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Enhancing visual working memory encoding: The role of target novelty

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Abstract

Perceptual salience improves the encoding of information into visual working memory (WM). However, the factors that contribute to this facilitation effect are not well understood. This study tested the influence of target familiarity on WM encoding. In each trial, participants were presented with either one or three targets and asked to encode their locations into WM. In Experiment 1, target familiarity was manipulated by presenting either an upright (familiar target) or upside-down (unfamiliar/novel target) A. Increasing the novelty of the targets led to improved performance in the spatial WM task. Experiment 2 showed that participants were faster in responding to novel versus familiar targets in a spatial detection task. Experiment 3 demonstrated that the beneficial effect of target novelty on WM encoding was not driven by differences in low-level features. Our results suggest that target novelty enhances the processes required for WM encoding, just as it facilitates perceptual processing.

Keywords

Attention; Encoding; Novelty; Salience; Spatial working memory

At any instant, out of the multitude of information that is available to the visual system, only a small subset can be selected for further cognitive processing. The human attentional system thus uses many mechanisms to limit processing to items that are salient and currently relevant to behaviour (Corbetta & Shulman, 2002; Egeth & Yantis, 1997; Posner, 1980). Perceptual salience can be driven by stimulus features such as colour, intensity, or sudden onset (Duncan & Humphreys, 1989; Egeth & Yantis, 1997; Itti & Koch, 2001; Nothdurft, 1993a; Treisman & Gelade, 1980), as well as prior knowledge, expectations, and current goals (Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992; Posner, Snyder, & Davidson, 1980; Wolfe, Horowitz, Kenner, Hyle, & Vasan, 2004). Even when selected, only a few items can be held in visual working memory (WM; Phillips, 1974). Although it is largely assumed that the capacity of visual WM is restricted to about three or four organized

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chunks (Cowan, 2001; Luck & Vogel, 1997; Pashler, 1988; Todd & Marois, 2004), it is less well understood how this limitation may be modulated or even overcome.

Recently, there has been considerable debate regarding whether visual WM capacity is fixed to a specific number of slots (Anderson, Vogel, & Awh, 2011; Fukuda, Vogel, Mayr, & Awh, 2010) and/or is influenced by the complexity of the items stored (Alvarez & Cavanagh, 2004; Bays & Husain, 2008). However, is visual WM solely modulated by stimulus factors such as object number and complexity, or can it be influenced by attentional mechanisms that help to overcome perceptual processing limitations?

Increasing evidence suggests that WM and attention closely interact (Awh & Jonides, 2001; Awh, Vogel, & Oh, 2006) during different stages of processing, including encoding (Jolicæur & Dell'Acqua, 1998, 1999; Vogel, Luck, & Shapiro, 1998), maintenance (Awh, Jonides, & Reuter-Lorenz, 1998; Cowan & Morey, 2007; Oh & Kim, 2004; Woodman & Luck, 2004), and retrieval of information from WM (Theeuwes, Kramer, & Irwin, 2011). With regard to WM encoding, recent findings indicate that similar to its beneficial effect on perceptual processing, perceptual salience can facilitate WM as well (Fine & Minnery, 2009; Schmidt, Vogel, Woodman, & Luck, 2002). For instance, Fine & Minnery (2009) demonstrated that increasing the perceptual salience of the targets to be encoded by changing low-level stimulus features, such as colour, intensity, and contrast, improved WM performance in a visuospatial task. Similarly, top-down driven attention can enhance performance in visual WM tasks (Sperling, 1960) by increasing target salience both through foreknowledge of the target's location (Schmidt et al., 2002) and identity (Vogel, McCollough, & Machizawa, 2005).

In the present study, we investigated the influence of another important attentional bias on visual WM, the bias towards novelty (Desimone & Duncan, 1995; Treisman & Gormican, 1988; Wolfe, 2001). Heightened sensitivity to novel events is a well-known phenomenon (Fantz, 1964; Ranganath & Rainer, 2003) that is of ecological importance. For well-learned or unchanging information, perceptual processing and/or motor responses can be automated for efficiency, but this automaticity breaks down if a change occurs, which prompts an orienting response that facilitates the processing of the novel stimuli (Sokolov, 1963).

