

The materials were 160 words taken from the word set used in Experiment 2. The experiment was conducted online in Pavlovia (https://pavlovia.org/). It consisted of a study phase, a filler task (math questions), and a test phase. The filler task and the test phase were the same as Experiment 2 with the exception that the math questions were decreased from 12 questions to 6 questions. The study phase included two attention conditions (Siegel & Castel, 2018b). In the FA condition, the memory task was the only task which was the same as Experiment 2; in the DA, participants were asked to do the memory task while performing a tone detection task. A series of low-pitched (440 Hz) and high-pitched (1000 Hz) tones were played in the background and participants were asked to press the left key for the low-pitched tone and the right key for the high-pitched tone. Each tone was played for 1s with a 0.75s interval, which resulted in exactly two tones being played during each item's presentation (3s presentation with 0.5s interval). The order of tones was randomized for each participant with the constraint that no pitch was played more than three times consecutively. There were 4 study blocks. The FA and DA conditions were implemented in turn in different blocks and the order was counterbalanced across participants. There were 20 words in each block, with 10 paired with high values and 10 paired with low values.

3.2.2 Results

3.2.2.1 Item memory

RKG responses were calculated as the mean proportion of old items that were attributed to the R, K and G options. Mean hit rates, false alarm rates, *d'*, R, K, G responses and point-value memory as a function of value and attention are displayed in Table 3.1. A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA revealed a main effect of attention on item memory [Hit rates, $F(1, 29) = 8.00$, $p < .01$, $\eta^2_p = 0.22$, $BF_{10} = 7.38$; *d'*, $F(1, 29) = 6.86$, $p < .05$, $\eta^2_p = 0.19$, $BF_{10} = 5.48$], such that memory was better with FA (*MMs* = 0.42 , *SE* = 0.03) than with DA (*MMs* = 0.36, *SE* = 0.03). The main effect of value [Hit rates, $F(1, 29) = 1.80$, $p = 0.19$, $\eta^2_p = 0.06$, $BF_{10} = 0.50$; *d'*, $F(1, 29) = 2.09$, $p = .16$, $\eta^2_p = 0.07$, $BF_{10} = 0.48$] and the interaction between value and attention were not significant [Hit rates, $F(1, 29) = 0.81$, $p = .38$, $\eta^2_p = 0.03$, $BF_{10} = 0.39$; *d'*, $\mathrm{F}(1, 29) = 1.09$, $p = .30$, $\eta^2_p = 0.04$, $BF_{10} = 0.38$]. These findings were corroborated by BF analysis, which revealed that the most likely model included a main effect of attention (Hit rates, $BF_{10} = 7.34$; *d'*, $BF_{10} = 5.30$, relative to the null model with random effects of participant only).

For R responses, repeated measures ANOVA revealed a main effect of attention [$F(1, 29) = 7.40$, $p < .05$, $\eta^2_p = 0.20$, $BF_{10} = 7.38$], with higher proportion in the FA condition (*MMs* = 0.18, *SE* = 0.02) than the DA condition (*MMs* = 0.12 , *SE* = 0.02). The effect of value [$F(1, 29) = 0.90$, $p = .35$, $\eta^2_p = 0.03$, $BF_{10} = 0.50$] and the interaction between value and attention [$F(1, 29) = 0.15$, $p = .70$, $\eta^2_p = 0.005$, $BF_{10} = 0.39$] were not significant. BF analysis revealed that the most likely model of R responses included a main effect of attention ($BF_{10} = 43.07$ relative to the null model with random effects of participant only). No significant effect was observed on K or G responses, and BF analysis suggested no better model than the null model for K or G responses.

3.2.2.2 Associative memory

Correct associative memory was calculated as the mean proportion of correctly recognized items that were attributed to the correct associative information. Colour memory as a function of value and attention is displayed in Figure 3.1. A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA on colour memory revealed a main effect of attention [$F(1, 29) = 8.09$, $p < .01$, $\eta^2_p = 0.22$, $BF_{10} = 7.24$], with higher memory accuracy in the FA condition (*MMs* = 0.41, *SE* = 0.04) than the DA condition (*MMs* = 0.29, *SE* = 0.04). The effect of value [$F(1, 29) = 0.81$, $p = .38$, $\eta^2_p = 0.03$, $BF_{10} = 0.33$] and the interaction between value and attention [$F(1, 29) = 0.43$, $p = .52$, $\eta^2_p = 0.02$, $BF_{10} = 0.40$] were not significant. These outcomes were supported by BF analysis. It showed that the most likely model included a main effect of attention ($BF_{10} = 7.13$ relative to the null model with random effects of participant only).

Point-value memory as a function of value and attention is displayed in Table

3.1. A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA on point-value memory revealed a main effect of value [$F(1, 29) = 9.77$, $p < .01$, $\eta^2_p = 0.25$, $BF_{10} = 85.56$], with better memory for high point-values (*MMs* = 0.32, *SE* = 0.04) than memory for low point-values (*MMs* = 0.20, *SE* = 0.04). The main effect of attention [$F(1, 29) = 0.12$, $p = .74$, $\eta^2_p = 0.004$, $BF_{10} = 0.20$] and the interaction between value and attention [$F(1, 29) = 1.33$, $p = .26$, $\eta^2_p = 0.04$, $BF_{10} = 0.44$] were not significant. BF analysis indicated that the most likely model included a main effect of value (BF_{10} = 85.51 relative to the null model with random effects of participant only).

Table 3. 1 Mean Hit Rates, False Alarm Rates (FAR), *d'*, Remember (R), Know (K), Guess (G) responses and Point-value memory as a function of value and attention in Experiment 4

	Full attention		Divided attention	
	High value	Low value	High value	Low value
Hit rates	0.45(0.03)	0.40(0.03)	0.36(0.04)	0.35(0.03)
FAR	0.22(0.03)			
d'	0.78(0.12)	0.61(0.13)	0.52(0.10)	0.49(0.10)
R	0.19(0.03)	0.17(0.03)	0.13(0.02)	0.12(0.02)
K	0.13(0.02)	0.11(0.02)	0.12(0.02)	0.11(0.02)
G	0.13(0.02)	0.11(0.02)	0.12(0.02)	0.12(0.02)
Point-value	0.31(0.04)	0.22(0.05)	0.33(0.04)	0.18(0.04)

Note. Standard errors presented in parentheses.

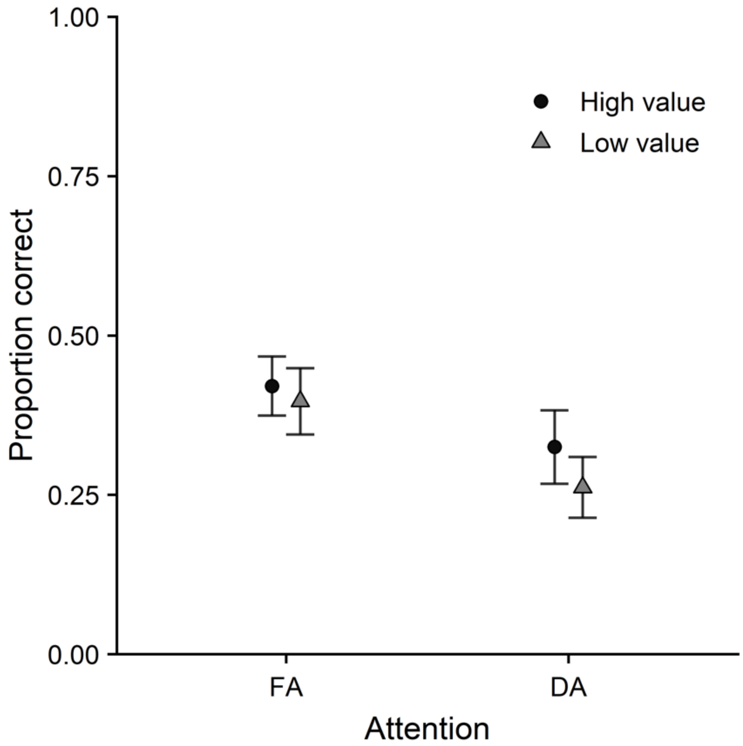

Figure 3. 1 Colour memory as a function of value and attention in Experiment 4. FA: full attention, DA: divided attention.

3.2.3 Discussion

The aim of Experiment 4 was to explore the role of attention in the value effect on item-colour binding memory. It was observed that DA decreased item memory and colour memory, consistent with previous findings that DA has detrimental effects on item memory (e.g., Baddeley et al., 1984; Craik et al., 1996; Naveh-Benjamin, Craik, Gavrilescu, et al., 2000; Naveh-Benjamin et al., 1998) and on associative memory (e.g., Naveh-Benjamin,1987, 1988, 1990; Naveh-Benjamin et al., 2000). While memory for point-value of items was better for high than low value items, we did not observe the effect of value on item memory or on colour memory, or any interactions between value and attention. The null effect of value on item memory and on colour memory with FA contrasts with the results found in Experiment 2. While the paradigm in the current experiment was similar to Experiment 2, a key difference between the two experiments was that Experiment 2 was conducted in the laboratory whereas Experiment 4 was conducted online (due to Covid-19 restrictions). Online participants may be less motivated in the task than those involved in a laboratory experiment (Kraut et al., 2004) and pay less attention to task instructions. This latter requirement is important given that the task is not merely to remember the words and word colours but also to maximize the point score. Thus, the paradigm used in the laboratory did not appear to be optimal for the online environment. To render the paradigm more online-friendly, several adjustments were made for Experiment 5.

3.3 Experiment 5

To improve online participants' engagement in the task, we reduced the task difficulty by using pictures rather than words, as memory for colour of pictures was substantially better than memory for colour of words (Park & Puglisi, 1985), and Experiment 1 demonstrated that the value effect on item-colour binding memory could be observed using pictures. We also separated the single long study list into several study-immediate test trials. Feedback regarding how many points participants earned in each trial was also provided to emphasise the point values and encourage participants to engage with this aspect of the task. The inclusion of multiple trials with feedback has also been used in previous studies which have shown that participants' ability to strategically remember items based on item value increases with continued task experience, possibly because they are able to assess their performance from the feedback and modify their strategy in later study trials (Castel et al., 2008; Middlebrooks et al., 2017; Siegel & Castel, 2018 a, 2018b).

3.3.1 Method

3.3.1.1 Design

The current experiment adopted a 2 (value: high, low) × 2 (attention: FA, DA) within-subject design. The FA and DA conditions were conducted in two separated blocks. Each block included 5 study trials and each trial included 4 high and 4 low value items. The binding between items and point-values, the items used in each attention condition, and the order of the two study blocks were counterbalanced across participants. Dependent variables were immediate item-colour memory and delayed item-colour memory.

3.3.1.2 Participants

Twenty-nine participants were recruited from University of Leeds (24 females; mean age = 18.9 years; range = 18-29 years). All participants reported having correct or corrected-to-normal vision and were without colour-vision deficits. None reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSYC-14, Date of approval: 08/04/2020).

3.3.1.3 Materials

Eighty neutral line drawings of daily objects were selected from Snodgrass and Vanderwart (1980) and Cycowicz et al. (1997). The items were presented in eight different colours (red, yellow, blue, green, orange, purple, brown and pink). Half of the items were paired with 1 point, and the other half were paired with 10 points. The binding of colours and point-values was balanced as much as possible so that there was no incidental association between a point value and a particular colour.

3.3.1.4 Procedure

The experiment was conducted online using the Gorilla Experiment Builder (Anwyl-Irvine et al., 2020)[2]. It consisted of a study-immediate test phase, a filler task and a delayed test phase. During the study-immediate test phase, participants were instructed that they would be presented with a series of images with different colours, each paired with a point-value they would earn if they could correctly remember the colour of the images in a later test. The goal was to maximize their point-score. Eight items (four high value items, four low value items) were each presented sequentially in the centre of the screen for 3s with a 0.5s fixation cross interval. The test phase followed a 1s mask, with the eight items being presented one by one as non-coloured outlines. Participants were asked to choose the colour for each item by clicking one from eight colour buttons (see Figure 3.2 for an example). They were then informed of how many points they scored in the current study-test trial and then the next trial began. There were two attention conditions (FA vs. DA), each including 5 study-test trials. The attention manipulation was the same as in Experiment 4. Next, participants completed a filler task to reduce mental rehearsal (same as in Experiment 4), followed by a delayed memory test, in which ten items (half high, half low) from each attention condition were selected and tested.

[2] The online experiment software was changed from Pavlovia to Gorilla because unexpected sounds were triggered by keyboard input if the program was run in Safari using Pavlovia.

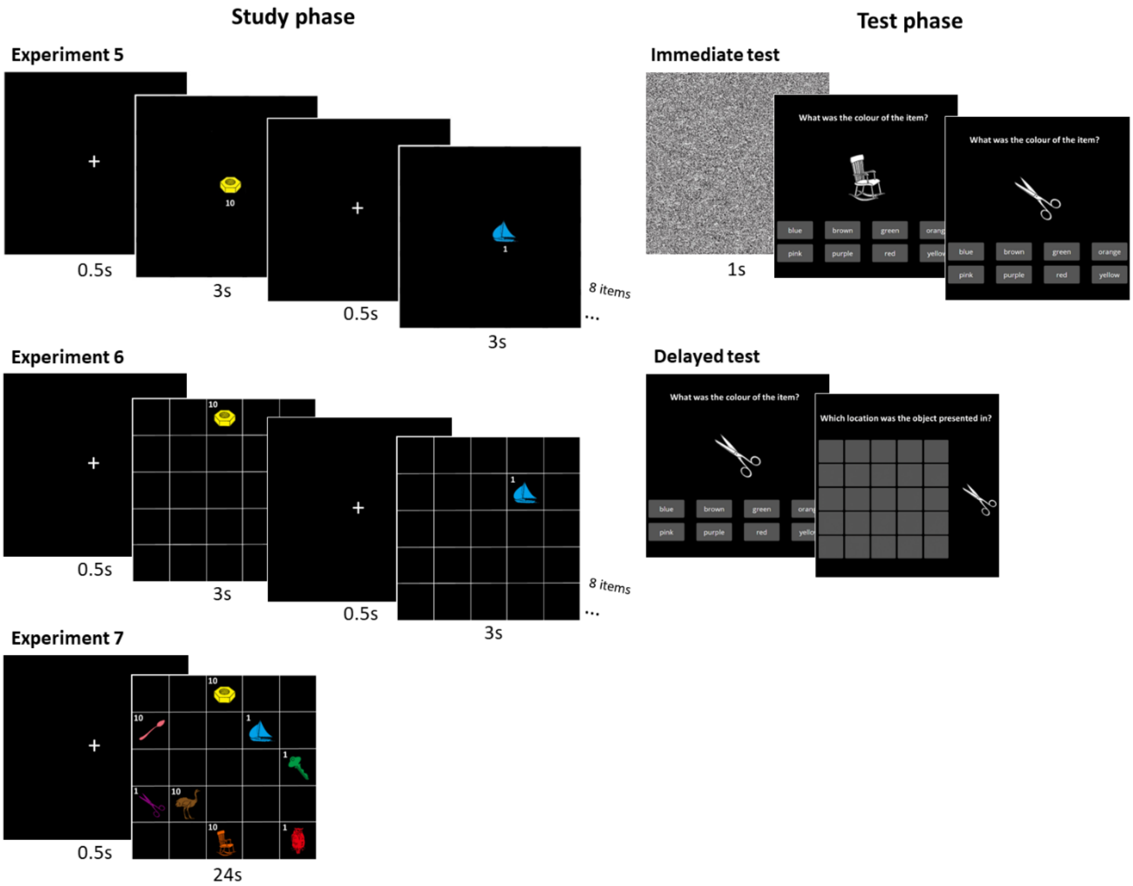

Figure 3. 2 Examples of the study phase and test phase in Experiment 5, Experiment 6 and Experiment 7. Note, in the delayed test in Experiment 5, there was no location memory test.

3.3.2 Results

Immediate item-colour binding memory and delayed item-colour binding memory as a function of value and attention are displayed in Figure 3.3.

