WHAT MAKES IT MEMORABLE: MEANING, LIKABILITY AND REWARD ASSOCIATIONS ON VISUAL WORKING MEMORY

YVETTE YONG YAN NI

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YVETTE YONG YAN NI

School of Social Sciences

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Abstract

We investigated the effects of past reward associations and preferences on visual working memory (VWM) by using stimulus sets which are more visually complex than those used in earlier studies. The other variable of interest is stimuli meaningfulness – specifically, we explored if VWM performance as a function of reward or preferences differs for meaningful versus meaningless stimuli. Reward was operationalised as a non-monetary incentive by way of a trial-by-trial performance feedback, while preference is measured based on participants’ rating on a 7-point Likert scale. In Experiment 1, participants were tested on their VWM of Liked, Neutral and Disliked stimuli – in every trial the memory display comprised all three stimuli types. Similarly Experiment 2 tested participants’ VWM for the High Reward, Low Reward and No Reward stimuli, and in every trial the memory display comprised all three stimulus types. Our results suggest that the current reward manipulation may have been too weak for effects of VWM to be observed. We also found that the effects of preferences on VWM is not the same for meaningful versus meaningless stimuli. Possible reasons for the above findings are discussed.
Introduction

Visual working memory (VWM) is understood as a limited resource (Luck & Vogel, 1997) serving to briefly retain information which is no longer perceptually available to support everyday behaviour, from safely avoiding cars when crossing roads to successful sports performance. Given its importance in our daily tasks and the finite nature of VWM, it is of little wonder that much research has sought to tease apart conditions which might benefit VWM performance. To this effect, numerous factors have been tested, including but not limited to emotions (Xie & Zhang, 2016), preferences (Kawasaki & Yamaguchi, 2012), reward (Infanti, Hickey & Turrato, 2014), attention allocation (Awh, Vogel & Oh, 2006; Theeuwes, Kramer, & Irwin, 2011), and properties of the stimuli to be remembered such as meaning (Brady, Stormer & Alvarez, 2016), novelty (Mayer, Kim & Park, 2014) and similarity (Lin & Luck, 2009;). Cumulating research in this field invites further curiosity in terms of how specific factors may come together to affect VWM performance. The present study aims to contribute to the understanding of what may affect VWM performance by focusing on three factors – preferences, reward and complexity of stimuli. In particular, this study will further explore the effects of preference and reward on VWM performance and how these relationships might vary across stimulus types.

Effects of Past Reward

Past knowledge such as learned reward associations can serve as an adaptive mechanism which enables individuals to efficiently select for or prioritise stimuli for encoding. It has been demonstrated that stimuli which had been paired with rewards or positive outcomes are better encoded in VWM than those which had been paired with low rewards or negative outcomes (Thomas, FitzGibbon & Raymond, 2015; Infanti, Hickey &
Turrato, 2014; Gong, M., & Li, S., 2014). Concerning the effects of past rewards on visual
tasks, earlier research
has documented more of its attention-capturing effects, and to a lesser extent, the effects on
VWM performance itself. For example, reward associations have been shown to increase
visual performance (Brielmann & Spering, 2015), influence visual selective attention
(Anderson, Laurent, & Yantis, 2011; Theeuwes & Belopolsky 2012; Olson, Jiang & Moore,
2005) and influence visual working memory (Infanti, Hickey & Turrato, 2014; Gong, M., &
Li, S., 2014; Thomas, FitzGibbon & Raymond, 2015). While most studies have trained
individuals to form reward-feature associations using features which were once task-relevant
i.e. the reward features once served as targets, more recent studies found that reward
associations can also be established with distractor colour features, and that such associations
were similarly able to influence visual attention despite conflicting with top-down goals
(Failing, Nissens, Pearson, Le Pelley & Theeuwes, 2015; Le Pelley, Pearson, Griffiths &
Beesley, 2015). In this way, the latter group of experiments further isolates the effects of past
reward association on visual attention from history of task-relevance or effect of training.

In a study dedicated to find out how past reward association influence VWM, reward-
associations were established with colour singletons during a visual search task by assigning
high monetary reward for one colour and low monetary reward for another colour (Infanti et
al., 2014). Subsequent to this, VWM performance was assessed in a memory task.
Participants were shown eight items in a brief memory display, all of which were grey except
for one which could be characterised by a high reward or low reward colour. Participants had
to then recall the identity of one of the eight items, which could be one of the grey items or
the colour item,. The authors did not find direct effects of past reward associations on VWM
– i.e. identification accuracies for items in high reward-associated colour vs those in low
reward associated-items did not differ. However, the study found indirect effects of past
reward associations on VWM performance. Specifically, when the coloured item was a
distractor item instead of a target, a high reward associated colour interfered with the memory
of nearby grey items more than a low reward associated colour. Such finding of indirect effects of past reward association on VWM performance seems to support the notion that past reward association improves VWM performance via modulation of attention linked to the rewards in early perceptual processes, rather than via better consolidation and retention of the reward-associated items per se (Infanti, Hickey & Turrato, 2014).

On the other hand, Gong and Li (2014)’s study found a direct effect of reward-associated features on VWM. Unlike the previous study, a change detection paradigm was used instead of identity recall, and the VWM memory display consists of eight items each of a different colour, as such there were no colour singletons as in the former study. VWM performance was found to be better for items characterised by a colour feature which was previously highly-rewarded. The degree of improvement in VWM performance was captured in a change detection task administered before and after learning reward associations. In these pre- and post- test tasks, observers were tasked to decide if the probed bar had rotated from its memory to test display. The colour of the probed target could be associated with a high reward, low reward, or no reward (no reward colours serve as control). Reward associations were established through a visual search training phase, given to participants between the two change detection tests. Importantly, the study also set up control experiments to preclude the possibility that the improvement in VWM observed in their study was due to attentional capture. This allowed them to conclude more confidently that apart from triggering attentional capture across space, reward associations may also induce feature-based attentional modulation to enhance perceptual representation of the reward-associated items. Following the above work, Thomas et al. (2015) went further to show that learned value-associations can influence VWM without the presence of selective encoding, the latter being strongly suggested by much of the earlier research (Olson, Jiang & Moore, 2005; Infanti et al., 2014). Indeed, by precluding possibility of selective encoding for any stimuli in the
experimental paradigm, the study found that reward-associated boost in VWM does not have to result from selective attention or selective encoding.