A substantial amount of research has focused on the influence of stimulus familiarity on visual processing. Studies of visual search consistently show that participants are faster at finding an unfamiliar/novel target embedded among familiar distractors than the reverse (Treisman & Gormican, 1988). For instance, a character that is presented upside-down or mirror reversed is detected more rapidly among characters presented upright, as compared with an upright character that is presented among upside-down or mirror reversed characters (Frith, 1974; Reicher, Snyder, & Richards, 1976; Richard & Reicher, 1978; Wang, Cavanagh, & Green, 1994). This pattern of findings has been reported with various stimuli such as letters and digits (Frith, 1974; Reicher et al., 1976; Richard & Reicher, 1978; Shen & Reingold, 2001; Wang et al., 1994), two-dimensional (Reicher et al., 1976; Wolfe, 2001), and three-dimensional shapes (Sun & Perona, 1996). Importantly, the beneficial effect of target novelty on perceptual processing has also been observed when low-level feature differences between familiar and unfamiliar stimuli were carefully controlled (Shen & Reingold, 2001). Taken together, there is considerable evidence for a beneficial effect of target novelty on perceptual processing. However, it is unclear whether increasing target salience through its novelty would facilitate WM encoding and thereby improve performance in WM tasks.

In the present study, we used a paradigm that varied the degree of target familiarity and tested its influence on WM performance (see Figure 1). The task required participants to encode the locations of one or three target items into WM (WM load 1 vs. 3). The familiarity of the target items was manipulated by presenting either the letter A upright (familiar target) or upside-down (unfamiliar/novel target) during the encoding phase. Thus, the manipulation of target familiarity was based on a local change in orientation. Any global changes in low-level stimulus features were avoided.

We asked the following questions. Does increasing target salience as determined by the novelty of the targets to be encoded improve performance in a spatial WM task? If so, does this putative advantage of target novelty for spatial WM performance differ between conditions of low versus high WM load? Previous evidence suggests that the enhancement effect of perceptual salience on visuospatial WM is more pronounced with high WM load (Fine & Minnery, 2009). Therefore, we expected that an improvement in WM performance for novel versus familiar targets would be stronger in the condition of high versus low WM load.

EXPERIMENT 1

In this experiment, participants were asked to encode the locations of either one or three target items into WM. The familiarity of the target items was manipulated by presenting either familiar targets (the letter A presented upright) or novel targets (the letter A presented upside-down) during the encoding phase. Similar to its beneficial effect on visual processing (Frith, 1974; Reicher et al., 1976), we expected that the novelty would enhance the salience of the targets and in turn improve WM performance.

Methods

Participants—Forty-six subjects (22 males, mean age = 24.1 ± 6.1 *SD*) participated for course credit or monetary reimbursement. Participants reported normal or corrected-to-normal visual acuity and no history of neurological or psychiatric illness. The study was approved by Vanderbilt University Institutional Review Board (IRB). All participants gave written informed consent.

Stimuli—Stimuli were presented and responses collected on a PC running Matlab software (Mathwork Inc., Natick, USA) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Target stimuli were black “A”s of approximately 0.48° visual angle, displayed upright or upside-down on a white background (see Figure 1). Stimuli were spaced evenly apart (1.9°) and appeared along an imaginary circle (4.8° radius) including 16 positions around a centrally presented fixation cross (0.36°). The positions of 0°, 90°, 180°, and 270° were excluded. A description of how target positions were determined in the different conditions is given later.

Design and procedure—We used a 2 × 2 within-subjects factorial design, with two levels of target familiarity (familiar vs. unfamiliar/novel) and two levels of WM load (one target vs. three targets). Each of these four experimental conditions was presented equally often (32 trials per condition). Participants performed one practice block (10 trials) followed by four experimental blocks of 32 trials each. The trials were presented fully randomized across blocks.