3.3.2.1 Immediate test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA showed a main effect of attention [$F(1, 28) = 10.74$, $p < .01$, $\eta^2_p = 0.28$, $BF_{10} = 85.21$], whereby memory was better with FA (*MMs* = 0.69; *SE* = 0.03) than with DA (*MMs* = 0.59; *SE* = 0.03). The effect of value [$F(1, 28) = 0.10$, $p = .76$, $\eta^2_p = 0.003$, $BF_{10} = 0.20$] and the interaction between value and attention [$F(1, 28) = 0.55$, $p = .47$, $\eta^2_p = 0.02$, $BF_{10} =$

0.30] were not significant. These outcomes were supported by BF analysis, which showed that the most likely model included a main effect of attention (BF_{10} = 85.52 relative to the null model with random effects of participant only).

3.3.2.2 Delayed test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA revealed a main effect of attention [$F(1, 28) = 7.39$, $p < .05$, $\eta^2_p = 0.21$, $BF_{10} = 17.10$], with greater memory accuracy in the FA condition (*MMs* = 0.56; *SE* = 0.05) than in the DA condition (*MMs* = 0.43; *SE* = 0.05). The effect of value [$F(1, 28) = 0.12$, $p = .74$, $\eta^2_p = 0.004$, $BF_{10} = 0.21$] and the interaction between value and attention [$F(1, 28) = 0.06$, $p = .82$, $\eta^2_p = 0.002$, $BF_{10} = 0.25$] were not significant. BF analysis showed that the most likely model included a main effect of attention (BF_{10} = 16.97 relative to the null model with random effects of participant only).

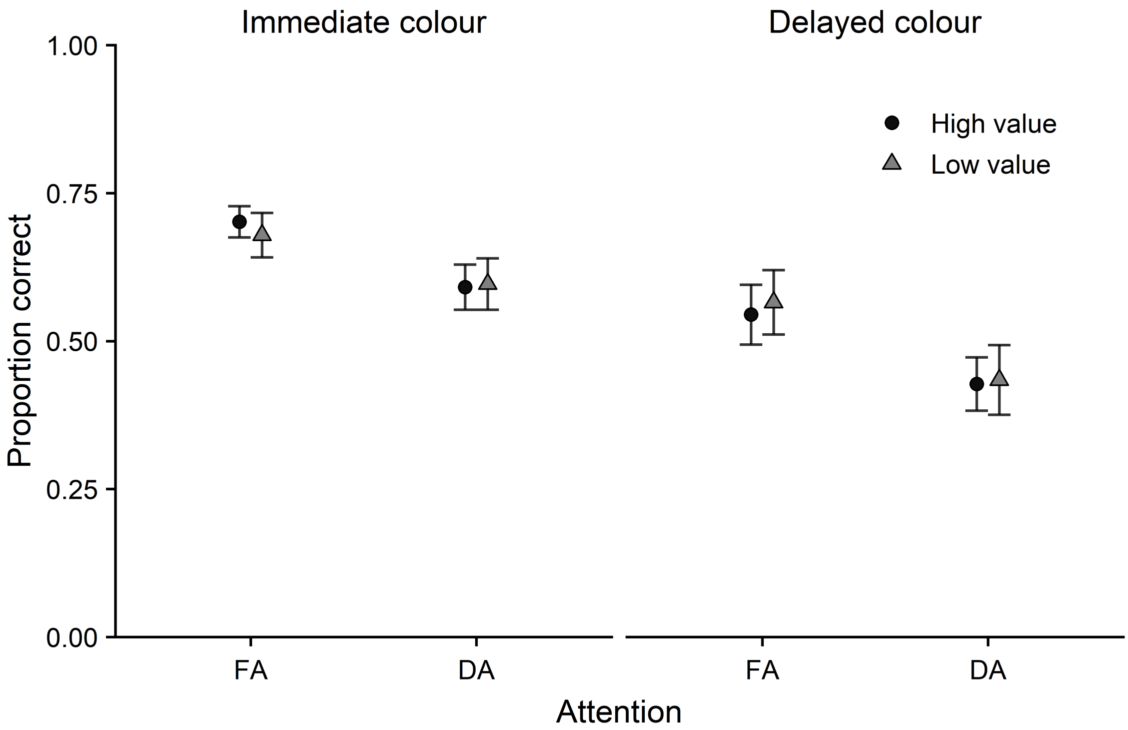

Figure 3. 3 Immediate item-colour binding memory and delayed item-colour binding memory as a function of value and attention in Experiment 5 using sequential presentation (same location). FA: full attention, DA: divided attention.

3.3.3 Discussion

In the previous experiment (Experiment 4), we failed to observe the value effect on item memory and on colour memory, perhaps because the task was too demanding when conducting it online. Thus, in Experiment 5, the task demand was reduced by using pictures, separating long study list into multiple study-test trials, and providing feedback. As a result, participants' memory performance was improved (immediate test: M_{high} = 0.70, M_{low} = 0.68; delayed test: M_{high} =0.55, M_{low} = 0.57) relative to Experiment 4 (delayed test: M_{high} = 0.42, M_{low} = 0.40). However, there was still no effect of value. When comparing the current paradigm with previous studies using similar paradigms (e.g., Siegel & Castel, 2018 a, 2018b), a difference was that in these studies items were presented in different locations within 5 × 5 grids, either sequentially or simultaneously.

In the current experiment, items always appeared in the centre of the screen. While prior research indicates that presenting items sequentially at the same location, relative to presenting them sequentially at different locations, does not impair feature bindings (Allen et al., 2015; Harrison & Bays, 2018; Schneegans et al., 2021), increasing spatial distance among items is beneficial for attentional control (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). Therefore, presenting items in different locations may help participants to apply selective encoding based on item value. Thus, in Experiment 6 and Experiment 7, items were presented in different locations within 5 × 5 grids, either sequentially (Experiment 6), or simultaneously (Experiment 7).

3.4 Experiment 6

Experiment 6 examined whether participants can selectively encode more valuable item-colour bindings when items were presented sequentially in different locations, and whether DA during encoding would affect this ability. In Experiment 5, memory performance was largely improved relative to Experiment 4 when several adjustments were made based on previous findings (e.g., Castel et al., 2008; Middlebrooks et al., 2017). However, there was still no effect of value. A further adjustment was made in Experiment 6 by presenting items in one of the 25 locations within 5 × 5 grids (see Figure 3.2 for an example, Siegel & Castel, 2018a, 2018b; Siegel et al., 2021).

It was expected to the see the effect of value on item-colour binding memory, as presenting items in different locations might serve to make each item more distinct and help participants to apply selective encoding more easily. Indeed, previous studies using the flanker task have found that increasing spatial distance between targets and distractors can improve the efficiency of attentional control (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). It was also expected to see the detrimental effect of DA on memory performance (e.g., Allen et al., 2006; Baddeley et al., 1984; Craik et al., 1996). If DA reduced the value effect, that would indicate that general executive resources is essential for strategically prioritizing high value item-colour bindings; if DA did not influence the value effect, that would suggest that strategically remembering item-colour bindings is a flexible ability that requires little executive resources.

3.4.1 Method

3.4.1.1 Design

As with Experiment 5, this experiment implemented a 2 (value: high, low) × 2 (attention: FA, DA) within-subject design. The dependent variables were immediate item-colour memory, delayed item-colour memory and delayed item-location memory. Counterbalancing and order of conditions was implemented as in Experiment 5.

3.4.1.2 Participants

Twenty-eight participants were recruited from University of Leeds (25 females; mean age = 18.5 years; range = 18-20 years). All participants reported having correct or corrected-to-normal vision and were without colour-vision deficits. None reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSYC-14, Date of approval: 08/04/2020).

3.4.1.3 Materials and procedure

The material and procedure were the same as Experiment 5 with the following exceptions. Firstly, the items were placed within 5 × 5 grids, in different locations. Secondly, in the delayed memory test, besides the memory test for the colour of the items, the location of the items was also tested. Participants were asked to choose the location for each item by clicking one from 25 buttons (see Figure 3.2 for an example).

3.4.2 Results

Immediate item-colour binding memory, delayed item-colour binding memory, and delayed item-location binding memory as a function of value and attention are displayed in Figure 3.4.

3.4.2.1 Immediate test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA revealed a main effect of value [$F(1, 27) = 5.00$, $p < .05$, $\eta^2_p = 0.16$, $BF_{10} = 7.09$], where memory for high value bindings (*MMs* = 0.69 ; *SE* = 0.03) was better than memory for low value bindings (*MMs* = 0.60; *SE* = 0.03). There was also a main effect of attention [$F(1, 27) = 32.25$, $p < .001$, $\eta^2_p = 0.54$, $BF_{10} > 1000$], such that memory was better with FA (*MMs* = 0.74; *SE* = 0.03) than with DA (*MMs* = 0.56; *SE* = 0.03). The interaction between value and attention was not significant [$F(1, 27) = 1.67$, $p = .21$, $\eta^2_p = 0.06$, $BF_{10} = 0.34$]. These outcomes were supported by BF analysis, which showed that the most likely model included main effects of value and attention ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

3.4.2.2 Delayed colour memory test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA was conducted on delayed colour memory. A main effect of attention was observed [F(1, 27)

= 14.75, $p < .001$, $\eta^2_p = 0.35$, $BF_{10} = 958.97$], such that memory was better with FA (*MMs* = 0.59; *SE* = 0.04) than with DA (*MMs* = 0.38; *SE* = 0.04). The main effect of value was not significant [$F(1, 27) = 0.22$, $p = .64$, $\eta^2_p = 0.008$, $BF_{10} = 0.21$], but there was an interaction between value and attention [$F(1, 27) = 11.77$, $p < .01$, $\eta^2_p = 0.30$, $BF_{10} = 5.72$]. Paired samples t-tests indicated that memory for high value item-colour bindings was better than memory for low value item-colour bindings in the FA condition [$t(27) = 2.59$, $p < .05$, Cohen's $d = 0.49$, $BF_{10} = 3.20$], but not in the DA condition [$t(27) = -1.66$, $p = .11$, $d = -0.31$, $BF_{10} = 0.67$]. BF analysis showed that the most likely model included a main effect of value, main effect of attention, and the interaction between value and attention ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

3.4.2.3 Delayed location memory test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA was conducted. The main effect of attention was marginally non-significant [$F(1, 27) = 4.07$, $p = .054$, $\eta^2_p = 0.13$, $BF_{10} = 6.06$], but it was supported by BF analysis that memory performance in the FA condition (*MMs* = 0.15; *SE* = 0.03) was higher than that in the DA condition (*MMs* = 0.08; *SE* = 0.03). The main effect of value [$F(1, 27) = 0.12$, $p = .73$, $\eta^2_p = 0.004$, $BF_{10} = 0.20$] and the interaction between value and attention [$F(1, 27) = 1.24$, $p = .28$, $\eta^2_p = 0.04$, $BF_{10} = 0.40$] were not significant. BF analysis showed that the most likely model included a main effect of attention ($BF_{10} = 6.07$ relative to the null model with random effects of participant only).

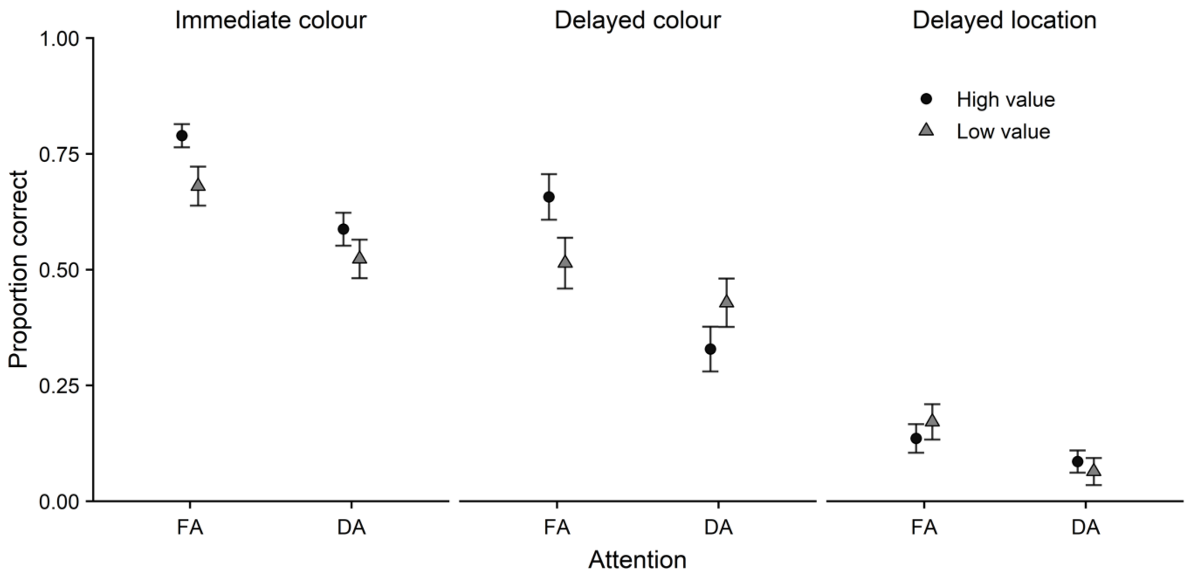

Figure 3. 4 Immediate item-colour binding memory, delayed item-colour binding memory, and delayed item-location binding memory as a function of value and attention in Experiment 6 using sequential presentation (different locations). FA: full attention, DA: divided attention.

3.4.3 Discussion

By varying location of items within each sequence (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021), the value effect on item-colour binding memory was observed in the immediate test, such that memory performance was greater for high value bindings than that for low value bindings. It was also found that while DA reduced overall memory performance, it did not reduce the value effect in the immediate test, consistent with previous findings (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b, but see Elliott & Brewer, 2019; Hu et al., 2016). However, in the delayed item-colour memory test, the value effect was observed with FA whereas it disappeared with DA. These results indicate that DA does not reduce participant's ability to better maintain high value bindings for a short time, but it does affect the ability to generate a long-lasting advantage of high value items. This might suggest that DA impaired general memory consolidation, thus decreased persistence of the value effect. Alternatively, it might suggest that DA specifically disrupted long-term maintenance, rather than short-term maintenance, for high value information. This implies that prioritisation of high value items might be supported by two different mechanisms. One can maintain value effect for a long period of time but is susceptible to DA, the other could survive DA but can only maintain value effect for a short period of time.

One possibility for these mechanisms could be maintenance rehearsal and elaborative rehearsal. Elaborative rehearsal is more effective than maintenance rehearsal in enhancing LTM (Bower, 1972; Craik & Watkins, 1973; Roenker, 1974; Sachs, 1967), but it is susceptible to DA (e.g., Craik & Byrd, 1982; Rabinowitz et al., 1982), as it is a complex and demanding process which requires attentional resources (Schneider & Sodian, 1997). In contrast, maintenance rehearsal requires little attentional resources (Baddeley, 1986; Cowan, 2001) and would be much less affected by DA. Therefore, in the FA condition, the value effect observed in the immediate test might be driven by selective encoding for high value items, via maintenance rehearsal and elaborative rehearsal, whereas the value effect observed in the delayed test may mainly be driven by those items participants applied elaborative rehearsal to as maintenance rehearsal is less effective in long term retention (Craik & Watkins, 1973; Roenker, 1974; Rundus, 1977). In the DA condition, DA may have greatly impaired elaborative rehearsal thus abolished the value effect in the delayed test, but it had little effect on maintenance rehearsal thus the value effect survived in the immediate test.

To summarise, results from the current experiment indicate that DA does not impact participants' ability to strategically encode item-colour bindings based on item value, but it impacts participants' ability to generate a long-lasting value effect. In addition, it appears that participants use different types of strategies to prioritise high value bindings, possibly including effective elaborative rehearsal and less effective maintenance rehearsal. DA may have disrupted elaborative rehearsal and thus abolished the value effect in the delayed test, but it may have little impact on maintenance rehearsal so a short-lived value effect was still observed in the immediate test. The type of strategies that may underlie the value effect on item-colour binding memory was further explored in Chapter 4. Before moving onto Chapter 4, we conducted Experiment 7 using a simultaneous presentation format which has been used in previous value effect studies on item-location associative memory (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021), but has never been used in exploring the value effect on memory for item-colour bindings.