These studies have tested the effects of reward associations in different ways – for example the reward-feature could be embedded in a target stimulus in some experiments or embedded in a distractor stimulus in other experiments, consequently they differ in inferring whether the effects of reward on VWM performance was due to selective attention or late VWM maintenance processes. There were also some common characteristics of previous studies, which include a. the use of a binary response to measure performance b. relatively pared-down memory items, such as rotated bars in coloured circles or basic shapes, and c. using money to incentivise performance.

Since the effectiveness of non-monetary incentives is unexplored, such research would be valuable to demonstrate the generalizability of reward types. We postulate that non-monetary rewards such as points may exert similar effects. For example, Sanada et al.’s (2013) observed an effect of reward even as participants were awarded points during the experiment trials and were only notified of the points-to-currency-exchange rate after the experiment had concluded. Therefore, we postulate that non-monetary reward should have similar motivational effects as monetary ones. The current study will also deviate from previous ones by using more visually complex stimuli instead of isolating memory items to one defining colour or angle of rotation. Finally, we will explore the different effects of reward on VWM using visual stimuli imbued with semantic meaning versus those which are more arbitrary.

**Effects of Subjective Preferences**

Besides previously learnt associations, the other aspect of interest here is subjective preferences – or likability on VWM performance. However, empirical research exploring the
relationship between subjective preferences and VWM is much scarcer than that of past reward associations with VWM.

Subjective preference, in terms of visual liking, is represented in the brain regions which overlap with those responsible for reward-association. For example, neuronal activities in the orbitofrontal cortex (OFC) – which is also involved in reward-related learning – correlate with aesthetic (Ishizu & Zeki, 2011; Kawabata & Zeki, 2004) or economic values (Padoa- Schioppa & Assad, 2006). Yue, Vessel & Biederman (2007) found that highly preferred images lead to more ventral striatum activation, suggesting that “perceptual preferences might engage the conventional reward system”. Also, the brain areas concerned with later stages of visual recognition, as compared to early stages of visual recognition, is found to have the densest opioid receptors – a mechanism that modulates pain and provides reward (Biederman & Vessel, 2006). It is therefore plausible that preferences might exert similar effects on VWM as reward associations.

Visual liking is determined quickly and unconsciously. Liking can be determined by low-level perceptual factors such as image contrast, contour sharpness, perceptual fluency and visual complexity, and subjective likability of common objects is reliably determined within 100ms of stimulus presentation (Niimi & Watanabe, 2012). Such instantaneous emotive reaction makes it a likely factor to drive or bias encoding of visual stimuli at the early stages, hence influencing VWM performance.

Indeed, preliminary neurobiological results could suggest that individuals’ subjective preferences may enhance VWM. Particularly, it was found that individual VWM capacities were significantly higher for a memory array with all stimuli in preferred colours than those in non-preferred colours (Kawasaki & Yamuguchi, 2012). In this experiment, task performance as well as the EEG data during task performance were recorded during a
delayed response VWM task whereby participants were required to memorize stimuli in the one colour that they preferred in one condition, and in their non-preferred colour in another condition. Not only did participants show higher VWM capacity when the task uses their favourite colour compared to their less liked colours, the corresponding EEG results also suggests that subjective preferences affect VWM processes in a similar fashion as reward-incentive motivations.

There are several possible explanations behind the likability enhancement effect. For example, processing of likeable stimuli enhances positive affect and hence facilitates performance (positive affect mediation hypothesis, e.g. Moshagen et al., 2009). A neurobiological account may posit yet another explanation that both subjective preference and reward-associations overlap in common brain regions such as the anterior frontal cortex, anterior cingulate, striatum and amygdala (Aharon et al., 2001; O’ Doherty et al., 2002). It is noteworthy, however, that the current findings on effects of preferences on VWM capacity, or even more generally, in cognitive performance, are mixed at best (Reppa, McDougall, 2015).

A reason why subjective preference is rarely investigated as an independent variable may be due to its multifaceted and dynamic nature, making it hard to experimentally manipulate or keep constant. For instance, subjective preference may not always be a uni-dimensional construct. It is possible that individuals can hold two or more distinct attitudes towards the same stimulus, even when context remain constant (Dai, Brendl & Ariely, 2015). As commented by Pugach, Leder & Graham (2017), studies exploring the stability of visual preferences have not been informative nor conclusive about how stable visual preferences are. What they did found, however, was that even though preferences change over time for most people, preference stability were “well above chance” even for the most unstable groups
in their study. Overall, uncertainty over the stability and robustness of visual preferences render the study of subjective preferences on VWM more challenging, as the individual’s expressed valence towards a single stimulus may be inconsistent or unstable across time and contexts, obscuring any possible effects of preferences on VWM.

Subjective preferences in the context of our study is almost synonymous with aesthetic appeal – in that it is subjective and disinterested – the latter meaning that they do not involve desire for the items rated (Kant, 1951). Palmer, Schloss & Sammartino’s paper (2013) summarises major theoretical accounts of why people like what they like, and these include the effects of mere exposure, visual similarity to prototypes, fluency of processing the stimuli perceptually or conceptually. Of interest here is not to determine which theoretical account is the most relevant, but to recognize that aesthetic appeal or subjective preferences, as we like to use interchangeably here, may result from one or more evaluative mechanisms, for example ecological (meaningfulness of the stimuli or associations with environmental stimuli), psychophysical (size, colour, complexity and brightness of the stimuli) or collative properties (stimuli novelty, familiarity, or conflict) (Berlyn, 1971). For example, a person may prefer an image of a rabbit to a dog for various reasons – a) one is in a more pleasing colour and form than another b) the rabbit image elicits a feeling of peacefulness c) it is familiar because he sees his pet rabbit every day. It is not clear what evaluative mechanisms underlie expressed subjective preferences, whether these mechanisms have different neural basis and how these might differentially influence memory processes.

Notwithstanding the above intricacies and complexities underlying subjective preferences for visual stimuli, this study focuses on expressed subjective preference which is conscious and may or may not correlate with objective and sometimes unconscious measures
of preference (i.e. neurobiological or psychophysical measures of arousal such as oculomotor activity and brain activation patterns).