In the WM load 3 condition, each trial began with presenting a fixation cross at the centre position for 1 s, then three targets were presented sequentially at three different positions, each for a duration of 750 ms and separated by an interstimulus interval of 250 ms. A long stimulus exposure time was chosen to maximize perceptual encoding and to prevent any decrement in performance due to suboptimal encoding (Anderson et al., 2011; Luck & Vogel, 1997). Within each trial, the target positions were determined pseudorandomly with the constraint that the targets appeared in three different quadrants of the screen and that they appeared at least two positions (3.8°) farther apart from each other on the imaginary circle. In the WM load 1 condition, only the first target appeared at a position on the imaginary circle; the second and the third target appeared at the centre of the screen.[1] In the unfamiliar/novel condition, all As were presented upside-down; in the familiar condition the As appeared upright.[2] After an 8 s delay interval, a question mark (0.48° visual angle) was presented as a probe until a response was given. Participants indicated whether the position of the question mark matched one of the target positions by a left or right keypress for match and nonmatch, respectively. Half of the trials were matches. In the nonmatch trials, the question mark always appeared one position further apart (1.9°) from one of the target positions along the imaginary circle to hold response difficulty constant. Participants made the response with the index finger and the middle finger of their dominant hand, and they were instructed to respond as fast and accurately as possible. Immediately after the decision, participants indicated the confidence level for their response by pressing the A button for "confident" and the S button for "not confident". The participants were given as much time as they wanted to make an accurate response. An intertrial interval (ITI) of 3 s followed the confidence rating before a new trial began. See Figure 1 for an illustration of the sequence of events at each trial.

Results and discussion

Response accuracy and RTs are shown in Figure 2. Two separate within-subjects ANOVAs were performed on response accuracy and RTs as a function of WM load (one vs. three targets) and target familiarity (familiar target vs. novel target). For response accuracy, the results revealed a main effect of WM load, $F(1, 45) = 35.42$, $p < .001$, $\eta^2 =.44$, with higher response accuracy for load 1 than load 3. Planned comparisons using paired *t*-tests indicated that this WM load effect was significant in both the familiar and the novel conditions, $t(45) = 4.80$, $p < .001$, and $t(45) = 5.09$, $p < .001$, respectively. In addition, there was a main effect of target familiarity, $F(1, 45) = 9.16$, $p < .01$, $\eta^2 =.17$, with response accuracy being higher in the novel condition than in the familiar condition. Importantly, this beneficial effect of target novelty was significant for both the WM load 1 condition, $t(45) = 2.21$, $p < .05$, and the WM load 3 condition, $t(45) = 2.09$, $p < .05$. This was also reflected in the lack of a significant interaction between the factors WM load and familiarity, $F(1, 45) = 0.07$, $p = .79$. In addition, we analysed WM capacity estimates[3] and revealed a similar effect of novelty indicating higher WM capacity for novel targets ($k = 1.26$) than familiar targets ($k = 1.17$), main effect of target familiarity, $F(1, 45) = 4.38$, $p < .05$, $\eta^2 = .09$. Also, the interaction

[1]In another group of 18 subjects (5 males, mean age = 19.94 ± 1.8 *SD*), we tested whether WM performance differed when the target stimulus was presented in the third frame, while presenting the first and the second A at the centre position. We found no significant group effect or interaction between group and the factors WM load and salience on response accuracy and reaction time (RT) (ANOVA, all *F*-values < 0.47, all *p*-values > .50). Specifically, there were no significant group differences in response accuracy for the WM load 1/familiar target condition (85.0% for first frame vs. 87.0% for third frame, one-way ANOVA), $F(1, 63) = 0.49$, $p = .49$, and the WM load 1/novel target condition (87.5% for first frame vs. 89.4% for third frame, one-way ANOVA), $F(1, 63) = 0.56$, $p = .46$. These findings indicate that the positioning of the target stimulus in the sequence of the As did not have a major impact on task performance.

[2]We expected that the A presented upside-down would be perceptually more salient due to its novelty then the A presented upright. In previous experiments it has been demonstrated that attention is automatically oriented in the direction of symbolic arrow cues (Posner et al., 1980). If participants were more likely to interpret the A presented upside-down as an arrow cue, this would have confounded our interpretation in terms of novelty. Therefore, we presented a group of 21 participants with an upright A and an upside-down A, and asked them the following question. Can you think of anything that this stimulus reminds you of? For each stimulus, participants wrote down everything that came immediately into their minds. Overall, they came up with more than 20 different items for both, the upright A and the upside-down A. Only three out of 21 participants interpreted the upside-down A as an arrow. The most consistent interpretation was the letter V (10 participants) and upside-down A (eight participants). Other interpretations included for example statistics symbol, vase, cartoon mouth, triangle, and Vanderbilt logo. In addition, two participants interpreted the upright A as an arrow. Other interpretations of the upright A included for example ladder, teepee, midterm grade, and apple. Taken together, we did not find evidence for a consistent interpretation of the A presented upside-down as an arrow in our participants.