3.5 Experiment 7

Experiment 7 examined whether participants can strategically encode more valuable item-colour bindings when items were presented simultaneously, and whether taxing attentional resources during encoding would affect this ability. Previous research has revealed important distinctions between sequential and simultaneous presentation formats. For example, memory accuracy for visual information is greater when information is presented simultaneously, as compared to sequentially (Allen et al., 2006; Blalock & Clegg, 2010; Gorgoraptis et al., 2011; Lecerf & De Ribaupierre, 2005; Siegel & Castel, 2018a, 2018b). The value effect is larger when participants study items in a simultaneous format than a sequential format (Ariel et al., 2009; Middlebrooks & Castel, 2018). In addition, participants are consistently selective throughout the task for simultaneously presented information (Siegel & Castel, 2018a, 2018b), while they require some task experiences to become more selective when information is sequentially presented (Castel et al., 2012; Middlebrooks & Castel, 2018; Siegel & Castel, 2018a, 2018b). This is thought to occur because, as compared with the simultaneous format, the sequential format may require participants to maintain information in WM while comparing the value of each item. The extra demands of the sequential format may diminish cognitive resources and disrupt the controlled top-down processing (Ariel et al., 2009; Siegel & Castel, 2018b).

Experiment 6 found that when items were presented sequentially, DA did not impact the value effect in the immediate test, but it abolished the effect in the delayed test. Experiment 7 were interested in whether similar outcomes would be observed when items were presented simultaneously. Considering simultaneous format is less demanding (Allen et al., 2006; Blalock & Clegg, 2010; Gorgoraptis et al., 2011; Lecerf & De Ribaupierre, 2005; Siegel & Castel, 2018a, 2018b) and is relatively more advantageous for selective encoding (Ariel et al., 2009; Castel et al., 2012; Middlebrooks & Castel, 2018; Siegel & Castel, 2018a, 2018b), it is possible that DA would not reduce the value effect in the immediate test or the delayed test in Experiment 7.

3.5.1 Method

3.5.1.1 Design

The current experiment adopted a 2 (value: high, low) × 2 (attention: FA, DA) within-subject design. Dependent variables were immediate item-colour memory, delayed item-colour memory and delayed item-location memory. Counterbalancing and order of conditions was implemented as in Experiment 6.

3.5.1.2 Participants

Thirty participants were recruited from University of Leeds (28 females; mean age = 19.1 years; range = 18-28 years). All participants reported having correct or corrected-to-normal vision and were without colour-vision deficits. None reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics reference number: PSYC-14, Date of approval: 08/04/2020).

3.5.1.3 Materials and procedure

The material and procedure were the same as Experiment 6 with the following exceptions: the eight items for each presentation phase were placed simultaneously within a 5 × 5 grid for 24s, in eight different locations (see Figure 3.2 for an example); in the DA condition, there were 8 tones in each study trial (in Experiment 6, each item was paired with 2 tones, thus 16 tones in each study trial).

3.5.2 Results

Immediate item-colour binding memory, delayed item-colour binding memory, and delayed item-location binding memory as a function of value and attention are displayed in Figure 3.5.

3.5.2.1 Immediate test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA was conducted. A main effect of value was found [$F(1, 29) = 10.17$, $p < .01$, $\eta^2_p = 0.26$, $BF_{10} = 43.72$], such that memory for high value bindings (*MMs* = 0.76; *SE* = 0.03) was better than memory for low value bindings (*MMs* = 0.67; *SE* = 0.03). There was also a main effect of attention [$F(1, 29) = 23.60$, $p < .001$, $\eta^2_p = 0.45$, $BF_{10} > 1000$], with superior memory performance in the FA condition (*MMs* = 0.78; *SE* = 0.03) than the DA condition (*MMs* = 0.64; *SE* = 0.03). The interaction between value and attention was not significant [$F(1, 29) = 0.26$, $p = .62$, $\eta^2_p = 0.009$, $BF_{10} = 0.27$]. These outcomes were supported by BF analysis, which showed that the most likely model included main effects of value and attention ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

3.5.2.2 Delayed colour memory test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA revealed a main effect of attention [$F(1, 29) = 5.70$, $p < .05$, $\eta^2_p = 0.16$, $BF_{10} = 3.14$], with better memory in the FA condition (*MMs* = 0.63; *SE* = 0.04) than the DA condition (*MMs* = 0.52; *SE* = 0.04). The main effect of value [$F(1, 29) = 0.35$, $p = .56$, $\eta^2_p = 0.01$, $BF_{10} = 0.24$] and the interaction between value and attention were not significant [$F(1, 29) = 0.46$, $p = .50$, $\eta^2_p = 0.02$, $BF_{10} = 0.31$]. Supporting these outcomes, BF analysis showed that the most likely model included a main effect of attention ($BF_{10} = 3.12$ relative to the null model with random effects of participant only).

3.5.2.3 Delayed location memory test

A 2 (value: high, low) × 2 (attention: FA, DA) repeated measures ANOVA was conducted. This revealed a main effect of value [$F(1, 29) = 6.43$, $p < .05$, $\eta^2_p = 0.18$, $BF_{10} = 2.90$], such that memory was better for high value bindings (*MMs* = 0.29; *SE* = 0.03) than low value bindings (*MMs* = 0.20; *SE* = 0.03). The main effect of attention [$F(1, 29) = 2.00$, $p = .17$, $\eta^2_p = 0.07$, $BF_{10} = 0.48$] and the interaction between value and attention were not significant [F(1, 29) = 0.41, $p = .53$, $\eta^2_p = 0.01$, $BF_{10} = 0.31$]. BF analysis showed that the most likely model included a main effect of value ($BF_{10} = 2.88$ relative to the null model with random effects of participant only).

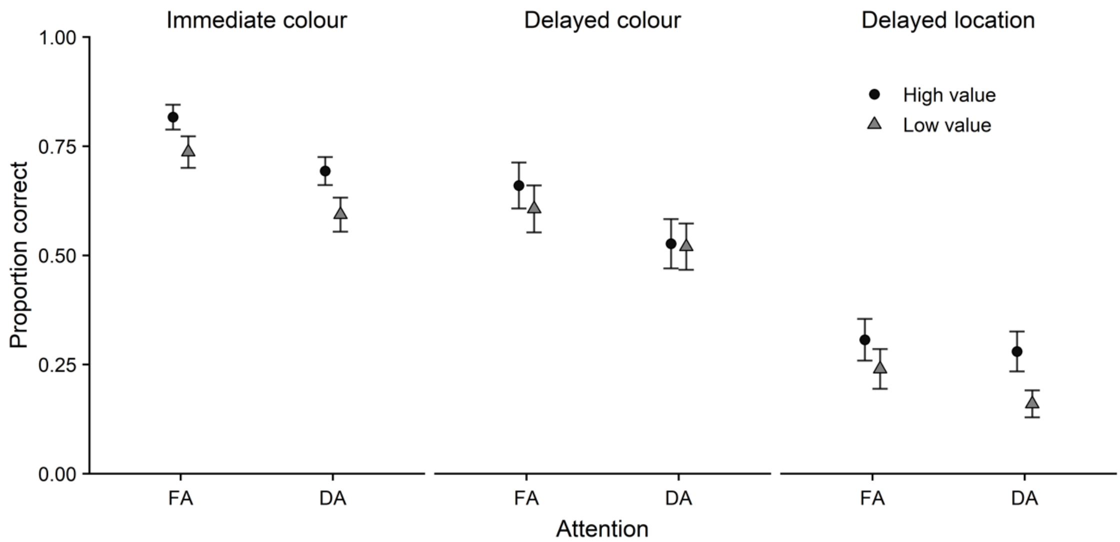

Figure 3. 5 Immediate item-colour binding memory, delayed item-colour binding memory, and delayed item-location memory as a function of value and attention in Experiment 7 using simultaneous presentation. FA: full attention, DA: divided attention.

3.5.3 Discussion

Experiment 7 found that when items were presented simultaneously, the value effect on item-colour binding memory was observed in the immediate test, with higher memory accuracy for high value bindings than low value bindings. This result replicated the finding from Experiment 6 and extended the value effect on item-colour binding memory to a simultaneous presentation format. Moreover, DA decreased memory performance overall, but it did not disproportionately reduce memory for high value bindings. This result is consistent with the finding from Experiment 6 and in line with previous findings (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b, but see Elliott & Brewer, 2019; Hu et al., 2016), suggesting the ability to selectively encode high value bindings is very flexible and requires little attentional resources.

In the delayed colour memory test, it was expected to see the value effect, because such an effect was observed in Experiment 6 using a sequential format, and previous studies demonstrated superior value effect when items were presented simultaneously relative to sequentially (Ariel et al., 2009; Middlebrooks & Castel, 2018). However, only a significant DA effect was observed. There was no effect of value. In fact, in Chapter 4, the value effect in the delayed test was observed using the simultaneous format (Experiment 8) but not using the sequential format (Experiment 9). These results indicate that the value effect in the delayed test is possibly unstable under the current paradigm. Several possible reasons are considered in the General Discussion.

Furthermore, there was a value effect on memory for the location of items, though memory performance was low. Speculatively, when encoding items in a simultaneous format, participants may have studied high value items for multiple times and may have also encoded them relative to each other. This would result in more frequent eye movements among high value items and more relational processing between them, both of which have been shown to enhance location memory (Awh & Jonides, 2001; Baddeley, 1986; Lilienthal et al., 2014; Taylor et al., 2014; Tremblay et al., 2006).

3.6 General discussion

The experiments reported in this chapter investigated whether DA during encoding impacts the ability to selectively encode more valuable item-colour bindings. In Experiment 4 and Experiment 5, the value effect was not observed, possibly because the online format of the paradigm we implemented was disadvantageous for the purposes of examining the effects of attentional control. Previous studies on the flanker task have found that increasing spatial distance between targets and distractors can improve the efficiency of attentional control (Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). Therefore, Experiment 6 and Experiment 7 adopted a similar paradigm to previous studies (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021), in which items were presented in different locations, rather than in the same location as in previous experiments. The value effect on memory for item-colour bindings was observed. In these experiments, participants studied item-colour bindings worth different point values while performing a tone detection task designed to divide attention. It was consistently found that the tone detection task decreased overall memory performance in the immediate and the delayed tests. Moreover, in the immediate test, even though participants' attention was divided during study, it did not impact participant's ability to prioritise high value information. This result was consistently observed in Experiment 6 and Experiment 7, in line with previous studies (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b, but see Elliott & Brewer, 2019; Hu et al., 2016). This demonstrates that the ability to selectively encode information based on allocated value is flexible and requires little attentional resources. In the delayed test, however, different patterns emerged. When items were presented sequentially (Experiment 6), the effect of value persisted to the delayed test with FA, but not with DA, suggesting DA might have influenced how high value bindings were encoded for long-term maintenance. When items were presented simultaneously (Experiment 7), no value effect was observed at the delayed test, even with FA. Furthermore, the current study also tested participants' memory for location of items in the delayed test. It was found that memory for location was better for high value items than low value items when items were presented simultaneously rather than sequentially, possibly because the simultaneous format allowed participants to restudy high value items multiple times and this incidentally improved learning of item location.

3.6.1 Is the ability to selectively encode valuable information cost-free?

The current study revealed that although DA reduced overall memory performance, it did not impact participants' ability to strategically encode and briefly maintain item-colour bindings based on item value, either when items were presented sequentially or simultaneously. These results are in line with previous research which have found that the value effect was maintained under DA in various situations, whether the primary task is relatively more attention-demanding (e.g., associative memory, Siegel & Castel, 2018b), dual tasks stress attention to different degrees (Middlebrooks et al., 2017), or the study stimuli are from the auditory-verbal domain (Atkinson et al., 2020). These findings reflect a flexible attentional control ability. When the general attentional resources are taxed by an unrelated dual task, participants can still reallocate the remaining resources according to item value, although sometimes more valuable items are prioritised at the expense of abandoning other, less valuable, items (Atkinson et al., 2020).

It appears that two abilities dissociated via divided attention. One is the ability to maintain information for a short time, which depends on attentional resources; the other is the ability to control what information should be maintained (e.g., more valuable information), which requires little attentional resources. Indeed, among various theories on attention, WM, and the relation between them, one view is that attentional resource is allocated to representations of objects and events that we perceive or hold in WM. The other view assumes a resource for the control of what we attend to (Oberauer, 2019). These notions have different implications in WM (Oberauer, 2019). According to theories assuming a limited resource allocated to representations in WM, attention limits how much information can be retained, and a separate parameter determines the control efficiency (i.e., keeping relevant information in WM and removing irrelevant information out of WM). These theories predict that individuals with lower WM capacity maintain a smaller amount of information, but their control efficiency should be independent of WM capacity. According to the attentional control view, by contrast, the attentional resource determines the control efficiency. Hence, individuals with lower WM capacity retain the same amount of information as those with higher capacity, but they differ in the ratio of relevant to irrelevant information that they retain (Oberauer, 2019).

Results from the current study show that loading attentional resources via a dual task during encoding decreased participants' memory for item-colour bindings but it does not impact their ability to selectively encode and briefly maintain more valuable bindings. This seems to be in line with the view that holding information in WM requires attentional resources whereas controlling/selecting which information to be held does not. However, it should be noted that the attentional control process in the current study, as reflected by selective encoding based on item value, might be different to the control process that involves inhibition. It has been well documented that control of inhibition requires attentional resources, such that DA increases distractor interference (e.g., Kelley & Lavie, 2011; Lavie et al., 2004). Indeed, using similar paradigms to the current study, it has been consistently found that older adults show equivalent control abilities to younger adults (e.g., Castel et al., 2002; 2013; Siegel & Castel, 2018a). However, when the cognitive control task involves inhibition (e.g., directed-forgetting paradigm or the value effect paradigm contains negative point values), older adults show deficits in cognitive control relative to younger adults (Castel et al., 2007; Hayes et al., 2013; Zacks et al., 1996). Therefore, it might be more appropriate to view selective encoding and inhibition as two different cognitive abilities rather than one cognitive control ability.

3.6.2 More effective encoding for more valuable information?

Experiment 6 showed that when items were presented sequentially, DA did not impact the value effect in the immediate item-colour binding test, but it abolished the value effect in the delayed test. A possible explanation, as discussed in Experiment 6, is that participants may have used different types of encoding strategies to prioritise high value bindings. The value effect observed in the immediate test is mainly driven by selective encoding for high value items, via maintenance rehearsal and elaborative rehearsal, whereas the value effect observed in the delayed test is mainly driven by the items encoded via elaborative rehearsal. This speculation is based on previous studies which have found that elaborative rehearsal is more robust than maintenance rehearsal in improving LTM (Bower, 1972; Craik & Watkins, 1973; Roenker, 1974; Rundus, 1977; Sachs, 1967), but it is more susceptible than maintenance rehearsal to DA (Schneider & Sodian, 1997). Therefore, DA might have specifically disrupted elaborative rehearsal and abolished the value effect in LTM, but the value effect survived in the immediate test via maintenance rehearsal which is less affected by DA (Baddeley, 1986; Cowan, 2001). These assumptions were further examined in Chapter 4.

It is important to note that the immediate and delayed tests assessed memory from the same initial encoding episodes. An interesting question that follows from this is whether the value effect arises because of selective encoding based on item value (i.e., select to encode more high value items, and use the same encoding strategies for all the selected items), or is it a result of differential strategy application based on item value, or are both processes are engaged? Differential strategy application according to item value is particularly possible in LTM studies because in these studies each item is usually presented for a relatively longer time. Participants can not only decide which information to study but can also decide how to study them. This is supported by behavioural studies (Bui et al., 2013; Hennessee et al., 2019) and fMRI studies (Cohen et al., 2014, 2016) demonstrating that participants encode high value items more deeply. It is also consistent with participants' self-report that they use more effective strategies (e.g., imagery mediators, keyword mediators) when learning high value word pairs (Ariel et al., 2015).

Distinguishing these two types of strategic encoding may help to explain why inconsistent outcomes were observed on the impact of dual tasks on value effects. If the value effect is driven by selective encoding (consistent strategies for all the selected items), a dual task taxing general attentional resources should influence all the items to the same extent, meaning the value effect is retained. If the value effect is driven by differential strategy application for high and low value information, and a) if the dual task influences how high value information is encoded and/or maintained, that will reduce the value effect; b) if the dual task influences how low value information is encoded and/or maintained, that will make the value effect larger. According to this view, Atkinson et al. (2020) found a larger value effect under articulatory suppression in verbal WM domain. The reason might be that participants engage in differential encoding for high and low value items. High value items are kept active through continual refreshing whereas low value items are maintained via verbal rehearsal. When the task is implemented with articulatory suppression, it specifically impaired the encoding for low value items, and the high value items were better retained (Atkinson et al., 2020). As a result, a larger value effect was observed.