**Use of Meaningful Vs Arbitrary Visual Stimuli for VWM Studies**

Research in the area of what benefits VWM performance - for legitimate reasons - have mainly relied on non-realworld stimuli and such findings cannot generalise to stimuli representing real world objects. Based on existing knowledge on perception and memory for visual stimuli, one’s processing abilities or capacities are different for visual stimuli depending on their salience or relevance to them. One example is the encoding and recall of faces – for example, Jiang, Shim and Makovski (2008) found that “when the similarity between memory and test stimuli was controlled for, face memory was more robust at high load”; Curby and colleagues showed “better visual short term memory for faces” than other complex objects (Curby & Gauthier, 2007) and for objects of expertise (Curby, Glazek & Gauthier, 2009). In the same vein, all things are not equal when it comes to processing of meaningless stimuli versus other real-world stimuli, with the capacity for visual working memory shown to be larger for the latter (Brady, Stormer & Alvarez, 2016). More crucially, the researchers demonstrated - using neural activity – that the enhanced VWM for real-world objects is a consequence of active storage in working memory, not merely because of the support given by long-term memory. Given that the processing of meaningless visual stimuli versus those which are more symbolic may rely on slightly different mechanisms, the effects of Preference on VWM for found in earlier experiments – with the use of arbitrary stimuli - may not be the same as that for more meaningful stimuli. It would thus be interesting to find out how preferences for meaningless stimuli affect VWM differently from preferences for meaningful stimuli. Preference ratings for meaningless stimuli may be purely based on
aesthetics while those for semantically rich ones may engage, to a greater extent, past experience or meaning.

Use of Visually Simple Versus Visually Detailed Stimuli

Another notable aspect in previous research is that it typically uses visually pared-down stimuli such as lines of different rotation angles and colour singletons. There is a need to verify these research findings with more visually-detailed stimuli. This could bring more value to understanding cognitive processing of stimuli which have compound features, commonly found in computer user-interface or other design elements.

To clarify, we define here visual complexity as the amount of detail and intricacies in an image (Snodgrass & Vanderwart, 1980). Without concerning with the subjective aspects of visual complexity, here, our stimuli are “simple” if they contain sparse visual details such as few lines, internal angles and are of single colours. On the other hand, the complex stimuli in this paper contain multiple colours, and have more lines. This definition is starkly different from those which deem complexity as the amount of time taken for individuals to process the image, in which the user’s prior knowledge and also the extent of symbolism embodied by the image becomes relevant as well. We recognise there is no consensus on the definition and measure of visual complexity. As Forsythe (2009) pointed out, “detail is perhaps a more neutral description of the structural components within an icon. Complexity implies difficulty; it suggests that a (complex) image will be more difficult to understand than a ‘simple’ image”. Nonetheless, here we refer to visual complexity as the extent of visual detail contained in an image.
Research Questions

Based on existing research concerning past reward associations, preferences and VWM, we identified several knowledge gaps which are of interest. First, the effects of subjective preferences on VWM performance are largely unexplored in the literature. Yamaguchi and Kawasaki (2012)’s study found evidence that preferences at the feature level can enhance visual working memory. We hope to extend their findings with stimuli which are more visually detailed than colour singletons and also with stimuli which bear greater semblance to real world objects. We expect that VWM for a stimulus would improve with increasing preference strength of the stimulus.

Second, while past research has established the VWM enhancing effects of learned reward associations using extremely simple stimuli such as lines of different rotation angles and colour singletons, the aim in this paper is to replicate such enhancement effect to more visually detailed as well as semantically-enriched stimuli. We also wanted to explore how the effects of past reward association on VWM might differ for these two sets of stimuli.

Third, the current study seeks to expand the understanding of reward effects on VWM performance by shifting away from the use of monetary incentives. As previously highlighted, use of non-monetary incentives has been largely unexplored in most of the reward-and-VWM-performance literature. In this study, we will test the robustness of points and real-time task performance feedback as a reward mechanism.

Last but not least, we wish to explore if the preference-VWM and reward-VWM relationships are similar or different across the two genre of stimuli – the visually simple and arguably meaningless stimuli against visually more detailed and semantically richer stimuli.
Holding all other variables constant, would we be better able to maintain representations for stimuli which were once goal-relevant? Also, would our liking towards stimuli help us to better maintain their representations in VWM? Should we assume that the effect of preferences on VWM performance is the same for all kinds of stimuli?

Traditionally, studies of VWM has used the delayed-matching-to-sample (DMTS) paradigm. However, in our current study, we chose location recall to avoid the confound of similarity between memory and test item, which has been known to affect VWM performance (Lin & Luck, 2009). This is a potential issue for the current study as each stimulus is a compound feature item and it is virtually not feasible to ensure that the degree of change used for every stimulus is of the same psychological magnitude. Also, the use of location recall is believed to be a more sensitive measure of performance as it allows us to quantify responses in a scalar manner.

**Methods**

**Design**

**Independent variables.** The within-group independent variables are Preference (Like, Dislike and Neutral) and Reward Association (High Reward, Low Reward and No Reward), which will be examined in Experiment 1 and Experiment 2 respectively. Preference level is determined by participants’ subjective rating of likeability for the stimuli before the experiments. Each stimulus is then assigned to one of the three preference levels. On the other hand, Reward Association levels are experimentally manipulated by administering a reward association task to participants. Only stimuli which have been rated neutrally by participants in the earlier likeability rating task are used in the Reward Association trials and its subsequent test of VWM. In this way, we minimise potential contamination of preferences while testing the effects of reward association on VWM performance. In the Reward
Association trials, four stimuli would be randomly assigned to each of the three possible reward levels. Stimuli from the three reward levels appear an equal number of times across the memory arrays, but only High and Low Reward stimuli are tested. No Reward stimuli only served as memory items and are never tested. In this way, both High and Low Reward stimuli are more task-relevant than No Reward stimuli. Hits for the High Reward stimuli will result in a stronger positive feedback (Correct! +50 points) than hits for Low Reward stimuli (Correct! +5 points). Experiment 2 is a test of VWM performance to assess the effects of the reward association task. In Experiment 2, the three stimulus types of High, Low and No Reward are probed an equal number of times (60 trials each) and VWM performances in these three conditions will be compared.