[3]WM capacity (k) was estimated using the formula first invented by Pashler (1988) and refined by Cowan (2001): $k = N$(hit rate – false alarm rate), where k represents the number of locations stored and N is the number of targets presented.

between target familiarity and WM load was not significant, $F(1, 45) = 1.18$, $p = .28$. We found a capacity estimate of $k = 1.70$ in the WM load 3 condition and a capacity estimate of $k = 0.73$ in the WM load 1 condition.

Consistent with the accuracy data, RTs increased from WM load 1 to WM load 3 (significant main effect of WM load), $F(1, 45) = 81.71$, $p < .001$, $\eta^2 = .65$, both in the familiar and novel conditions, $t(45) = -8.43$, $p < .001$, and $t(45) = -7.11$, $p < .001$, respectively. The main effect of target familiarity was not significant, $F(1, 45) = 2.02$, $p = .16$, nor did the interaction between the factors WM load and familiarity reach significance, $F(1, 45) = 2.16$, $p = .15$. The lack of a main effect of familiarity or a familiarity-by-load interaction on RTs indicates that the findings for response accuracy were not a result of speed–accuracy tradeoffs. Together, the accuracy and RT results indicate that increasing the novelty of the targets presented during the encoding phase improved spatial WM performance in our task. Although the beneficial effect of target novelty was rather small, it could be observed when participants needed to memorize either one or three locations.

Confidence rating—The confidence rating allowed us to examine the type of accurate and erroneous responses. Our classifications were as follows: If a subject gave the correct response with high confidence this was classified as true memory, in contrast to a correct response that was given without being confident (= correct/not confident response). If an incorrect response was giving with confidence, this was classified as false memory, in contrast to an incorrect response that was given without confidence (= incorrect/not confident response). Overall, about 80% of the correct trials were true memories (67.3% of all trials), and about 20% of the correct responses were given without confidence (14.9% of all trials). About half of the errors were false memories (9.9% of all trials) and incorrect/not confident responses (7.9% of all trials). Most interestingly, there was an effect of target familiarity on the percentage of true and false memories. Across WM load conditions, participants gave more true memory responses and less false memory responses in the condition of novel versus familiar targets, $t(45) = -2.12$, $p < .05$, and $t(45) = 3.25$, $p < .01$, respectively. There was no difference in the percentage of correct and incorrect responses that were given without confidence between the two familiarity conditions, $t(45) = -0.09$, $p = .93$, and $t(45) = 0.49$, $p = .63$, respectively (see Figure 3).

EXPERIMENT 2

In Experiment 1 we revealed that target novelty could enhance performance in a spatial WM task, but it is not clear how the effect of novelty is manifested during the encoding phase. Experiment 2 was, therefore, conducted to test the effect of the familiarity manipulation on visual processing. In each trial, we presented one target stimulus (an A presented upright or upside-down) and asked participants to indicate whether it appeared on the left or the right side of the screen. This task required engagement of attentional mechanisms for target detection but did not place any demands on WM. We reasoned that if target novelty increased its salience, response times should be faster when the target was presented upside-down (novel target) compared to upright (familiar target).

Methods

Participants—Twenty-four subjects (16 males, mean age 25.5 ± 5.1 *SD*) participated for course credit or monetary reimbursement. Participants reported normal or corrected-to-normal visual acuity and no history of neurological or psychiatric illness. The study was approved by the Vanderbilt University IRB. All participants gave written informed consent.

Stimuli, design, and procedure—The stimuli were the same as in the WM task. The design included only the factor familiarity with two levels (familiar vs. unfamiliar/novel).