Moreover, Siegel et al. (2021) used a similar paradigm to the current study to explore the impact of different types of dual tasks on the value effect on item-location binding memory. It was found that only the dual task (judgement of spatial patterns) that relies on overlapping processing resources with the primary task that attenuated participants' selectivity. However, another possible explanation for this result is that participants' selectivity was not attenuated, rather, the dual task specifically disrupted maintenance for high value item-location bindings, which possibly operates through relational processing/creating patterns among high value items (Siegel & Castel, 2018b).

Future studies should consider the two different mechanisms (i.e., selective but same encoding strategies for high and low value information or differential strategy application for high and low information) in the value effect, and consider the encoding processes that DA specifically disrupts when exploring the mechanisms of value effects.

3.6.3 Longevity of the value effect

The value effect was observed in the delayed test when items were presented sequentially, but not when they were presented simultaneously. In fact, the observed value effect (Cohen's $d = 0.49$, i.e., a medium effect) is relatively small compared with Experiment 1 ($\eta^2_p = 0.47$, i.e., a large effect). There are several possible reasons for the somewhat unstable value effect on LTM. One reason could be that the current study was conducted online, and online participants may have invested less energy and concentration in the task than those involved in a laboratory experiment (Kraut et al., 2004). Thus, they may have been less likely to use attention-demanding elaborative encoding, which might be an important mechanism in the value effect on LTM (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). Online testing may also be less sensitive to the value manipulation, as can be seen from Experiment 4 and Experiment 5 in which no value effect was observed, even though the paradigms (especially Experiment 4) were similar to the paradigm in Experiment 2 (laboratory). While value effects were observed online after several adjustments (Experiment 6 and 7), the possible difference in the sensitivity to the value manipulation may have impaired longevity of the value effect.

Another possible reason is that the total number of items during the encoding phase may have influenced the extent to which participants apply selective encoding and this might have influenced the persistence of the value effect. The current study has eight items in each study-test trial. Participants may have encoded both high and low value items but encoded more high value items. In previous studies which have observed the value effect in LTM (e.g., Ariel et al., 2009; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017), there were 20 or 30 items during the study phase. Participants in these studies may have clearly realised that it is difficult/impossible to remember all the items, so they have largely ignored low value items (Robison & Unsworth, 2017) and primarily encoded high value items. Thus, the current study may have a lower selectivity (ratio of high and low value items participants selected) compared to previous studies and this might have influenced the stability of the value effect in LTM. It would be useful for future studies to explore whether factors such as the total number of study items, the proportion of high and low value items and the subjective judgment of the task difficulty, will influence the extent of implementing selective encoding and influence the longevity of the value effect.

The third possible reason is that the delayed test was a surprise test, and this may have influenced how participants encode and maintain information, which in turn might influence the persistence of the value effect. Previous research indicates that expectation of delayed test (Jacoby, 1973; Shaughnessy, 1981; Shimizu, 1996) and expectation of the test format (free recall, cued recall, recognition; Finley & Benjamin, 2012; Neely & Balota, 1981; Rivers & Dunlosky, 2020) affect participants' encoding strategies. There is some evidence suggesting that participants use more elaborative encoding when the delayed test was expected than unexpected (Jacoby, 1973; Shimizu, 1996; but see Shaughnessy, 1981). In the context of the current study, as the delayed test was a surprise test, participants may have used less effective strategies when prioritising high value bindings, resulting in an unstable/weak value effect in LTM. In addition, there is a body of research showing that people can remove no-longer relevant information from WM (Souza et al., 2014; for a review see Lewis-Peacock et al., 2018). Since participants did not expect the delayed test, they may have removed memory for item-colour bindings in the current trial to free capacity to encode the new bindings in the next trial, making the value effect in LTM unstable.

3.7 Conclusions

The experiments within this chapter indicate that DA during encoding does not impact participant's ability to selectively encode and briefly maintain item-colour bindings based on item value, suggesting selective encoding is flexible and requires little attentional resources. This is consistent with previous findings which have demonstrated that value effects were maintained under DA in various situations, either when the primary task is relatively more attention-demanding (Siegel & Castel, 2018b), when the dual tasks stress attention to different degrees (Middlebrooks et al., 2017), or when the value effect is from the verbal domain (Atkinson et al., 2020). However, DA abolished the value effect in the delayed test within a sequential presentation format. This may suggest that DA disrupted overall memory consolidation, thus reducing persistence of the value effect. Alternatively, DA may have particularly disrupted long-term maintenance for high value information, which might reflect elaborative encoding. Future research is needed to explore these possibilities.

CHAPTER 4

THE ROLE OF STRATEGY TYPE IN THE VALUE EFFECT ON ITEM-COLOUR BINDING MEMORY

4.1 Introduction

Chapter 3 found that DA during encoding did not impair the value effect on item-colour binding memory in the immediate test, but it abolished the value effect in the delayed test when items were presented sequentially. One possible explanation is that the value effects observed in the immediate and the delayed tests might be supported by different mechanisms and that DA may have particularly disrupted the encoding process that are essential for long-term maintenance of high value information. This means participants may have used different types of encoding strategies in a value effect task. The current chapter thus explored what types of encoding strategies might underlie the value effect on item-colour binding memory.

Craik and Lockhart (1972) distinguished two types of rehearsal strategies on the basis of the levels-of-processing framework. Maintenance rehearsal/Type I rehearsal is a type of memory rehearsal that involves repeating information at one level of processing without thinking about its meaning or connecting it to other information. It is thought that maintenance rehearsal merely improves an item's accessibility and does not lead to formation of a more permanent memory trace (Craik & Watkins, 1973; Roenker, 1974; Rundus, 1977). Elaborative rehearsal/Type II rehearsal is hypothesized to involve a "deeper" level of encoding, such as thinking about the meaning of the information and connecting it to other information already stored in memory. It is thought that only elaborative rehearsal should lead to improved long-term memory performance (Craik & Lockhart, 1972). However, some studies indicate that maintenance rehearsal enhances long-term recognition as well, but it does not enhance long-term recall (Glenberg et al., 1977; Woodward Jr et al., 1973). Others have demonstrated that rehearsal does indeed enhance delayed recall (e.g., Dark & Loftus, 1976; Nelson, 1977; Rundus & Atkinson, 1970). While the theoretical interpretation from the levels-of-processing framework may be somewhat incomplete (Baddeley, 1978; Morris et al., 1977; Nelson, 1977), a phenomenon that was robustly observed is that elaborative rehearsal is more effective than maintenance rehearsal in enhancing LTM (e.g., Bower, 1972; Sachs, 1967).

Whether elaborative rehearsal also has a beneficial effect on WM is currently inconclusive. Previous correlational studies have shown a positive relationship between elaborative strategy reporting and verbal WM recall (Bailey, Dunlosky, & Kane, 2008, 2011; Dunlosky & Kane, 2007; Kaakinen & Hyönä, 2007). Conversely, some experimental work has shown that, compared with shallower processing (i.e., colour processing or rhyme processing), deeper semantic processing only benefited LTM but not WM (Loaiza & Camos, 2016; Rose, 2013; Rose et al., 2010). These latter results are consistent with more recent studies which have directly compared the influence of different types of rehearsal on WM and LTM (Bartsch et al., 2019; Bartsch et al., 2018). It was found that while sub-vocal rehearsal and elaborative rehearsal improved WM relative to a baseline condition (i.e., without instructed processing), the beneficial effect from elaborative rehearsal, relative to sub-vocal rehearsal, only emerged on LTM but not on WM. Other work suggests that the extent to which deep encoding benefits WM depends on the amount of retrieval from LTM (Rose et al., 2014; 2015). They revealed that the beneficial effect from deep encoding on WM was observed when the active maintenance process (i.e., the maintenance phase after encoding) for the to-be-remembered items was interrupted by an unrelated maths task, but not when the maintenance process was uninterrupted. The authors argued that in the WM test without interruption, the to-be-remembered items were retrieved directly from the FoA and accessing it did not involve retrieval from LTM. Thus, the beneficial effect from deep encoding was not observed. However, an unrelated task disrupted maintenance processes in the FoA and encouraged retrieval from LTM. Therefore, the beneficial effect from deep encoding emerged on WM. To summarise, experimental evidence suggest that maintenance rehearsal has a comparable effect to elaborative rehearsal on WM when information can be retrieved directly from the FoA, and that the advantage from elaborative rehearsal becomes more evident in LTM.

Except for the difference in long-term maintenance of information, maintenance and elaborative rehearsal also differ in the ease with which they can be implemented. Maintenance rehearsal is generally assumed to be a cost-free process. It requires little, if any cognitive resources (Baddeley, 1986; Cowan, 2001). Indeed, prior research indicate that recoding visual input into a phonologically based verbal form is a default, perhaps sometimes even obligatory, tendency (Forsberg et al., 2020; Lewis-Peacock et al., 2015; Postle et al., 2005; Shulman, 1971; Simons, 1996). Elaborative rehearsal, however, is a more complex and demanding process (Schneider & Sodian, 1997). For example, older adults, generally suffering from decline in cognitive resources, typically have difficulty in engaging elaborate and effortful encoding strategies (Salthouse, 1991, 1996).

Research into the encoding strategies underlying the value effect is limited, but there is some evidence suggesting that high value items are engaged with via elaborative encoding, such as sentence generation, mental imagery or relational processing (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). For example, Bui et al. (2013) used a modified form of the Deese-Roediger-McDermott (DRM) paradigm in which participants studied lists with semantically related words (e.g., nurse, hospital, etc.). Each list was paired with low, medium, or high point values. After a delay, subjects were asked to do a recognition test, in which some lure words (related but never presented words, e.g., doctor) were presented. The results revealed that better memory for high value words was accompanied by more false memories than lower values words, possibly because prioritizing information enhanced relational processing among high value words. In addition, disrupting relational processing selectively reduced false memories for high value words, and facilitating relational processing selectively increased false memories for low value words. These results suggest that the mechanism underlying the value effects depends on the ability to successfully engage in relational processing (Bui et al., 2013).

Other evidence supporting this idea comes from value effect studies using the Remember/Know (R/K) paradigm (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018). Previous research distinguished two types of memory; remembering and knowing (e.g., Gardiner, 1988; Tulving, 1985; Yonelinas, 2002). Remembering involves being able to consciously recollect a previous experience or event, typically including the memory of various details related with this episode. In contrast, knowing involves recognizing information without consciously recollecting related details, which is most often described as a feeling of familiarity. Though remembering and knowing are two types of process during retrieval, studies suggest that they are influenced by the type of rehearsal during encoding. Maintenance rehearsal affects knowing but not remembering, and elaborative rehearsal affects remembering but not knowing (Gardiner, 1988; Gardiner et al., 1994). According to this view, the value effects consistently observed on R responses but inconsistently on K responses (Cohen et al., 2017; Elliott, Blais, et al., 2020; Elliott & Brewer, 2019; Elliott, McClure, et al., 2020; Hennessee et al., 2017; 2018) may suggest that high value encourages deeper elaborative encoding (Hennessee et al., 2017).

These findings are consistent with participants' self-report that they use more effective strategies (i.e., imagery mediators, keyword mediators, sentence generation, or relational processing) when learning high value word pairs (Ariel et al., 2015). In addition, fMRI studies revealed that greater selectivity scores (i.e., the degree to which participants optimize their point score) were associated with greater differences in the activation of semantic processing brain regions (e.g., left inferior frontal gyrus and left posterior lateral temporal cortex) during the encoding of high value words relative to low value words, suggesting that elaborative semantic processing may be an important mechanism for encoding valuable items (Cohen et al., 2014, 2016).

The current study aimed to explore strategy use in the value effect on memory for item-colour bindings. How might we measure the strategies participants use? There are two main methods from the literature. The first one is by subjective reports (Bailey et al., 2009; Bailey et al., 2008, 2011; Dunlosky & Hertzog, 1998; Dunlosky & Kane, 2007; Kuhlmann & Touron, 2012; Paivio & Yuille, 1969; Richardson, 1998; Rowe &

Schnore, 1971), either concurrently with study or retrospectively after the experimental task. For concurrent reports, participants need to designate the strategies they have used from one of several response categories (e.g., imagery, sentence generation, rote repetition, some other strategy, or no strategy) immediately after an item/a trial has been studied (e.g., Dunlosky & Hertzog, 1998; Paivio & Yuille, 1969; Rowe & Schnore, 1971). This method is relatively accurate in measuring the strategy use during the encoding phase because participants may have remembered how they encoded each item due to the minimal time between encoding and strategy report. However, a concern about concurrent report is that the strategy reports themselves may alter the strategies that participants use (Dunlosky & Hertzog, 2001). One way to solve this problem is to use retrospective reports, in which the strategy reports were placed at the end of the experimental task (e.g., Ariel et al., 2015; Rowe & Schnore, 1971). Nevertheless, a main concern about retrospective reporting is that it may result in inaccurate estimates of strategy use. For example, participants may forget how they encoded many of the items, they may draw on beliefs about how they should have performed the task, or they may remember how they encoded a few items and generalize these particular instances to the remaining items (Dunlosky & Hertzog, 2001; Dunlosky & Kane, 2007).

The second way of assessing strategy use during the encoding phase is by instructing participants to use single strategies and compare them to a baseline condition (Bartsch et al., 2018; Blumenfeld & Ranganath, 2006; Naveh-Benjamin & Jonides, 1984; Thalmann et al., 2019). For example, Hennessee et al. (2019, Experiment 2) have used this methodology and examined the contribution of different encoding strategies in the value effect on item recognition. Participants studied a list of words with different point-values. They were either given no instruction regarding what strategy to use or were instructed to use a rote rehearsal strategy or a mental imagery strategy for all learned items. There were significant effects of value when no strategy instruction was given or when items were studied under rote rehearsal. However, effects of value were nearly eliminated when participants used a mental imagery strategy. The authors argued that the differences in memory performance between high and low value items was due in part to differences in elaborative encoding, as instructing participants to encode all the items with a mental imagery strategy boosted memory for low value items, and thus, substantially reduced the value effect.

The current chapter adopted the strategy instruction method to explore the types of encoding strategies driving the value effect on item-colour binding memory. Two experiments were conducted by using the paradigms developed from Experiment 6 and Experiment 7, which were adapted from prior studies in the literature (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021). Participants were presented with a series of coloured images, either simultaneously in Experiment 8 or sequentially in Experiment 9. Each item was paired with a point value they could earn in a later colour memory test. The goal was to maximize the point score. Participants were instructed either to use verbal rehearsal to remember the item and its colour, to build an association between each item and its colour, or received no specific strategy instruction. Immediate colour memory, delayed colour memory and delayed location memory were tested in each case.

According to the results observed in Experiment 6 and 7, it was expected to see the value effect in the no-instruction condition, especially in the immediate colour memory test. Several assumptions were adopted regarding the different strategy conditions and possible patterns of performance: 1). It is assumed that the no-instruction condition gives a view of what participants normally do, possibly with various encoding strategies being implemented (e.g., Ariel et al., 2015); 2). It is also assumed that if a strategy condition produces outcomes that resemble the no-instruction condition, in terms of overall performance levels, and value effects, this indicates this instructed strategy to be the predominant strategy underlying the value effect under non-instructed conditions; 3) If a strategy condition improves or decreases overall performance relative to the no-instruction condition, this suggests it is not the dominant approach normally adopted by participants; 4) If a strategy condition changes the value effect (i.e., an interaction between value and strategy is observed), this indicates this is not how participants strategically approach high and low value items under non-instructed conditions. Outcomes from these experiments might not only help uncover the strategies driving the value effect, but also are likely to have practical insights about how different types of strategies (maintenance rehearsal vs. elaborative rehearsal) might influence and interact with selective encoding to boost memory.

4.2 Experiment 8

Experiment 8 adopted a similar paradigm to Experiment 7. Item were presented simultaneously and participants in each study block received different encoding strategies regarding how to remember an item and its colour (i.e., no instruction, verbal rehearsal, association), with the goal of maximizing the point score. It was aimed to see to what extent verbal rehearsal and elaborative rehearsal resembles the no-instruction condition, in terms of both overall memory performance and the value effect.