The between-subjects independent variable is Complexity, for which there are two conditions, Simple and Complex. In the Simple condition, experimental tasks are run using a set of 100 coloured shapes of solid colours (20 shapes X 5 colours). In the Complex condition, experimental tasks are run using an existing database of coloured drawings depicting real-world objects (Rossion & Pourtois, 2004), which has considerably greater visual detail and symbolic meaning than the 100 coloured shapes. Although the simple stimuli were intended to encompass little symbolic meaning, we do recognise that they are not completely devoid of it. For example, a heart shape would presumably embody more meaning than a filled circle, while a filled circle with a quadrant missing may resemble the Pacman icon to some persons (See Figure 1 for examples of the simple stimuli). Since there was research which has considered coloured polygons as complex (Jiang, Shim & Markovski, 2008), it should also be clarified that use of the label “simple” in this paper is to juxtapose its visual detail and the level of meaning they imbue with that of the complex stimuli. In summary, the two stimuli sets were labelled simple and complex respectively for two reasons
one, the simple set items contain less visual details than the complex stimuli set, and two, items from the simple set are also imbued with less semantic meaning.

**Dependent variables.** Finally, visual working memory performance will be quantified using Angle Error and Accuracy. Angle Error is the degree of deviation between a response and the target location. Figure 3 illustrates how Angle Error is derived. Accuracy is the proportion of correct trials in each condition (number of correct trials in a condition/total trials in the condition). A response is regarded correct if its Angle Error is less than 36 degrees. This value is chosen as a cut-off because it is half of the angle of separation between two adjacent items on the memory display -i.e. 72 degrees - as shown in Figure 4.

![Shapes](image1)

*Figure 1.* Not drawn to scale: examples of simple stimuli in all the five possible colours.

There is a total of 20 unique shapes in each colour.

![Pictures](image2)

*Figure 2.* Not drawn to scale: items from the Rossion & Pourtois (2004) picture set which are used as stimuli in the Complex condition.
Figure 3. An illustration of how Angle Error is derived from a participant’s mouse click position on screen. The grey figure indicates original location of the test item. The dashed ring indicates the range of possible locations on which memory items appear in any given trial. The cross indicates position of the mouse click, while the dot indicates the central point on the screen with coordinates (0,0). Angle Error \( y \) is calculated using the centre of the screen as reference point.

Participants

Participants were recruited through two ways – students were recruited through posters and advertisement in the university campus (n=7) and employees of a government agency were recruited via their work email (n=39). Participants were reimbursed at a rate of $10 per hour for their time. Participants were all male and age range 20 – 28. Due to scheduling constraints, not all completed all parts of the Experiments. Table 1 shows the distribution of participants in each experimental condition.

Table 1

<table>
<thead>
<tr>
<th>Complexity</th>
<th>Type of Stimuli Used</th>
<th>Experimental Condition</th>
<th>Sample Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simple</td>
<td>Coloured shapes</td>
<td>Preference Rating</td>
<td>28</td>
</tr>
<tr>
<td>Complex</td>
<td>Coloured drawings of real-world objects</td>
<td></td>
<td></td>
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<tr>
<td>------------------</td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td>Experiment 1a: Test of Visual Working Memory based on preference ratings</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Reward association trials</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>Experiment 2a: Test of VWM after reward association</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preference Rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experiment 1b: Test of VWM based on preference ratings</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reward association trials</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Experiment 2b: Test of VWM after reward association</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There was overlap of participants in across the complexity conditions, such that all 25 who participated in Experiment 1a (test of Preference in Simple condition, \( n=25 \)) also did Experiment 1b (test of Preference in Complex condition, \( n=40 \)). Likewise, all 28 who participated in Experiment 2a (test of Reward Association in Simple condition, \( n = 28 \)) also did Experiment 2b (test of Reward Association in Complex condition, \( n = 38 \)). Since at not all participants who took part in the Complex condition were in the Simple condition, the second IV, Complexity, was assigned as a between-groups variable. Order of receiving Experiment 1a and 1b was counterbalanced across participants who were involved in both conditions of Complexity in Experiment 1. Likewise, order of Experiment 2a and 2b was counterbalanced across participants who were involved in both conditions of Complexity in Experiment 2.

**Apparatus**

Stimuli were either presented on a 15.6-inch Dell monitor of resolution 1152X864 and refresh rate 60 Hz, or a 13.3-inch Dell monitor with resolution 1366X768 and refresh rate
60 Hz. Participants responded on either a keyboard or mouse provided between the display screen and themselves.

**Stimuli**

The simple stimuli are coloured shapes of varying visual complexities in the following RGB colours – Orange (247, 146, 63); Green (133, 255, 162); Purple (179, 162, 199); Pink (249, 119, 252) and Blue (148, 218, 228). They were created using the “insert shapes” function of the Microsoft Powerpoint software. There were twenty unique shapes in five possible colours. Stimulus sizes were standardized on the computer screens to be 2.2 cm X 2.2 cm.

Complex stimuli set consists of 248 items and were taken from the larger 260-item Rossion & Pourtois Picture Set (See Figure 2 for examples) (Rossion & Pourtois, 2004). Stimuli with a portrait orientation is standardised to 1.8cm x 2.7cm and those with a landscape orientation, 2.7cm x 1.8cm. 12 items were dropped from the original set due to artefacts produced in the process of conversion.

**Procedure**

A pilot test was conducted whereby 6 individuals (3 males) were asked to rate their liking for stimuli for the Simple and Complex stimuli sets. The pilot test was necessary to establish two things – first, that both stimuli sets were able to elicit a sufficiently broad range of ratings, and second, that within each rating category – Like, Neutral and Dislike - there were sufficient stimuli. These two conditions are needed to establish the three required levels of the Preference IV. Another objective of the pilot test was to ensure that no specific colours (for the simple set) or semantic category (for the complex set) were systematically linked to
either end of the preferences ratings. This is to avoid confound of colour or concepts with preference. Results of the pilot test indicated that these conditions were met. For the simple stimuli set, five out of the six raters gave sufficient spread in their responses, in that their responses were spread across at least 4 points on the 7 point Likert scale. The data from the same five individuals also showed that there were at least 18 items within each of the three preference categories. Lastly, there was no strong positive or negative bias towards any colour – with the mean rating for Orange, Green, Purple, Pink and Blue stimuli as follows: 3.97, 4.15, 4.3, 4.23, 4.36.

**Preference rating task.** Participants were required to complete a preference rating task online no earlier than 48 hours before the experimental tasks. As it is uncertain how stable such preferences are over time, use of an arbitrary cut-off time is thought to be necessary. Using the preference ratings, the experimental tasks were then configured so that stimuli used for each condition were unique to every participant.

In the preference rating task, participants were asked to rate items in the simple and/or complex stimuli sets on a 7-point scale of likability with the instructions “Rate each picture according to how much you like it”. Items which cluster at the two extreme ends of the scale were assigned as Disliked and Liked respectively, while those clustered in the middle are assigned as Neutral. Assignment of stimuli in each preference level was based on their rank order on the likeability scale within each participant, rather than absolute cut-off points. For example, a participant may have a rating range of 2-6, in this case 20 of the highest rated stimuli would be assigned Liked while the 20 of the lowest rated assigned Disliked. Another 20 items from the middle range scores were then assigned as Neutral. As a result, the mean rating for Like stimuli for one participant could be different from the mean rating for Liked stimuli for another participant. Participants whose stimuli are not spread over a sufficient
range of preference ratings were excluded from taking part in Experiment 1 and proceeded to Experiment 2. Therefore, although 28 participants took part in the preference rating task for Simple stimuli, only 25 went on to Experiment 1a (Table 1).

**Experiment 1a and 1b: Test of visual working memory based on preferences.** In this series of experiments participants underwent a location-recall VWM task. They were presented with instructions on a screen and could take their time to read before proceeding. They were then allowed 20 to 30 trials to familiarise with their task before beginning the actual experiment. The experimental task starts with a blank visual display on a white background with a fixation cross in the centre (700ms). A memory display comprising 5 items were presented for 500ms. This display consists of one Liked item, one Disliked item and three Neutral items – the relative positions of stimuli from each preference were shuffled across trials. Items were equidistant from the central fixation cross, 72-degree apart and could be at any possible location on the circumference of an imaginary ring 360 pixels in radius (Figure 4). This is followed by an ISI (blank display), and finally a test display showing the probed item at the position of the centre fixation cross.

The ISIs for Complex and Simple conditions were designed to differ - 1200ms for the former and 1000ms for the latter. During the pilot trials of experimental paradigm across both stimulus sets, it was found that participants were much better with the Complex than Simple stimuli. To ensure comparable task difficulty between the two conditions, the experimental parameters were adjusted by allowing a longer ISI for the complex condition trials. This manipulation of different ISIs for the two Complexity conditions served to mitigate for the possibility that any observed Reward-VWM or Preference-VWM trend differences between the conditions was a result of task difficulty rather than the stimuli differences.
Participants are required to click on the location where the probed item first appeared (Figure 5). Trial type – Like, Dislike or Neutral – is defined by the probe stimuli. For instance, a Like Trial will have a Liked stimulus as the probe. A total of 180 trials were run, with 60 trials per condition – Like, Neutral and Dislike. The simple stimuli set was used in Experiment 1a while the complex one was used in Experiment 1b.

**Experiment 2a and 2b: Tests of visual working memory after learning reward associations.** After the reward association tasks, tests of VWM based on the same paradigm and experimental parameters as Experiment 1a and 1b were given to participants. A total of 180 trials were run, with 60 trials per condition – Like, Neutral and Dislike. In every trial, the memory display will consist of one Liked item, one Disliked item and three Neutral items. Only four items were probed within each Preference category. The simple stimuli set was used in Experiment 2a while the complex one was used in Experiment 2b.
Figure 5. A) A sample trial for Experiments 1 and 2. Participants click on the screen to indicate the original location of the probe stimuli. B) Feedback display during the reward association trials. The reward association trials are similar to Experiments 1 and 2 except that the five memory items always appear in five fixed locations on the screen without rotating. After a response is made, feedback is shown on the screen for 1000ms. Participants respond with five pre-assigned keys on the keyboard instead of mouse clicking.

Results

Before delving into the relationships between Preference, Reward, Complexity and VWM performance, we examine the overall VWM performance of the participants in each of the Complexity Conditions. This is to provide an indication of the appropriateness of task difficulty as well as the degree of task engagement. Overall VWM performance across both Experiment 1 and 2 data are presented in Table 2.

Based on our experimental design, chance performance is estimated to be 20%, while perfect performance is 100%. Given this, we consider that the observed range of 75 – 83 %
correct trials satisfactorily reflect adequate task engagement as well as absence of ceiling or floor effects across all experimental tasks.

**Main Effects of Complexity**

We also wanted to address if the overall task difficulty significantly differed between complexity levels. Based on the descriptive statistics in Table 2, there seems to be better performance in the Complex condition than the Simple condition across both Experiments. ANOVA revealed that VWM performance differences between Complex and Simple condition in Experiment 1 were not statistically significant. However, the advantage of Complex stimuli over Simple Stimuli was statistically significant in Experiment 2 in terms of lesser mean Angle Error in the former - mean difference in Angle Error = 6.63, $F(1,64) = 5.32, p = .024, \eta^2_p = .077$.

Table 2

**Overall VWM Performance according to Complexity**

<table>
<thead>
<tr>
<th></th>
<th>Experiment 1 (Preference as IV)</th>
<th>Experiment 2 (Reward Association as IV)</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Standard Error</td>
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<tr>
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</tr>
<tr>
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<tr>
<td>Complex</td>
<td>28.648</td>
<td>2.157</td>
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</table>
**Experiment 1: Effects of Preferences on visual working memory**

To reiterate, we are keen to examine the effects of Preferences on VWM performance in both Simple and Complex conditions, and we also would like to know if the trends differ for these two conditions.