4.2.1 Method

4.2.1.1 Design

The experiment used a 2 (value: high, low) × 3 (strategy: no instruction, verbal rehearsal, association) within-subject design. Different strategy instructions were implemented in three separated blocks. The no-instruction condition was always conducted first to avoid possible influences from other conditions. The order of the other two conditions were counterbalanced across participants. In each block, half of the words were paired with high values and the other half were paired with low values. Dependent variables were immediate item-colour memory, delayed item-colour memory and delayed item-location memory.

4.2.1.2 Participants

The participants in Experiment 8 were 29 students (19 females; mean age = 21.1 years; range = 20-23 years) from University of Leeds. All participants reported having correct or corrected-to-normal vision and were without colour-vision deficits. None reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds Psychology Ethics Committee (Ethics number: PSYC-111, Date of ethics approval: 19/10/2020).

4.2.1.3 Materials and procedure

The materials and procedure were similar to that used in Experiment 7, with the following exceptions. Five further study trials (40 items) were added to the paradigm such that there were three study-immediate test blocks. Participants were instructed to use different strategies in different blocks, with the goal of maximizing their point-score. In the no-instruction condition, participants did not receive any specific strategy instruction. In the verbal rehearsal condition, participants were instructed to only use verbal rehearsal to remember an item and its colour (e.g., say “grey shoe, grey shoe” out loud). In the association condition, participants were asked to associate an item with its colour (e.g., grey shoe - I imagined the shoe walking on the street and the street is grey). In the verbal rehearsal and association conditions, following the point score feedback, participants were asked to indicate to what extent they adhered to the instructed strategy. They gave their responses through a slider bar ranging from 0 to 100, and then were reminded to only use the instructed strategy in the current study block.

4.2.2 Results

4.2.2.1 Self-reported strategy usage

One participant’s strategy use reports for both verbal rehearsal and elaborative rehearsal were three standard deviations (SD) below the mean. Removing this data did not change the memory performance or the value effects significantly. Therefore, data analyses were based on all the collected data. Paired samples t-test revealed that verbal rehearsal strategy (M = 92.65, SE = 2.60) was more successfully adopted than elaborative rehearsal strategy (M = 85.33, SE = 3.76), $t(28) = 2.37$, $p < .05$, $d = 0.44$, $BF_{10} = 2.14$, although this was weakly supported by BF analysis. These results suggest that participants followed the instructions properly, and verbal rehearsal was used well than elaborative rehearsal, possibly because verbal rehearsal is easier than elaborative rehearsal to be implemented (Baddeley, 1986; Cowan, 2001; Schneider & Sodian, 1997).

4.2.2.2 Immediate colour memory

Immediate colour memory, delayed colour memory and delayed location memory as a function of value and strategy are displayed in Figure 4.1. A 2 (value: high, low) × 3 (strategy: no instruction, verbal rehearsal, association) repeated measures ANOVA was conducted on immediate colour memory. There was a main effect of value [$F(1, 28) = 6.68$, $p < .05$, $\eta^2_p = 0.19$, $BF_{10} = 316.36$], whereby memory for high value items (*MMs* = 0.81 , *SE* = 0.03) was better than that for low value items (*MMs* = 0.73 , *SE* = 0.03). There was also a main effect of strategy [$F(2, 56) = 14.43$, $p < .001$, $\eta^2_p = 0.34$, $BF_{10} = 834.22$]. Post hoc analysis (Holm) revealed that memory in the association condition (*MMs* = 0.83, *SE* = 0.03) was better than that in the no-instruction condition [*MMs* = 0.77, *SE* = 0.03, $t = 2.83$, $p < .05$, Cohen's $d = 0.53$, $BF_{10} = 11.83$] and verbal rehearsal condition [*MMs* = 0.71, *SE* = 0.03, $t = 5.37$, $p < .001$, $d = 1.00$, $BF_{10} > 1000$]; memory in the no-instruction condition was better than that in the verbal rehearsal condition [$t = 2.54$, $p < .05$, $d = 0.47$, $BF_{10} = 7.76$]. The interaction between value and strategy was not significant [$F(2, 56) = 0.07$, $p = .93$, $\eta^2_p = 0.003$, $BF_{10} = 0.11$]. These outcomes were corroborated by BF analysis. It revealed that the most likely model included a main effect of value and a main effect of strategy ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

4.2.2.3 Delayed colour memory

A 2 × 3 repeated measures ANOVA revealed a significant effect of value [$F(1, 28) = 4.78$, $p < .05$, $\eta^2_p = 0.15$, $BF_{10} = 1.94$], such that colour memory was better for high value items (*MMs* = 0.59 , *SE* = 0.05) than low value items (*MMs* = 0.52 , *SE* = 0.05), though with relatively weak BF support. There was also a main effect of strategy [*F*(2, 56) = 16.77, $p < .001$, $\eta^2_p = 0.38$, $BF_{10} > 1000$]. Post hoc analysis (Holm) indicated that memory in the association condition (*MMs* = 0.70 , *SE* = 0.05) was better than memory in the no-instruction condition [*MMs* = 0.48 , *SE* = 0.05, $t = 5.02$, $p < .001$, $d = 0.93$, $BF_{10} > 1000$] and verbal rehearsal condition [*MMs* = 0.48 , *SE* = 0.05, $t = 5.02$, $p < .001$, $d = 0.93$, $BF_{10} > 1000$]; the difference between no-instruction condition and verbal rehearsal condition was not significant [$t = 0.00$, $p = 1.00$, $d = 0.00$, $BF_{10} = 0.14$]. There was no interaction between value and strategy [*F*(2, 56) = 0.66, $p = .52$, $\eta^2_p = 0.02$, $BF_{10} = 0.14$]. These results were supported by BF analysis, which showed that the most likely model included a main effect of value and a main effect of strategy ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

4.2.2.4 Delayed location memory

A 2 × 3 repeated measures ANOVA was conducted on delayed location memory. A significant effect of value was found [*F*(1, 28) = 7.43, $p < .05$, $\eta^2_p = 0.21$, $BF_{10} = 5.77$], with better colour memory for high value items (*MMs* = 0.23 , *SE* = 0.03) than low value items (*MMs* = 0.16 , *SE* = 0.03). The effect of strategy was not significant [Greenhouse-Geisser, *F*(1.58, 44.19) = 0.88, $p = .40$, $\eta^2_p = 0.03$, $BF_{10} = 0.13$]. However, there was a significant interaction between value and strategy [*F*(2, 56) = 5.18, $p < .01$, $\eta^2_p = 0.16$, $BF_{10} = 4.10$]. Paired samples t-tests indicated that memory for location of high value items was better than that of low value items in the no-instruction condition [*t*(28) = 2.39, $p < .05$, $d = 0.44$, $BF_{10} = 2.20$] and verbal rehearsal condition [*t*(28) = 3.10, $p < .01$, $d = 0.58$, $BF_{10} = 9.22$], but no difference was found in the association condition [$t(28) = -1.15$, $p = 0.26$, $d = -0.21$, $BF_{10} = 0.36$]. BF analysis showed that the most likely model included a main effect of value ($BF_{10} = 5.72$ relative to the null model with random effects of participant only).

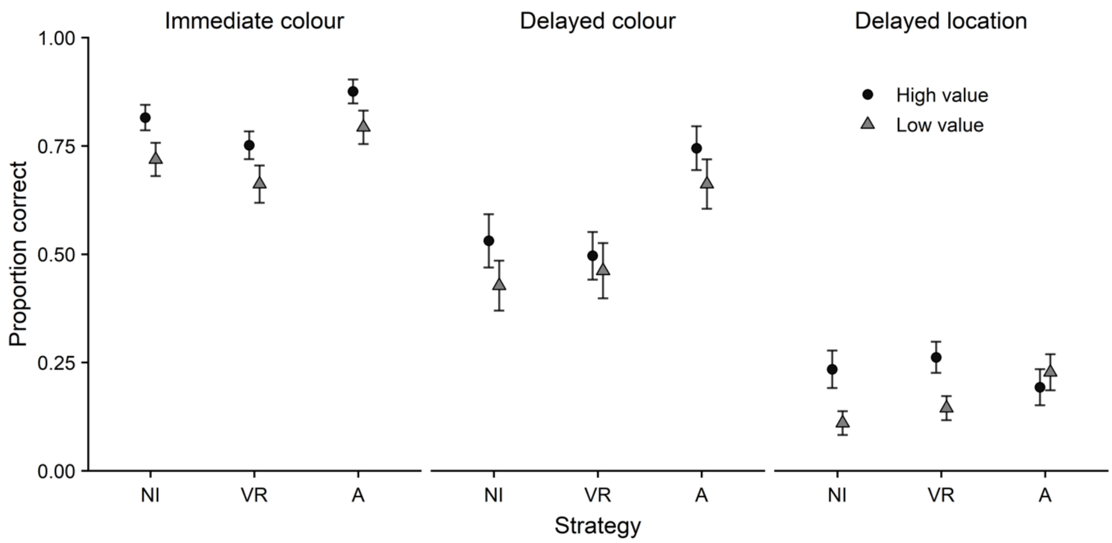

Figure 4. 1 Immediate colour memory, delayed colour memory and delayed location memory as a function of value and strategy in Experiment 8 using simultaneous presentation. Error bars represent one standard error of the mean. NI: no instruction; VR: verbal rehearsal; A: association.

4.2.3 Discussion

Experiment 8 explored the possible types of encoding strategies that might underlie the value effect on item-colour binding memory in a simultaneous presentation format. This was implemented by comparing to what extent maintenance rehearsal and elaborative rehearsal resemble the no-instruction condition in terms of the value effect and the overall memory performance. Regarding the value effect, it was consistently found in all the strategy conditions, in both the immediate and the delayed colour memory tests. There was no interaction between value and strategy, suggesting participants were able to apply these strategies based on item value to the same extent. These results imply that maintenance rehearsal and elaborative rehearsal are both possible strategies that could drive the value effect.

In terms of overall performance, memory accuracy in the association condition was superior to the other two conditions across the immediate and the delayed tests. Accuracy in the no-instruction condition was higher than that in the verbal rehearsal condition in the immediate test, but this advantage did not persist to the delayed test. These results indicate that the strategies participants normally use fall in between maintenance rehearsal and elaborative rehearsal in terms of short-term retention, and are equivalent to maintenance rehearsal in terms of long-term retention. One possibility could be that participants may have used both types of rehearsal when prioritising more valuable bindings, with maintenance rehearsal perhaps being the primary strategy.

Maintenance rehearsal being the primary strategy is also supported by the results from location memory. Memory for location of items was superior for high than low value items in the no-instruction and verbal rehearsal conditions, but not in the association condition. This might be driven by how participants approached high value information. Maintenance rehearsal involves repetition of information (Craik & Lockhart, 1972). Participants in the verbal rehearsal condition (a type of maintenance rehearsal) may have restudied high value items more times than low value items. This may have resulted in more eye movements and/or created spatial patterns among high value items, and thus enhanced location memory (Awh & Jonides, 2001; Baddeley, 1986; Lilienthal et al., 2014; Taylor et al., 2014; Tremblay et al., 2006). Elaborative rehearsal, in contrast, involves deeper semantic encoding (Craik & Lockhart, 1972). Participants in the association condition may have spent longer time on individual high value items but not necessarily more eye movements among them. Therefore, no effect of value on location memory was observed. The similar pattern of value effects between no-instruction and verbal rehearsal conditions suggests that maintenance rehearsal is possibly the main strategy participants normally use when selectively remembering more valuable item-colour bindings. It should be noted, however, that location memory performance was low, likely due to the incidental encoding nature for this dimension.

Taken together, the current experiment indicates that both maintenance rehearsal and elaborative rehearsal are possibly involved in the value effect on item-colour binding memory, with maintenance rehearsal perhaps being the primary strategy that is implemented. Experiment 8 adopted a simultaneous presentation format, in which participants can flexibly direct their attention towards more valuable information and apply encoding strategies more selectively. In Experiment 9, we were interested in whether participants could also strategically apply different strategies based on item value when the flexibility of directing attention was relatively restricted by using a sequential presentation format.

4.3 Experiment 9

The aims of Experiment 9 were to examine whether participants can strategically apply different types of encoding strategies (i.e., verbal rehearsal vs. elaborative rehearsal) based on item value when items were presented sequentially, and to what extent these strategies resemble the no-strategy-instruction condition in terms of overall memory performance and the value effect. The paradigm was identical to Experiment 8 except the presentation format. The presentation format was the same as that in Experiment 6, in which items were sequentially presented in different locations.

4.3.1 Method

4.3.1.1 Design

Experiment 9 implemented a 2 (value: high, low) × 3 (strategy: no instruction, verbal rehearsal, association) within-subject design. The dependent variables were immediate item-colour memory, delayed item-colour memory and delayed item-location memory. Counterbalancing and order of conditions was implemented as in Experiment 8.

4.3.1.2 Participants

The participants in Experiment 9 were 29 students (25 females; mean age = 19.1 years; range = 18-22 years) from University of Leeds. They had normal or corrected-to-normal vision and normal colour vision. No one reported a history of neurological disorders. Informed consent was acquired in accordance with the guidelines set by the University of Leeds's Psychology Ethics Committee (Ethics number: PSYC-111, Date of ethics approval: 19/10/2020).

4.3.1.3 Materials and Procedure

The procedure was basically the same as Experiment 8, except for the presentation format during the encoding phase. Instead of showing eight items concurrently for a total of 24s, in Experiment 9, the items were presented sequentially in different locations within a 5 × 5 grid, each for 3s (same presentation format used in Experiment 6).

4.3.2 Results

4.3.2.1 Self-reported strategy usage

One participant's verbal rehearsal strategy report was three SD below the mean.

Removing this data did not change the memory performance or the value effects significantly. Thus, all the collected data were included in the analyses. Paired samples t-test revealed that verbal rehearsal strategy (*M* = 93.90, *SE* = 1.70) was more successfully adopted than elaborative rehearsal strategy (*M* = 86.66, *SE* = 3.06), $t(28) = 2.12$, $p < .05$, $d = 0.39$, $BF_{10} = 1.36$. BF analysis revealed weak evidence to support this. These results are consistent with Experiment 8 and indicate that participants followed the instructions properly.

4.3.2.2 Immediate colour memory

Immediate colour memory, delayed colour memory and delayed location memory as a function of value and strategy are displayed in Figure 4.2. A 2 (value: high, low) × 3 (strategy: no instruction, verbal rehearsal, association) repeated measures ANOVA was conducted on immediate colour memory. This revealed a main effect of value [$F(1, 28) = 7.13$, $p < .05$, $\eta^2_p = 0.20$, $BF_{10} = 27.96$], whereby memory for high value items (*MMs* = 0.76 , *SE* = 0.03) was better than memory for low value items (*MMs* = 0.69 , *SE* = 0.03). It also revealed a main effect of strategy [$F(2, 56) = 11.17$, $p < .001$, $\eta^2_p = 0.29$, $BF_{10} > 1000$]. Post hoc analysis (Holm) revealed that memory in the association condition (*MMs* = 0.80 , *SE* = 0.03) was better than memory in the no-instruction condition [*MMs* = 0.68 , *SE* = 0.03, $t = 4.34$, $p < .001$, $d = 0.81$, $BF_{10} = 837.53$] and verbal rehearsal condition [*MMs* = 0.69 , *SE* = 0.03, $t = 3.79$, $p < .001$, $d = 0.70$, $BF_{10} = 413.26$]; no difference was found between no-instruction and verbal rehearsal conditions [$t = -0.56$, $p = .58$, $d = -0.10$, $BF_{10} = 0.19$]. There was also an interaction between value and strategy although BF provided little evidence to support this [*F*(2,

56) = 0.07, $p < .05$, $\eta^2_p = 0.15$, $BF_{10} = 0.64$]. Paired samples t-tests showed that colour memory for high value items was better than low value items in the no-instruction condition [$t(28) = 2.68$, $p < .05$, $d = 0.50$, $BF_{10} = 3.89$] and verbal rehearsal condition [$t(28) = 3.22$, $p < .01$, $d = 0.60$, $BF_{10} = 12.04$], but no difference was observed in the association condition [$t(28) = 0.27$, $p = 0.79$, $d = 0.05$, $BF_{10} = 0.20$]. BF analysis showed that the most likely model included a main effect of value and a main effect of strategy ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

4.3.2.3 Delayed colour memory

A 2 × 3 repeated measures ANOVA revealed that the main effect of value was marginally non-significant [$F(1, 28) = 3.95$, $p = .057$, $\eta^2_p = 0.12$, $BF_{10} = 0.37$], with a trend that colour memory for high value items (*MMs* = 0.55 , *SE* = 0.04) was better than that for low value items (*MMs* = 0.51 , *SE* = 0.04). There was a main effect of strategy [$F(2, 56) = 14.52$, $p < .001$, $\eta^2_p = 0.34$, $BF_{10} > 1000$]. Post hoc analysis (Holm) indicated that memory in the association condition (*MMs* = 0.67 , *SE* = 0.05) was better than memory in the no-instruction condition [*MMs* = 0.39 , *SE* = 0.05, $t = 5.39$, $p < .001$, $d = 1.00$, $BF_{10} > 1000$] and verbal rehearsal condition [*MMs* = 0.53 , *SE* = 0.05, $t = 2.66$, $p < .05$, $d = 0.49$, $BF_{10} = 3.24$]; memory in the verbal rehearsal condition was better than that in the no-instruction condition [$t = 2.73$, $p < .05$, $d = 0.51$, $BF_{10} = 8.15$]. The interaction between value and strategy was not significant [$F(2, 56) = 0.34$, $p = .71$, $\eta^2_p = 0.01$, $BF_{10} = 0.13$]. BF analysis showed that the most likely model included a main effect of strategy ($BF_{10} > 1000$ relative to the null model with random effects of participant only).