To examine the effects of Preferences and Stimuli on VWM performance, a 3x2 mixed ANOVA was run with factors for Preferences (Like, Neutral, Dislike) and Complexity (Simple Stimuli or Complex Stimuli). The results are discussed for two DVs—Proportion Correct as well as Angle Error, which will also be referred to collectively as VWM performance. Figures 6 and 7 illustrates results of the two-way ANOVA in terms of Proportion Correct and Angle Error. In the Simple condition, VWM performance was better for Dislike and Like than Neutral stimuli. However, an almost reverse trend is observed for the Complex condition, whereby Figure 6 showing that the effects of Preference on Proportion Correct was different for Simple vs Complex Stimuli conditions. Simple effects analysis showed that Preference influenced Proportion Correct - $F(2,48) = 3.399$, $p = .042$, $\eta_p^2 = .124$ - in the Simple but not the Complex condition. Error bars indicate SEM.
Figure 7. Results from Experiment 1 showing that the effects of Preference on mean Angle Error was different for Simple vs Complex Stimuli conditions. Simple effects analysis for both Complexity conditions were not significant. Error bars indicate SEM.

VWM performance for Neutral stimuli appears better than both Dislike and Like stimuli. There was no significant main effect of Complexity for either Percentage Correct – F(1,63) = .314, p = .577, \( \eta^2_p = .005 \) – or Angle Error – F(1,63) = .863, p = .356, \( \eta^2_p = .014 \), indicating that participants’ overall task performance was not influenced by the complexity of stimuli. There was a significant Preference X Stimuli interaction on Percentage Correct – F(2,126) = 6.44, p = .002, \( \eta^2_p = .093 \). There was also a significant interaction effect on Angle Error, with the Greenhouse-Geisser corrected F values: F(1.8,112.9) = 4.26, p = .020, \( \eta^2_p = .063 \). The interaction effects present in both DVs mean that the effect of Preference on visual working memory performance is different for Simple vs Complex condition.

Within-subjects contrasts verified how the Preference-VWM trend differed between the Simple and Complex conditions. First, we looked at the contrasts between Dislike (Level 1) and Neutral (Level 2) for Proportion Correct as well as Angle Error. Both of these contrasts were significant, F(1,63) = 13.89, p < .001, \( \eta^2_p = .181 \) and F(1,63) = 6.18, p = .016,
\( \eta_p^2 = .089 \), respectively. This shows that when the task involves visually simple and relatively meaningless stimuli, participants were better in their VWM tasks with stimuli they disliked than stimuli they felt indifferent to (Neutral). However, when the task involves more meaningful and visually detailed stimuli, a different trend was seen, whereby the performance for Neutral stimuli was better than liked and disliked ones.

We also found that contrasts between Neutral (Level 2) and Liked (Level 3) stimuli for both DVs Proportion Correct and Angle Error were significant, \( F(1,63) = 8.099, \ p = .006, \eta_p^2 = .114 \), and \( F(1,63) = 9.298, \ p = .003, \eta_p^2 = .129 \), respectively. In other words, participants’ VWM performance seemed better for simple stimuli they liked compared to those they were indifferent to. This effect was not present in the task using complex stimuli, whereby participants did marginally better for Neutral than Liked stimuli.

While informative, the above trend differences between the complexity conditions does not tell us how robust the effect of Preference is on VWM performance within each complexity condition, which is also one of our key research questions. As such, we proceeded to conduct one-way ANOVAs for the Simple and Complex conditions independently. In the Simple condition, Preference influenced Proportion Correct - \( F(2,48) = 3.399, \ p = .042, \eta_p^2 = .124 \) - but not Angle Error - \( F(2,48) = 3.038, \ p = .069, \eta_p^2 = .112 \). Pairwise comparisons showed that participants did better in the Dislike condition than the Neutral condition, with a mean difference of .045, \( p = .042 \). Conversely, in the Complex condition, effects of preference on VWM performance were not robust enough to reach significance for either DV - the F statistic for Proportion Correct is \( F(2,78)= 2.50, \ p = .088, \eta_p^2 = .06 \), while that for Angle Error is \( F(2,78) = .647, \ p = .526, \eta_p^2 = .016 \).

**Experiment 2: Effect of Reward Association on VWM**
To investigate the hypothesized effects of reward association, a 3 x 2 mixed ANOVA was run with factors for Reward (High, Low or No) and Complexity (Simple Stimuli or Complex Stimuli). There was no main effect of Reward for both Angle Error $F(2,128) = .2.531$, $p = .084$, $\eta_p^2 = .038$ and Proportion Correct, $F(2,128) = .762$, $p = .469$, $\eta_p^2 = .012$. There was also no interaction between Reward and Complexity for both Angle Error $F(2,128) = .575$, $p = .564$, $\eta_p^2 = .009$, and Proportion Correct $F(2,128) = 1.866$, $p = .159$, $\eta_p^2 = .028$, showing that effect of Reward on VWM performance did not markedly differ between Complex and Simple stimuli. However, as earlier described, there was a main effect of Complexity on Angle Error – mean difference $= 6.63$, $F(1,64) = 5.32$, $p = .024$, $\eta_p^2 = .077$. Participants were seen to have greater error in the Simple Stimuli condition compared to the Complex Stimuli condition.

Despite null results from the two-way ANOVA, we went ahead to conduct one way ANOVAs for each complexity condition. This is to be sure that the lack of effect in one condition did not obscure effect of reward in another. The analyses for the Simple condition showed no significant effects of past reward associations on the DVs – for Proportion Correct, $F(2,54) = .235$, $p = .792$, $\eta_p^2 = .009$; and for Angle Error, $F(2,54) = .273$, $p = .762$, $\eta_p^2 = .010$. However, in the Complex condition, past reward association has a modest effect on Angle Error- with the Greenhouse-Geisser corrected values, $F(1.694, 64.367) = 3.91$, $p = .031$, $\eta_p^2 = .093$ - and no effect on Proportion Correct. Pairwise comparisons revealed that Angle Error was significantly lower in the High Reward condition than the No Reward condition, with a mean difference of 3.19, $p = .011$ (Figure 11). All other pairwise comparisons of mean Angle Error in the Complex condition did not reach significance.
\textbf{Figure 8.} Results from Experiment 2 showing the effects of Reward and Complexity on the DV Angle Error. There were no significant main effects of Reward and no Reward X Complexity interaction. There was a significant effect of Complexity, with a lower mean Angle Error in the Complex condition. Simple effects analysis for Reward on Angle Error in the Complex Stimuli condition reveals an effect of Reward, F(1.694, 64.367) = 3.91, p = .031, $\eta_p^2 = .093$. Error bars indicate SEM.