4.3.2.4 Delayed location memory

A 2 × 3 repeated measures ANOVA was conducted on the delayed location memory. No significant effect was observed (*ps* ≥ 0.14). This outcome was supported by BF analysis, which showed that no model was better than the null model (with random effects of participant only).

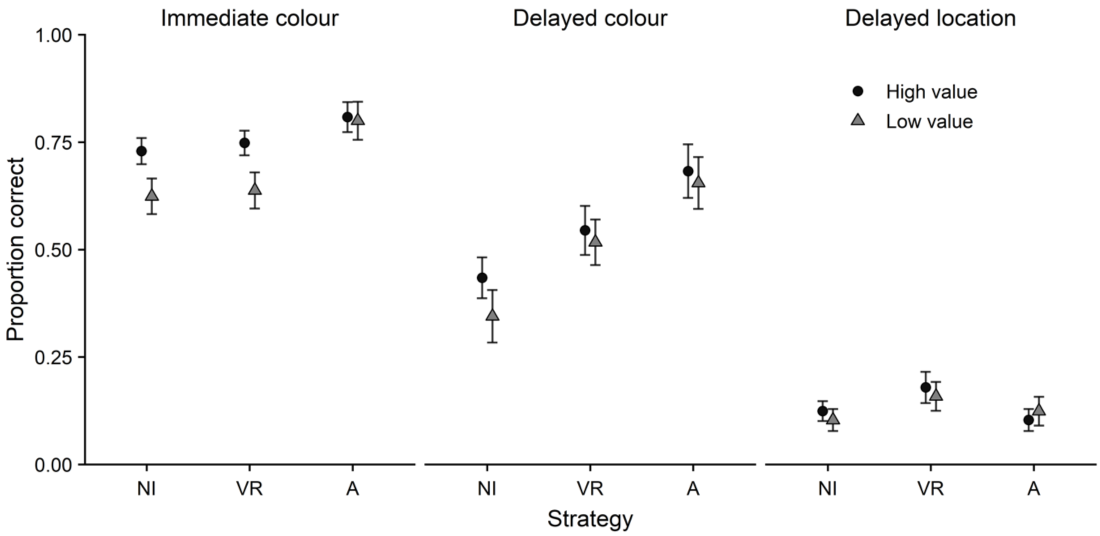

Figure 4. 2 Immediate colour memory, delayed colour memory and delayed location memory as a function of value and strategy in Experiment 9 using sequential presentation (different locations). Error bars represent one standard error of the mean. NI: no instruction; VR: verbal rehearsal; A: association.

4.3.3 Discussion

Experiment 9 explored the types of encoding strategies that may be driving the value effect on item-colour binding memory in a sequential presentation format. In the immediate colour memory test, when participants received no specific strategy instruction, the value effect emerged, with higher memory accuracy for high than low value items. This replicated the findings observed in Experiment 6 in which the same sequential presentation format was adopted, and in Experiments 7 and 8 using the simultaneous presentation. The value effect was also observed when participants were instructed to use a maintenance rehearsal strategy, but no such effect was observed with instructed elaborative rehearsal. In other words, participants selectively encoded more valuable bindings using maintenance rehearsal whereas they encoded the bindings regardless of item value using elaborative rehearsal. This finding suggests that value effect on item-colour binding memory is probably primarily driven by maintenance rehearsal when the participant is free to approach the task in any way they choose. In the delayed colour memory test, no effect of value was observed in any strategy condition, suggesting the value effect observed in the sequential presentation format is short-lived.

Why might elaborative rehearsal have abolished the value effect? One possible reason is that elaborative rehearsal is so effective that it can significantly improve memory thus making selective encoding less necessary. The need to be selective when encoding information is usually under a situation where it is impossible to process and remember all of it due to our limited-capacity memory and attentional systems (Cowan, 1988; Oberauer & Hein, 2012). Maintenance rehearsal might not be effective enough to help participants remember all the eight item-colour bindings implemented in the current experiment. To achieve a high score, it is useful to selectively encode more valuable bindings. In contrast, elaboration is effective in boosting memory. Participants may feel more confident of remembering all the eight bindings using this strategy and thus encoded the bindings regardless of item value. As a result, no effect of value was observed. It would be useful for future research to directly manipulate the length of the study list to explore whether it will influence the extent of selective encoding, and how the strategy type might play a part in it.

In terms of overall memory performance, elaborative rehearsal was more effective than verbal rehearsal and no-strategy-instruction in enhancing item-colour binding memory, especially in the delayed test. Verbal rehearsal did not differ from no-strategy-instruction in the immediate test, but it was superior in the delayed test. These results indicate that the strategy participants normally use might be a type of maintenance rehearsal which is equivalent to verbal rehearsal in terms of short-term retention but less effective than it in long-term retention. One possibility could be subvocal rehearsal. Although previous laboratory studies indicate that silent rehearsal is better than overt rehearsal in enhancing LTM (Fischler et al., 1970; Kaernbach & Schlemmer, 2008; Madigan, 1973), possibly because of the various effective strategies participants could use to facilitate learning in the silent condition (Fischler et al., 1970), caution should be taken when generalising these findings to the online studies. When participants were free to approach the task in the current online experiment, they might be less likely to actively adopt effective strategies to enhance memory, because previous studies indicate that online participants may investigate less concentration and energy than those involved in a laboratory experiment (Finley & Penningroth, 2015; Kraut et al., 2004). In contrast, when they were instructed to read each item and its colour out loud, this may have improved their engagement and concentration in the current online task, and thus enhanced LTM. Future studies should systematically explore whether study environment (online vs. laboratory) would mediate the effect of rehearsal (overt vs. covert) on LTM. Such findings would improve understanding of the mechanisms of the value effect on item-colour binding memory.

Taken together, results from Experiment 9 indicate that participant normally use maintenance rehearsal when selectively encoding item-colour bindings based on item value, although the type of maintenance rehearsal is still unclear.

4.4 General discussion

In two experiments, the current chapter explored the possible types of encoding strategies (i.e., maintenance rehearsal, elaborative rehearsal) underlying the value effect on item-colour binding memory. When participants received no specific strategy instruction, the value effect was observed, replicated the findings found in Chapter 3 (Experiment 6 and 7, with full attention). More of interest was to what extent maintenance rehearsal and elaborative rehearsal resemble the no-instruction condition, in terms of the value effect and the overall memory performance. It was found that participants were able to selectively encode more valuable item-colour bindings using a verbal rehearsal strategy to the same extent as the no-instruction condition, either with simultaneous presentation (Experiment 8) or with sequential presentation (Experiment 9). However, when using an elaborative rehearsal strategy, they selectively encoded high value bindings when items were presented simultaneously, but encoded item-colour bindings regardless of value when items were presented sequentially. In addition, overall memory performance in the no-instruction condition was more similar to performance in the verbal rehearsal condition than the elaborative rehearsal condition. Elaborative rehearsal was consistently found to be the most effective strategy than the other two conditions in boosting memory, especially in the delayed test. Furthermore, when items were presented simultaneously, memory for location of items in the delayed test was better for high than low value items in the no-instruction and verbal rehearsal conditions, but not in the elaborative encoding condition. Together, based on the relative differences between the no-instruction condition and each of the instructed strategy conditions, these results indicate that maintenance rehearsal is normally the primary encoding strategy underlying the value effect on item-colour binding memory.

Previous studies indicate that participants use more effective strategies when encoding high value information (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). However, the current study indicates that maintenance rehearsal is probably the dominant strategy underlying the value effect. One possible reason for the inconsistent findings is that prior work investigated the value effect on item memory (mostly using words) while the current study focused on item-colour binding memory. It is relatively easy to encode words elaboratively in various ways, such as constructing a mental image of the word (e.g., Lutz & Lutz, 1978; MacInnis & Price, 1987), relating it with self (e.g., Klein & Kihlstrom, 1986; Symons & Johnson, 1997), organizing related words together (e.g., Lange et al., 2011; Melkman et al., 1981; Tulving, 1962), and generalizing a sentence using several words (e.g., Ariel et al., 2015; Dunlosky & Hertzog, 1998). When the information differs in importance, participants could selectively study high value information and apply these strategies. Nevertheless, it might be difficult to spontaneously apply these strategies to memory for item-colour bindings because these strategies rely upon processing of semantic relationships, and the semantic relationship between an item and a colour might be limited and less apparent relative to that between two items. A more intuitive way of encoding item-colour bindings might be to attentionally refresh an item in its original colour or/and verbally rehearse the item and its colour (Atkinson et al., 2018; Hitch et al., 2018; Hitch et al., 2020; Hu et al., 2014; 2016; Sandry et al., 2014). Therefore, participants may primarily use these maintenance rehearsal strategies when selectively encoding high value item-colour bindings.

Other work on the effect of value on associative memory also suggest little contribution from elaborative encoding. For example, Siegel and Castel (2018a) used a similar paradigm to the current study and tested participants' memory for item-location bindings. It was found that both younger and older adults had a better visuospatial memory for high value items than low value items. The authors argued that the underlying mechanism is less likely due to elaborative encoding as this may be difficult, or even impossible to elaborately rehearse the visuospatial associations. For instance, how would participants elaboratively rehearse that the kettle is at the intersection of the first row and the second column (Siegel & Castel, 2018a)? Similarly, the value effect was also observed on memory for face-name bindings (Festini et al., 2013; Hargis & Castel, 2017). This might be less likely driven by elaborative encoding for high value bindings because names are usually meaningless and lack semantic associations (e.g., Cohen, 1990; McCluney & Krauter, 1997; Terry, 1994).

The maintenance rehearsal mechanism is in line with previous WM studies on the value effect. It has been found that participants can prioritise high value information in WM, including memory for words (Sandry et al., 2020), shapes (Sandry & Ricker, 2020), shape-colour bindings (Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016) and verbal stimuli (Atkinson et al., 2020; Sandry et al., 2014). An important mechanism that has been raised is that participants prioritise high value information through attentional refreshing (Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014). While attentional refreshing and verbal rehearsal bear some similarity in terms of being types of maintenance rehearsal, it should be noted that they are two independent processes. Verbal rehearsal relies on the overt or covert vocalization of information via phonological loop (Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Baddeley et al., 1975). Attentional refreshing relies on refreshing of the memory traces through attentional focusing (Barrouillet et al., 2004; Barrouillet & Camos, 2001, 2007; Cowan, 1999; Johnson, 1992). Whether the value effect on item-colour binding memory observed in this thesis is driven by subvocal rehearsal or attentional refreshing or both are involved is in fact unclear. To disentangle these two processes, future studies could ask participants to do an articulatory suppression task while performing the memory task (e.g., Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry et al., 2014). If articulatory suppression abolished the value effect, this would suggest verbal rehearsal to be the primary strategy; if the value effect remained under articulatory suppression, attentional refreshing may be more important.

The current study also found that elaborative encoding is highly effective in enhancing memory for item-colour bindings more generally, particularly in the delayed test. This is in line with classic work showing that elaborative encoding is robust in boosting LTM (e.g., Bower, 1970; Craik & Tulving, 1975; Gobet et al., 2001; Hyde & Jenkins, 1969; Katona, 1940; Paivio & Yuille, 1969), and also in line with more recent work demonstrating that the memory improvement from elaborative encoding is more apparent in LTM relative to WM (Bartsch et al., 2019; Bartsch et al., 2018; Loaiza & Camos, 2016; Rose, 2013; Rose et al., 2010). A seeming inconsistency with those more recent studies is that they found no WM improvement with elaborative encoding, while the current study observed a memory improvement from elaborative encoding in the immediate test. This is probably because that the immediate test in the current study may include both a WM and a LTM component. WM has a limited capacity of approximately three to five items (Cowan, 2001, 2010; Luck & Vogel, 2013; Todd & Marois, 2004), whereas the current study included eight items. Therefore, in the immediate test, some of items might have been maintained in WM while others might have entered into LTM.

Elaborative encoding was so effective that it abolished the value effect on item-colour binding memory when items were presented sequentially. This has also been found in a previous study in which participants were instructed to use mental imagery or sentence generation to study words, with the result that value effects were eliminated/nearly eliminated (Hennessee et al., 2019). A possible reason for these findings could be that elaboration strategies could substantially improve immediate and long-term memory, thus making selective encoding less necessary. This is possible in the current study where there were only eight study items in each study-test trial. Participants may have abandoned selective encoding and encoded all the bindings using this effective strategy. However, in Hennessee et al. (2019)'s study, there were 48 study words. It might be difficult to remember all the words, even with elaboration. In that case, abandoning selective encoding is an unwise option in maximizing one's score, suggesting it might not be the cause of the elimination of value effects. This is supported by the results from Experiment 8 in which items were presented simultaneously. If elaboration strategies have decreased the necessity of being selective, no effect of value should be observed in Experiment 8 following the elaboration strategy. However, the value effect emerged.

Another possibility could be that the sequential presentation format may have limited participants' ability to selectively encode items. Prioritisation of high value information in that case might have been achieved through more active encoding. For example, in the current study, participants may have verbally/subvocally repeated or attentionally refreshed high value item-colour bindings more frequently relative to low value bindings (no-instruction and verbal rehearsal conditions), and may have been more active in creating associations between an item and its colour for high value bindings (association condition). As a result, memory for high value bindings was improved. However, elaborative encoding was so effective that it may have obscured the difference from degree of encoding and therefore, abolished the value effect.

Why elaborative encoding abolished value effects in a sequential presentation format is an open question, but it is clear that this is a robust strategy and one that interacts with selective encoding when items are presented sequentially. This may provide some practical insights on boosting memory. Firstly, while elaboration is an effective memory strategy, it might not be the type of strategy that individuals generally use. To facilitate utilization of this strategy, some instructions/reminders on how to use this strategy could be introduced before remembering the information. Secondly, while previous studies indicate that selectively encoding more valuable information could optimise memory performance (e.g., Castel et al., 2002; Castel et al., 2013; Hitch et al., 2018; Hu et al., 2014; Sandry & Ricker, 2020), it is difficult to apply selective encoding using elaboration strategies when information is presented in a sequential format. In that case, it would be beneficial to place the most important information at the beginning of the list. Alternatively, presenting information simultaneously might be preferable, not only because memory performance in the simultaneous presentation format is often superior than that in the sequential format (e.g., Allen et al., 2006; Blalock & Clegg, 2010; Gorgoraptis et al., 2011; Lecerf & de Ribaupierre, 2005; Siegel & Castel, 2018a, 2018b), but also because individuals could adopt selective encoding and elaboration concurrently, thus remembering the most important information in a relatively more effective way.

The value effect in the delayed item-colour memory test does appear to be somewhat unstable. Such an effect was observed when items were presented simultaneously (Experiment 8) but not sequentially (Experiment 9). This instability has also been observed in Chapter 3, but reversely regarding in which presentation format the value effect appears; the value effect was observed under full attention in a sequential format (Experiment 6) but not in the simultaneous format (Experiment 7). However, Chapter 2 has observed robust value effects in LTM and these effects persisted after approximately 24 hours. The possible reasons for the inconsistency, as discussed in Chapter 3, might include the study environment, the length of study list and the expectation of the delayed test. Future research could systematically explore how these factors might impact the size and longevity of value effects.

It was also observed that memory for location of high value items was better than that for low value items when items were presented simultaneously under the no-instruction and verbal rehearsal conditions, although memory performance on this measure was low. Such value effects are consistent with the findings in Experiment 7 using the same presentation format. As discussed earlier, the reasons could be that when items were presented simultaneously, participants may have restudied high value items multiple times under the no-instruction and verbal rehearsal conditions, resulted in constant eye movements among high value bindings and thus enhanced location memory (Awh & Jonides, 2001; Baddeley, 1986; Tremblay et al., 2006). Alternatively, when items were presented simultaneously, items might be more likely to be organized on a global spatial configuration (Jiang et al., 2000). High value items might have been encoded particularly in relative to each other under the no-instruction and verbal rehearsal conditions, and thus location memory was enhanced (Lilienthal et al., 2014; Taylor et al., 2014). Elaborative rehearsal, however, may encourage a local, item-specific encoding, resulting in less eye movement and/or relational processing, undermining the occurrence of the value effect on location memory.

4.5 Conclusions

The two experiments presented in this chapter indicate that value-based selective encoding and instructed encoding strategy both influence memory performance, but with only limited evidence of interaction. Participants were able to prioritise high value item-colour bindings using a verbal rehearsal strategy, either when items were presented simultaneously (Experiment 8) or sequentially (Experiment 9). In contrast, they selectively encoded high value bindings using an elaborative rehearsal strategy under a simultaneous presentation but showed no selectivity under a sequential presentation. The value effect observed in the no-instruction condition resembles the results from the verbal rehearsal condition. In addition, overall memory performance was more similar between no-instruction and verbal rehearsal conditions, with elaborative rehearsal consistently found to be the most effective strategy in boosting memory, especially in the delayed test. Therefore, participants may vary in the strategies they choose to implement, but the findings from Chapter 4 suggest maintenance rehearsal to perhaps be the more commonly implemented strategy driving the value effect on item-colour binding memory, at least in the current task context.

CHAPTER 5

GENERAL DISCUSSION

5.1 Thesis overview

Due to our limited capacity memory and attentional systems, it is often impossible to remember all the information that is present in the environment. To operate our cognitive system efficiently, one approach is to selectively remember the information that is more valuable or goal-relevant. This strategy has been shown to be beneficial for shape-colour binding in WM (Allen & Ueno, 2018; Atkinson et al., 2018; Hitch et al., 2018; Hu et al., 2014; 2016; Sandry & Ricker, 2020; Sandry et al., 2014; 2020) and for words in LTM (Castel et al., 2002; 2013; Elliott, Blais, et al., 2020; Elliott, McClure, et al., 2020; Hennessee et al., 2017; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016; 2017; Robison & Unsworth, 2017; Stefanidi et al., 2018). However, studies in associative LTM have yielded inconsistent results, with some studies supporting beneficial impact on associate memory (Ariel et al., 2015; Castel et al., 2007; Cohen et al., 2017; Elliott, McClure, et al., 2020; Festini et al., 2013; Griffin et al., 2019; Hargis & Castel, 2017; Siegel & Castel, 2018a, 2018b), while others not (Villaseñor et al., 2021; Hennessee et al., 2017; 2018). This thesis therefore aimed to extend this literature by examining 1) whether participants can selectively remember more valuable item-colour bindings in immediate and delayed tests (Chapter 2); 2) how might reduced attentional resources impact such value effect (Chapter 3); and 3) the possible encoding strategies driving the value effect (Chapter 4). The outcomes of each chapter will be discussed.

5.2 Summary of the key findings

5.2.1 Chapter 2

Previous studies have found inconsistent results regarding the value effect on associative memory. One possible reason is that it might depend on the binding condition between item and associative information. Based on prior work which found no evidence of the effect of value on memory for word colour (Hennessee et al., 2017; 2018), Chapter 2 examined whether such effect would be observed when the binding condition between item and colour was optimised. Across four experiments, it was found that when the colour information was well integrated with items, either through using images in Experiment 1 or through using intentional learning of word colour in Experiment 2 and Experiment 3b, the effect of value emerged on memory for colour of items, such that colour memory was better for high value items than low value items. When item and colour information were not closely related, as reflected by incidental learning of word colour in Experiment 3a, no colour memory boost was observed from high value cues, consistent with previous findings (Hennessee et al., 2017; 2018). These results suggest that the effect of value on associative memory is possibly mediated by the binding condition between item and associative information. The binding condition implemented in a task might help determine whether associative information would be registered and maintained within the FoA (see e.g., Cowan, 1999; Hitch et al., 2020), and therefore impacted by further value-based encodings.

Moreover, Chapter 2 also generally replicated previous findings that item recognition and item recollection (as indicated by R responses) were better in high value items, relative to low value items (Castel et al., 2002; 2013; Hennessee et al., 2017;

2018), although no effect of value was observed on item memory in the online Experiment 3b. It would be useful for future work to directly compare value effect studies running online and in the laboratory. Furthermore, to the best of our knowledge, all previous studies have observed value effects with immediate or short retention intervals (typically 5 minutes) between the study and the test phase. Chapter 2 extended these observations over longer periods of time (approximately 24 hours). These results suggest that high value information is not merely being temporarily held in the FoA (Hu et al., 2014). Further encoding processes, such as elaborative encoding, may have been implemented to store more valuable information in LTM.

5.2.2 Chapter 3

One of the suggested mechanisms underlying value effects is that high value information may have been allocated with more attentional resources (Allen, 2019; Castel et al., 2002). Chapter 3 investigated whether DA during encoding impacts such effect on item-colour binding memory. In the FA condition, the value effect task was the only task for participants to focus on; in the DA condition, participants performed this task while also performing an unrelated tone detection task. No effect of value was observed in Experiment 4 or Experiment 5, even with FA. This might be because the online format of the paradigms was disadvantageous for the implementation of selective encoding. Experiment 6 and Experiment 7 adjusted the paradigm based upon previous studies (Siegel & Castel, 2018a, 2018b; Siegel et al., 2021), such that the long study list was divided into several study-immediate test trials provided with feedback, and the items were presented in different locations within 5 × 5 grids. As a result, the value effects were observed. In both Experiment 6 (sequential presentation) and Experiment 7 (simultaneous presentation), DA decreased overall memory performance but it did not impact participant's ability to prioritise high value information. These results are in line with previous studies in this area (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b, but see Elliott & Brewer, 2019; Hu et al., 2016), suggesting that the ability to selectively encode and briefly maintain information based on allocated value is flexible and requires little attentional resources.

In addition, memory was also tested after a delay following the last study-immediate test trial. When items were presented simultaneously (Experiment 7), no value effect was observed at the delayed test, suggesting the value effect observed online in a simultaneous context is short-lived. When items were presented sequentially (Experiment 6), the effect of value persisted to the delayed test with FA, but DA abolished this effect. This might suggest that DA disrupted overall memory consolidation, thus decreased persistence of the value effect. Alternatively, it might suggest that DA specifically disrupted long-term maintenance for high value information. The second possibility implies that participants may have used various strategies in a value effect task and may have applied them differentially based on item value, in line with previous findings (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). Chapter 4 followed this up by exploring the role of encoding strategy in the value effect on item colour binding memory.

5.2.3 Chapter 4

Chapter 4 explored the possible types of encoding strategies that might underlie the value effect on item-colour binding memory. When participants were instructed to use a verbal rehearsal strategy in the value effect task, they were able to selectively encode more valuable item-colour bindings to the same extent as the no-instruction condition, either with simultaneous format (Experiment 8) or with sequential format (Experiment 9). However, when they were instructed to use an elaborative rehearsal strategy, they selectively encoded high value bindings when items were presented simultaneously, but there was no such selectivity when items were presented sequentially. Regarding overall memory performance, elaborative rehearsal was the most effective strategy in boosting memory. This was consistently observed in both the immediate and the delayed tests, and across the simultaneous and sequential formats. Performance level was more similar between the no-instruction condition and the verbal rehearsal condition. Together, based on the relative differences between the no-instruction condition and each of the instructed strategy conditions, these results suggest that while there is likely to be substantial within- and between-individual variability, maintenance rehearsal may be the primary encoding strategy underlying the value effect on item-colour binding memory, at least in the current task context. It should be noted, however, maintenance rehearsal is not the optimal strategy to improve memory overall, as can be seen from the evident memory improvement from elaborative rehearsal, especially at the delayed test.

5.3 Limitations and future directions

5.3.1 Limitations

One limitation of the experiments conducted within this thesis is that in the experiments that included two test points, the same items were used. Previous literature on the testing effect indicates that memory can be enhanced through testing and retrieval (e.g., Karpicke & Roediger, 2007; Roediger & Karpicke, 2006). Value effects at the second test may at least partly reflect their more successful retrieval at the earlier test point.

Future studies exploring longevity of value effect could test only part of study items at each test point. Another possible limitation is the order of condition implementation in Chapter 4. When instructing participants to use different encoding strategies in a value effect task, the no-instruction condition was always conducted first to avoid possible influences from other conditions. This may have resulted in greater decay and retroactive interference for the items studied in this condition in the delayed test, and thus partly decreased memory performance in this condition relative to other conditions. To tackle this issue, future research could treat strategy type as a between-subject factor.

5.3.2 Future directions

5.3.2.1 Comparing online and laboratory-based value effects

Due to Covid-19, all the experiments except for Experiment 1 and Experiment 2 were conducted online. Although value effects were observed online after several adjustments in the paradigm, outcomes from online studies do differ to some extent from the laboratory studies. Firstly, a difference was observed with regard to the value effect on item memory. Experiment 3b found a value effect on colour memory but no such effect was observed on item memory. This contrasts with previous laboratory findings in which the effect of value on item memory was quite consistent and robust (Castel et al., 2002; 2013; Elliott, Blais, et al., 2020; Elliott, McClure, et al., 2020; Hennessee et al., 2017; Middlebrooks & Castel, 2018; Middlebrooks et al., 2016; 2017; Robison & Unsworth, 2017; Stefanidi et al., 2018; Chapter 2, Experiment 1 & 2). Secondly, differences were observed regarding the long-term maintenance of value effects. Experiments 5-9 (online) found better colour memory for more valuable items in the immediate tests, but the persistence of such effects after an approximately 5-minute delay was unstable. Experiments 1 & 2 (laboratory), however, observed value effects not only after a 5-minute delay, but also after an approximately 24-hour delay. Thirdly, although it was not the main focus of the current research, Experiment 9 found that overt rehearsal (verbal rehearsal condition) was better than silent study (no-instruction condition) in enhancing LTM, contrasting previous laboratory studies which usually found superior LTM from silent rehearsal than overt rehearsal (Fischler et al., 1970; Kaernbach & Schlemmer, 2008; Madigan, 1973).

The possible reasons for the differences between online and laboratory testing may include several factors. For instance, the presence of a researcher in the laboratory may facilitate participants to focus more on the task (Kraut et al., 2004). The researcher can also provide additional explanation for the task where needed (Backx et al., 2020; Schmand, 2019). However, these are not available for the unsupervised online experiments. Moreover, the testing environment in the laboratory can be kept constant, whereas there is little control over it online (Backx et al., 2020; Bauer et al., 2012; Skitka & Sargis, 2006). Thus, participants online may get more distraction than those involved in the laboratory. Furthermore, due to relatively reduced concentration, online participants may be less likely to use attention-demanding elaborative encoding, which is an important mechanism suggested by previous laboratory studies (Ariel et al., 2015; Bui et al., 2013; Cohen et al., 2014, 2016; Hennessee et al., 2019). Therefore, it would be worthwhile for future research to explore how might different environments (laboratory vs. online) impact value effects, in terms of its size, persistence and mechanisms.

5.3.2.2 Does length of study list impact the extent of selective encoding?

It would also be useful to explore how the length of the study list may impact selective encoding. One factor that may have influenced the consistency of value effects in LTM is the length of the study list. Previous studies using longer study lists (e.g., 20 or 30 items) have observed value effects in LTM (Ariel et al., 2009; Middlebrooks & Castel, 2018; Robison & Unsworth, 2017; Chapter 2, Experiment 1 & 2), whereas Experiments 5-9 in this thesis have used short study lists and found that the value effects in LTM was somewhat unstable. Longer study lists may encourage a more selective encoding as it might be more obvious to participants that it is impossible/difficult to remember all the items. Indeed, a strategy that participants often use in that case is to largely ignore low value items and strategically focus on high value items (Robison & Unsworth, 2017). However, participants may not be as selective in short study lists as in long study lists, because the total number of items in a short list may not exceed some participants' ability or participants may have not clearly realised it is beyond their capacity. When prioritising high value items in that case, they may also have encoded some low value items. Therefore, long and short study lists may differ in the extent of selective encoding, and this may have partly impacted consistency of value effects in LTM. Reducing length of study lists may have decreased task demand and thus made selective encoding less necessary. By the same logic, an effective memory strategy could also make a memory task relatively easy, and may reduce value effects. Indeed, studies have shown that elaboration strategy substantially improved memory and abolished value effects in a sequential presentation context (Hennessee et al., 2019; Chapter 4, Experiment 9). Future research could explore how the length of the study list and strategy type may impact the extent of selective encoding.

5.3.2.3 Are selective encoding and inhibitory encoding two distinct attentional control abilities?

Based on previous studies and the findings in the current thesis, some differences emerged between selective encoding and inhibitory encoding. One difference is the detrimental effect from DA. Consistent with previous studies (Atkinson et al., 2020; Middlebrooks et al., 2017; Siegel & Castel, 2018b, but see Elliott & Brewer, 2019; Hu et al., 2016), Chapter 3 demonstrated that DA during encoding did not impact the ability to selectively encode and briefly maintain more valuable information, suggesting such ability is flexible and requires little attentional resources. In contrast, control of inhibition requires attentional resources, as indicated by increased distractor interference from DA (e.g., Kelley & Lavie, 2011; Lavie, Hirst, de Fockert, & Viding, 2004). Another difference is from the impact of aging. It is well-documented that older adults' ability to selectively encode more valuable information is equivalent to younger adults (e.g., Allen et al., 2021; Castel et al., 2002; 2013; Siegel & Castel, 2018a). However, when the attentional control task involves inhibition (e.g., the directed-forgetting paradigm, or a value effect paradigm containing negative point values), older adults show deficits in attentional control relative to younger adults (Castel et al., 2007; Hayes et al., 2013; Zacks et al., 1996). Furthermore, the two abilities differ in the relationship with WMC. Evidence suggests no correlation or minimal correlation between selective encoding and WMC (Castel et al., 2009; Elliott, McClure, et al., 2020; Griffin et al., 2019; Miller et al., 2019). Nevertheless, inhibitory encoding (i.e., a value effect paradigm containing negative point values) is largely mediated by individual differences in WMC (Hayes et al., 2013).

Therefore, it would be useful for future research to directly compare to what extent selective encoding and inhibitory encoding differ from each other. For example, studies could explore whether spatial distance among items could improve selective encoding as inhibitory encoding appear to be (i.e., the flanker task, Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1973). Studies could also explore whether the length of study list might similarly impact the two attentional control abilities. As mentioned earlier, long study list may encourage higher extent of selective encoding. For inhibitory encoding, however, long study list means more distractors. This may decrease attentional control ability. Alternatively, more distractors may facilitate an efficient focus on target information, resulting in equivalent or even better attentional control.