\textbf{Figure 9.} Results from Experiment 2 showing the effects of Reward and Complexity on the DV Proportion Correct. There were no significant main effects of Reward nor Complexity, and no Reward X Complexity Interaction. Error bars indicate SEM.


Discussion

The current study set out to find out the effects of preferences and past reward associations on VWM for two types of visual stimuli – one which is visually simpler and contains little semantic meaning, another which is visually more detailed and contains semantic meaning. The results of our studies revealed that stimulus preference has effects on VWM performance in the Simple condition but not the Complex condition. We also found modest effects of past-reward association on VWM performance in the Simple but not Complex condition.

Before going further to discuss the effects of interest, it should be emphasized that the task difficulties for the two complexity conditions were adjusted, by way of different ISIs, so that they are comparable. As such, we do not expect to see strong main effects of Complexity in any of our analyses. The between-subjects analyses for Complexity on VWM performance largely, though not entirely, confirmed this expectation. There were no main effects of Complexity on either outcome measure in Experiment 1, and no main effects of Complexity on Proportion Correct in Experiment 2. Main effect of Complexity was only observed on the DV Angle Error in Experiment 2, whereby there was better performance for Complex condition. Given that the overall task performance across the Complexity conditions are largely comparable, any observed trend differences between the conditions should not be attributed to task difficulty.

Effect of Preferences on VWM

Our hypotheses regarding effects of preference on VWM performance were not supported. We were expecting that strongly liked stimuli would be better remembered than the other stimuli. However, this pattern did not emerge in our results for both complexity conditions. Instead, we discovered an interesting trend whereby presence of extremely
positive or negative valence benefited VWM in the simple stimuli condition. In the complex condition, however, preferences appeared to exert little, if any, influence on VWM performance.

Possibly, the presence of valence facilitates the encoding of stimuli which are otherwise meaningless and hard to remember – that is, the simple stimuli. Such valence may serve as anchors to which arbitrary stimuli might be better remembered. It is possible that preferences for relatively arbitrary stimuli are more affectively-based and automatic, presumably because of the minimal engagement of higher order evaluative mechanisms for stimuli of little semantic significance. On the other hand, evaluating complex stimuli may recruit higher order cognitive processes to a larger extent because of the semantic meaning and associations they embody. For instance, the notion of vices behind the image of a cigarette; or, the notion of violence elicited by the image of a gun, may come to mind during the evaluation of complex stimuli and such notions may be positive or negative, upon which preferences may be based upon. We argue that the expressed preferences towards the complex stimuli may be less immediate than the simple stimuli set due to more involvement of higher order processing. Consequently, affectively-based preferences (the simple stimuli set) may exert stronger effects on VWM than preferences which are less-affectively based (the complex stimuli set).

An alternative explanation for the different results between Simple and Complex stimuli could arise from the different average preference strength for each stimulus set. During preference rating task, participants were asked to assign ratings within each stimulus set, without any between-set comparison. It is hence possible that participants, on average, prefer one stimuli set more than the other. Because the liking appraisals are done separately, a 7 rating in the simple stimuli rating task may not represent the same preference strength as a
7 rating in the complex stimuli set. Consequently, such difference may be the reason why the effect of preference on VWM is not seen the Complex stimuli - it may be that the average preference strength for Complex stimuli lies above or below the threshold for which VWM is sensitive to preference. However, we find this explanation less compelling given that the Complex stimuli have shown a wider spread of preference ratings than the Simple stimuli, yet it is in the Simple stimuli that we observe a significant preference effect.

**Reward Association on VWM**

We anticipated that VWM performance for High Reward stimuli would be better than Low Reward and No Reward ones across both stimuli conditions. Our findings only provided weak support for the hypothesized trends. First, there was no influence of past reward associations on VWM performance in the Simple condition. Next, in the Complex condition, VWM performance was more accurate when participants had to recall the location of stimuli previously associated with high reward than those which were never associated with reward. The difference in VWM performance between High and Low Reward trials were in the predicted direction but did not reach statistical significance. A difference between High and Low Reward trials would have provided more definitive evidence for the influence of reward, as both groups of stimuli had been probed the same number of times during the training phase, while the No Reward stimuli only served as memory items but were never probed for location recall during the training phase. As such, it may be that selection history – i.e. the fact that participants were previously trained to attend to the High and Low Reward stimuli but never the No Reward stimuli - rather than the reward feedback per se that led to better performance. However, we believe that the performance advantage cannot be largely attributed to selection history since VWM performance measures in the Low Reward trials were very similar to that in No Reward trials. Hence, it is more likely that the lack of effect
between High and Low Reward trials is due to weak discriminability between High and Low Reward feedback.

To better make sense of the current findings, it is important to draw reference to three earlier studies which found notable effects of reward associations on VWM performance. The first is Infanti et al.’s study (2014), which explored the effects of the reward associated feature, a colour singleton, when it was part of a target and when it was part of a distractor. When the reward associated colour was embedded within the target, the study found that raw accuracy between high reward feature targets and low reward feature targets did not differ (Infanti et al., 2014). This manipulation is similar to Experiment 2, in that the reward feature defined the target identity. Also, our results partially parallel theirs in that we found no VWM performance differences between High and Low Reward targets. However, when the reward-associated features were embedded in distractors instead of targets, it was found that distractors associated with high reward caused greater interference effect than distractors associated with low reward. Interference effect is the difference in accuracies between congruent trials (when target resembles the reward-associated distractor) and incongruent trials (when target does not resemble the reward-associated distractor). The authors believed that the reward association effect might have been too subtle to be observed by raw accuracy measures in their paradigm (Infanti et al., 2014). Our study design did not allow us to capture similar interference effect, as such we cannot ascertain if such effects exist in the current reward manipulation.