5.3.2.4 Metacognition and complexity of value allocation in value effects

It might be useful examine how metacognition may play a role in value effect. While a great amount of literature on metacognition focused on the phase after encoding and before testing, typically using judgement of learning (JOL) paradigm, metacognitive processes during the acquisition phase may particularly be important to value effects. According to Nelson and Narens (1990), these metacognitive processes include a clear understanding of the goal and a plan to attain this goal. This plan contains the decision of which information to study (i.e., ease-of-learning in this framework) and allocation of time (Nelson, 1990). In a value effect task, to optimise memory performance, one has to be aware of which information is more important, and then be able to allocate attention towards important information. If the ability to distinguish more valuable information from other information is reduced, one might expect a reduced value effect. One way to probe such ability might be through manipulating the variability and complexity of value points. Simple value-point structure (e.g., 10 points for high value and 1 point for low value) may make it easier to distinguish between high and low value items and enable a more effective focus on high value items. Consistent with this idea, Villaseñor et al. (2021) found a value effect on a subjective measure of context memory when the range of point values were reduced from 1-8 to 1-4. However, there is no clear evidence on the best way to implement point values to optimize value-directed remembering effects, and few if any other studies have systematically examined this question. Therefore, future studies could explore how the variability and complexity of value allocation might impact on changes in value effects, such as binary vs. continuous value-point structure, big (high value: 10 points; low value: 1 point) vs. small (high value: 6 points; low value: 5 points) differences between high and low value items.

5.3.2.5 Examining value effects in real-world situations

When exploring value effects in experimental research settings, information is often associated with different "point values". This makes it relatively clear that information differs in value and that which information is more valuable. In everyday life, however, the value of information may not be as apparent as "points" and it may vary between individuals. It would, therefore, be useful for future work to explore whether selective encoding observed in laboratory would also generalize to the real-world, and how to facilitate application of such strategy to improve everyday cognition. Some related work has been conducted and found that individuals could indeed apply selective encoding in real-world situations, such that they are able to better remember allergens and medication interactions with high severity (Friedman et al., 2015; Hargis & Castel, 2018; Middlebrooks, McGillivray, et al., 2016), although sometimes this is dependent upon a required consideration of the importance of information (Murphy & Castel, 2021). Future work could continue to explore this area. For instance, our schedule is usually filled with numerous events, including various meetings, deadlines, family and friends' birthdays etc. It is often difficult to remember all the dates and times for these events in the future. It would be useful to examine whether individuals are able be to strategically remember some of the important dates at a time, such as those within a week or with more personal significance, and update the content with time passing by. This should reduce memory load to some extent and optimise our daily performance.

5.4 Conclusions

This thesis demonstrated that when the binding condition between item and colour information is optimised, the effect of value could be observed on colour memory in immediate and delayed tests. Chapter 3 explored the role of attention in this effect. The results showed that DA during encoding did not impact the ability to selectively encode and briefly maintain high value item-colour bindings. Taken with previous work, this suggests that such ability is flexible and requires little attentional resources. However, DA indeed decreased persistence of value effect in a sequential presentation format. Chapter 4 explored the role of encoding strategy in this value effect. Without specific strategy instruction, memory performance and value effects more closely resemble that using a verbal rehearsal strategy than using an elaboration strategy, suggesting the primary encoding strategy typically driving the value effect is possibly a type of maintenance rehearsal. Taken together, these studies found value effects in associative memory, in delayed tests, under dual-task conditions, and with different encoding strategies. Therefore, individuals can selectively encode more valuable associative information across a range of task contexts.

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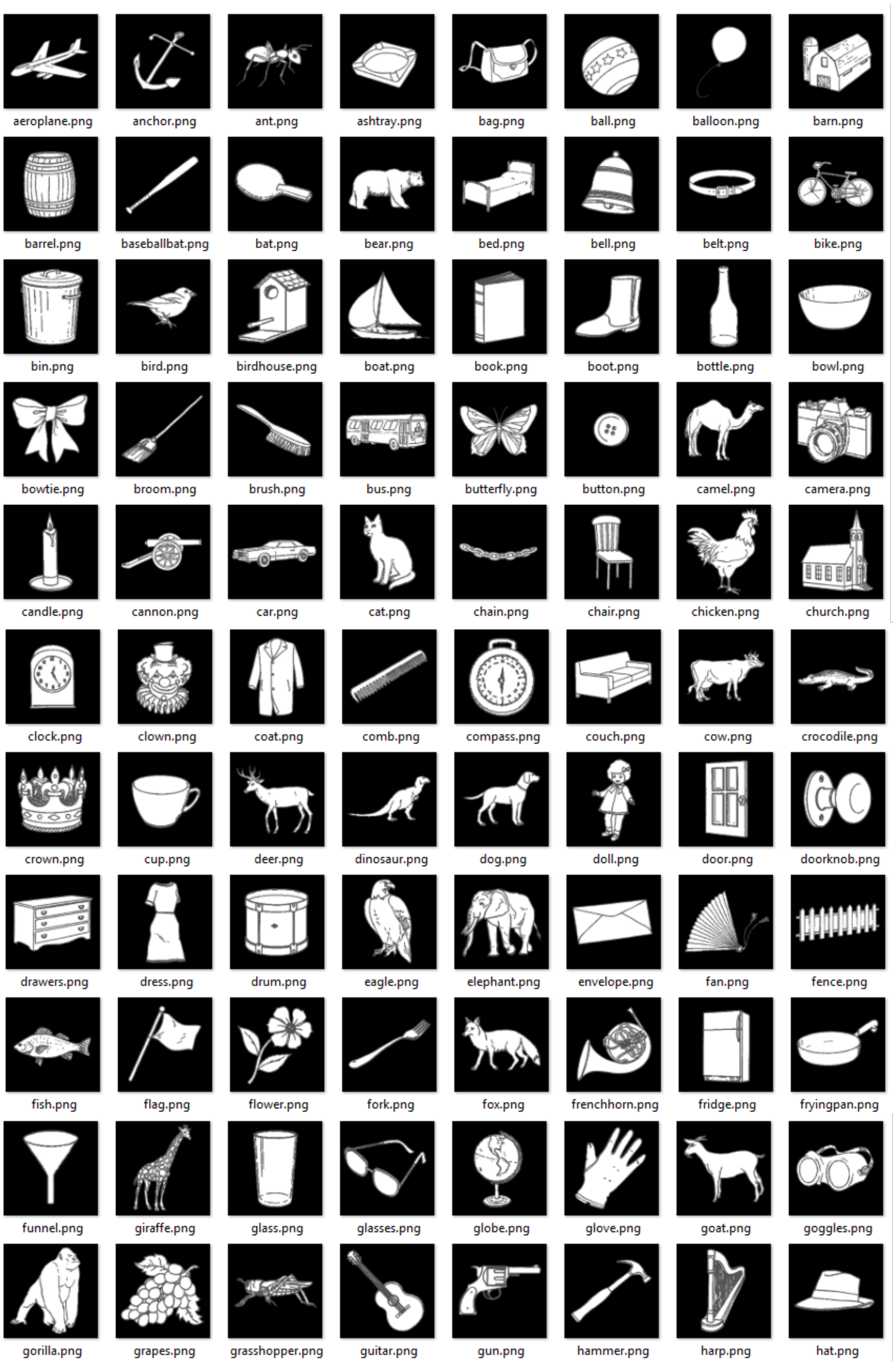
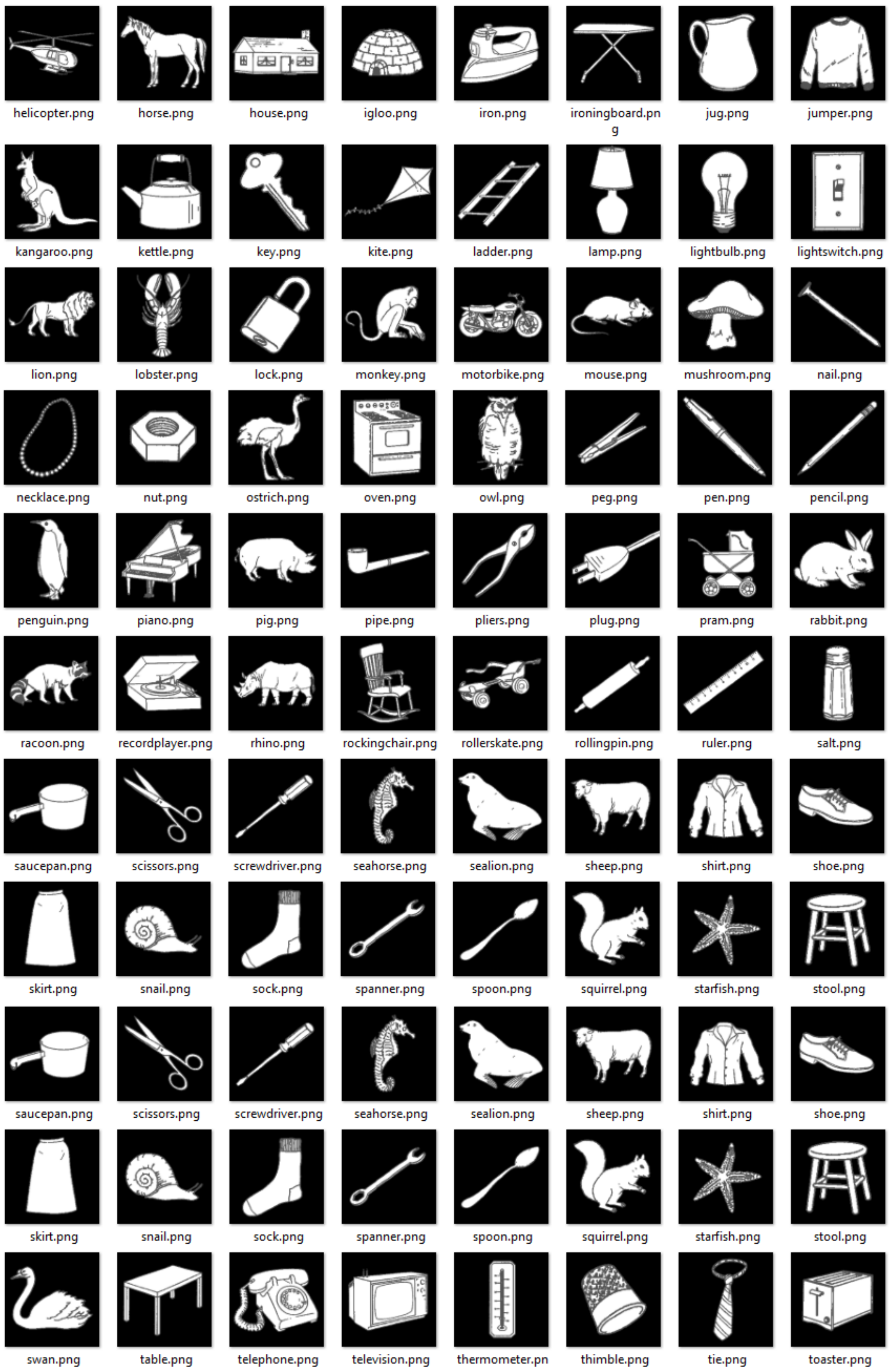
APPENDICES

Appendix A: Image stimuli used in this thesis




helicopter.png horse.png house.png igloo.png iron.png ironingboard.pn g jug.png jumper.png
kangaroo.png kettle.png key.png kite.png ladder.png lamp.png lightbulb.png lightswitch.png
lion.png lobster.png lock.png monkey.png motorbike.png mouse.png mushroom.png nail.png
necklace.png nut.png ostrich.png oven.png owl.png peg.png pen.png pencil.png
penguin.png piano.png pig.png pipe.png pliers.png plug.png pram.png rabbit.png
racoon.png recordplayer.png rhino.png rockingchair.png rollerskate.png rollingpin.png ruler.png salt.png
saucepan.png scissors.png screwdriver.png seahorse.png sealion.png sheep.png shirt.png shoe.png
skirt.png snail.png sock.png spanner.png spoon.png squirrel.png starfish.png stool.png
saucepan.png scissors.png screwdriver.png seahorse.png sealion.png sheep.png shirt.png shoe.png
skirt.png snail.png sock.png spanner.png spoon.png squirrel.png starfish.png stool.png
swan.png table.png telephone.png television.png thermometer.pn thimble.png tie.png toaster.png


toothbrush.png


tortoise.png


trolley.png


trousers.png


truck.png


trumpet.png


umbrella.png


vase.png


violin.png


waistcoat.png


watch.png


wateringcan.png


well.png


wheel.png


whistle.png


wineglass.png

Appendix B: Word stimuli used in this thesis

agent	cause	door	ground	mayor	priest	shut	teeth
arm	change	dry	guess	middle	public	side	tell
army	charge	due	heavy	mood	push	sign	ten
back	cheap	duty	hide	move	put	signal	third
bag	church	eight	hill	navy	radar	single	throat
bar	claim	end	hole	neck	remind	sir	ticket
bear	client	engine	hour	need	repeat	six	tie
bet	close	excuse	joint	news	report	sorry	tiny
bit	closet	figure	junior	nine	row	source	total
board	coat	file	knock	nurse	rule	spot	truck
bone	code	final	lab	office	sake	square	turn
borrow	cop	firm	lane	other	school	staff	unit
boss	copy	five	law	paper	seat	stand	use
bottle	corner	floor	leave	part	second	stick	usual
box	county	follow	legal	past	secret	stone	wait
break	cow	foot	lift	piece	seem	stop	wall
bridge	credit	four	line	pig	sell	street	warn
bus	dark	freeze	lock	plate	senior	switch	watch
busy	deep	gate	loose	point	serve	table	week
button	desert	glass	madam	post	set	take	weird
cab	dig	grab	main	press	seven	tank	wire
case	dirt	grade	man	price	shape	taxi	work

Appendix C: Instructions in Experiment 1

Study phase instructions

Welcome to our experiment! This session will last around 30 minutes. You will be presented with a series of images. Each of them is associated with a point-value (1 point or 10 points) which you could earn later for recognition. Each image will be shown for 3 seconds. Your task is to try to remember the images and to maximize your points score. Following this presentation phase, there will then be a brief calculation task lasting a few minutes. After this, you will be shown a mixture of the images you saw earlier and some new images, and a recognition test will be conducted.

Remember-know-Guess instructions

Remember:

When you see an image, if it triggers something that you experienced when you saw it previously, like, for example, something about its appearance on the screen or the order in which the image came in, please indicate this kind of recognition, by choosing the REMEMBER option. In other instances the image may remind you of something you thought about when you saw it previously, like an association that you made to the image, or something of personal significance that you associated with the image; again if you can recollect any of these aspects of when the image was first presented please choose the REMEMBER option.

Know:

At other times you will see an image and you will recognize it as one you saw previously, but the image will not bring back to mind anything you remember about seeing it then. When you feel confident that you saw the image previously, even though you do not recollect anything you experienced when you saw it, please choose the KNOW option. With KNOW responses you are sure about seeing the image previously but cannot remember the circumstances in which the image was presented, or the thoughts elicited when the image was presented.

Guess:

With a GUESS response, you think it possible that the image was presented but you are not sure that it was. For some reason, you think there was a chance that the image was presented. Some people say ‘‘it looks like one of those images that could possibly have been there.’’ When you think your response was really just a guess, please choose the GUESS option.

Appendix D: Instructions in Experiment 2

Study phase instructions

Welcome to our experiment! This session will last around 30 minutes. You will be presented with a series of words in different colours (red, yellow, blue and green), each associated with a point-value (1 point or 10 points) you could earn later for recognition. Each word will be shown for 3 seconds. Your task is to try to remember the words and their colours and to maximize your points score. Following this presentation phase, there will then be a brief calculation task lasting a few minutes. After this, you will be shown a mixture of the words you saw earlier and some new words, and a recognition test will be conducted.

Remember-know-Guess instructions

Remember:

When you see a word, if it triggers something that you experienced when you saw it previously, like, for example, something about its appearance on the screen or the order in which the word came in, please indicate this kind of recognition, by choosing the REMEMBER option. In other instances the word may remind you of something you thought about when you saw it previously, like an association that you made to the word, or an image that you formed when you saw the word, or something of personal significance that you associated with the word; again if you can recollect any of these aspects of when the word was first presented please choose the REMEMBER option.

Know:

At other times you will see a word and you will recognize it as one you saw previously, but the word will not bring back to mind anything you remember about seeing it then. When you feel confident that you saw the word previously, even though you do not recollect anything you experienced when you saw it, please choose the KNOW option. With KNOW responses you are sure about seeing the word previously but cannot remember the circumstances in which the word was presented, or the thoughts elicited when the word was presented.

Guess:

With a GUESS response, you think it possible that the word was presented but you are not sure that it was. For some reason, you think there was a chance that the word was presented. Some people say "it looks like one of those words that could possibly have been there." When you think your response was really just a guess, please choose the GUESS option.