While Infanti et al.’s study used memory displays which contained colour singletons among other grey items – which was the reason they thought overwhelmed the effect of their reward association - our experimental design was more similar to Gong and Li’s study (2014) in that the latter did not use a memory display with any singletons which could “pop out”
amongst other memory items. Every item in their memory display had a unique colour, which parallels this study’s memory display, as each memory item had a unique identity and there was no one item which stood out amongst the others systematically. As predicted, Gong and Li (2014) documented reward association effects in terms of better detection sensitivities when target was associated with a highly rewarded colour. The present study may have failed to isolate the effects of reward on VWM performance due to several differences in the experimental design. First, it could be because they had used a many more training trials than our current study did, as such the learning effects were more robustly established. Second, the lack of effect may be due to the lack of incentive value from non-monetary performance feedback.

It is also crucial to note that at the point of this research, no known studies have attempted to associate reward with a compound object with the aim of testing the object’s subsequent effects on VWM. Previous research which documented VWM effects of reward associations have used pared-down single features such as colour or orientation to associate with different levels of reward (Thomas, FitzGibbon, Raymond (2015); Infanti et al., 2014, Gong & Li, 2014). The present study may be the first to test the effectiveness of associating reward values to an object with multiple features, and then subsequently testing its effectiveness in modulating VWM. As such, it is presumably more challenging for robust item-reward representations to form – i.e., more training trials may be required.

The lack of reward association effects on simple stimuli may have to do with the latter’s higher threshold for encoding compared to the complex stimuli. The complex stimuli used in our experiment illustrate real world objects and are rich in semantic meaning, which facilitates their perceptual processing (Lupyan & Spivey, 2008) and forming of representations, relative to the simple stimuli which are relatively meaningless. Since
information from the complex stimuli can be encoded in a more compressed fashion (Brady, Konkle & Alvarez, 2009). For example, the mind can represent the flower image as a single entity, “flower”, instead of a “looped shape + a long line with green, blue and yellow”; on the other hand, encoding of the simple stimuli consists of at least two pieces of information (e.g., Pink + Triangle). As such, we posit that stimuli-reward associations can be more easily formed for the Complex set. Consequently, it is likely that the stimuli-reward associations formed for the simple stimuli were much weaker given the same number of trials (i.e., 50 trials per stimuli in our experiments), and presumably insufficient to exert its effect on VWM performance. Furthermore, the repertoire of simple stimuli is made of repeated colours and shapes combined to result in the 100 unique object identities. Due to such repetition of features across stimuli, there is potential for interference between, say, a High Reward pink triangle and a No Reward green triangle, as the reward association effect may carry over to the non-rewarded item which shares a common feature. In other words, the intra-set stimuli distinction in the simple set is poorer than the intra-set stimuli distinction in the complex set, and such poor discriminability between stimuli may have obscured the effects of reward associations.

In summary, although the effects of reward associations on VWM performance were not as robust as we had anticipated, we did find that the effect of reward associations on VWM is different for visually simple and meaningless stimuli compared to visually complex but meaningful stimuli. Also, because only neutrally rated stimuli were chosen for Experiment 2, we mitigated for a possible interference of stimuli valence on the VWM performance.
Limitations

We did not explicitly check for the stability and robustness of the preference ratings during the pilot test, i.e., we did not perform an assessment of test-retest variability during pilot testing. The current study did not establish how enduring the expressed preferences were over time for the two stimuli sets. We had implicitly assumed preferences for both sets of stimuli would be similarly stable. However as discussed above, that may not have been the case. Establishing a degree of certainty about the stability of the preference ratings over time has implications on the subsequent effects of preferences on VWM performance, and also how the results may be interpreted.

Another key point of deviation between this study and the previous ones that could explain the weak effects of reward is that in the current study, stimuli associated with high reward and low reward would appear together in a memory display, while previous studies had only one item with reward association in each memory display. In retrospection, our memory display ought to be configured such that there was only one reward-associated stimulus (either High or Low reward) amongst other neutral stimuli to increase the discrimination power between the effects of high vs low reward associations. As the current display consists of stimuli of both high and low reward association, they may compete with each other for attentional or encoding resources, across two different locations on the screen. Resulting advantage of the reward manipulation may be consequently diffused.

Although effort was made to standardise the Complex and Simple stimuli sizes, the contrast ratio of the stimuli sets against the white display background was not standardised. Intuitively, compared to the Simple stimuli, the Complex stimuli appear to have higher contrast against the white background for two reasons – one is the use of black or dark outlines for most, not all, pictures in the Complex set, the other being that some of the higher
contrast pictures in the Complex set has a contrast ratio of almost to 21:1 (for example, the image of a very dark coloured bug). On the other hand, the monotone Simple stimuli have no outline, and have contrast ratios between 1.25:1 (blue) to 2.36:1 (purple) with a white background. Beyond such intuitive comparisons, the precise measurement of the contrast ratios for the Complex stimuli should be made and the current stimuli sets improved by normalising their maximum or average contrast.

Considering the rather weak effects of reward on VWM in our results, it may also be postulated that the use of non-monetary incentive, in the form of performance feedback, had not been an effective reward mechanism. There was no manipulation check in our study to evidence that participants successfully formed associations between reward and stimuli. Since the use of non-monetary reward is relatively novel in the area of VWM studies, the study could be improved by conducting a pilot test to show that the reward-manipulation task results in some form of measurable behavioural change in participants. This way, it could be more definitively concluded that any lack of effects is due to the stimuli properties but not the reward efficacy. Future studies may consider juxtaposing the effects of both monetary and non-monetary yet robust incentives (e.g. by way of motivational statements which imply task performance as an index of intelligence and/or providing normative benchmark for performance) to tease apart the effectiveness of non-monetary incentives.

**Conclusion**

This study explored the preference-VWM and reward-VWM relationships with two sets of stimuli, one which is more meaningful and visually detailed than the other. This is possibly the first study to go beyond the use of simple features in examining effects of preferences on VWM, and the results suggest that subjective preferences can affect VWM even in more visually detailed stimuli, although meaningfulness of the stimuli may modulate
this effect. We found that the effects of non-monetary incentives as operationalised in this study was suboptimal, and as such we proposed alternative approaches to incentivise VWM tasks. More importantly, our findings provide preliminary evidence that the effects of reward and preference on VWM is different for meaningful compared to more arbitrary stimuli.
References