Each of the two experimental conditions was presented equally often (48 trials per condition). Participants performed one practice block (10 trials) followed by four experimental blocks of 24 trials each. The trials were presented fully randomized across blocks. Each trial began with presenting a fixation cross at the centre position for 1 s. Then the letter A appeared either on the right or the left side (4.8°) of the fixation cross at one of the 12 possible positions along the imaginary circle. Each position (six on the right side and six on the left side) was chosen equally often across the experiment. In the novel condition, the A was presented upside-down; in the familiar condition the A appeared upright. Participants were asked to indicate as quickly as possible whether the A appeared on the left or the right side of the screen by pressing a left or right button on the keyboard, respectively. After an ITI of 2 s the next trial started.

Results and discussion

Participants responded faster in the novel condition (389.61 ms) compared to the familiar condition (398.30 ms), paired *t*-test, $t(23) = 3.89$, $p < .001$. There was no sign of a speed–accuracy tradeoff. Response accuracy was high and did not differ between novel and familiar targets (99.1% and 99.2% correct for novel and familiar targets, respectively), $t(23) = 0.36$, $p = .72$. Thus, increasing target novelty increased its salience and in turn enhanced perceptual processing of the targets in our task. This is consistent with the beneficial effect of selective attention on visual processing (Corbetta & Shulman, 2002; Egeth & Yantis, 1997; Posner, 1980) and with previous visual search studies showing a beneficial effect of target novelty using similar stimuli (Frith, 1974; Reicher et al., 1976; Shen & Reingold, 2001; Wolfe, 2001).

EXPERIMENT 3

In Experiment 1 we revealed that target novelty enhanced performance in a spatial WM task. We carefully controlled for any global changes in low-level features between novel and familiar targets. However, the manipulation of familiarity was based on a local change in a low-level feature, i.e., a change in the orientation of the targets. In Experiment 3 we used the same procedure as in Experiment 1 with the target stimulus being a Korean (Hangeul) syllable block presented either upright or upside-down. To rule out that the novelty effect was driven by any differences in global or local low-level stimulus features, we used a cross-cultural approach. We compared WM performance between native Korean speakers (i.e., experts in Hangeul), and native English speakers who were unfamiliar with written Korean. If the novelty of the target items rather than their physical properties was the factor that critically drives its salience and enhances WM, we expected to find better WM performance for characters presented upside-down versus upright in the Korean group but not the English group.

Methods

Stimuli—The target stimulus was a familiar black Korean syllable block (nonsense syllable) of approximately 0.48° visual angle, displayed upright or upside-down on a white background (see Figure 1). The positioning of the stimuli was the same as that in Experiment 1.

Design and procedure—A mixed design was used, with group (Korean vs. English) being the between-subjects factor and target familiarity (familiar vs. unfamiliar/novel) and WM load (1 vs. 3) being the within-subjects factors. Each of the four experimental conditions was presented equally often (48 trials per condition). Participants performed one practice block (10 trials) followed by six experimental blocks of 32 trials each. The trials

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were presented fully randomized across blocks. The experimental procedure was the same as that in Experiment 1.

Participants—Nineteen native Korean speakers (11 males, mean age 28.7 ± 6.1 *SD*) with expertise in reading and writing Korean, and 23 native English speakers, who had no knowledge of the Korean language (10 males, mean age 21.2 ± 3.3 *SD*) participated for course credit or monetary reimbursement. Participants reported normal or corrected-to-normal visual acuity and no history of neurological or psychiatric illness. The study was approved by the Vanderbilt University IRB. All participants gave written informed consent.

Results and discussion

Response accuracy and RTs are shown in Figure 4. Two separate repeated-measures function of WM load (one vs. three targets), target familiarity (familiar target vs. novel target), and group (Korean vs. English). For response accuracy, the results revealed a main effect of target familiarity, $F(1, 40) = 5.25$, $p < .05$, $\eta^2 = .12$, with response accuracy being higher in the novel condition (84.5% correct) than in the familiar condition (82.7% correct). Most importantly, this beneficial effect of target novelty differed between the two groups as reflected in the significant interaction between group and familiarity, $F(1, 40) = 5.34$, $p < .05$, $\eta^2 = .12$. There was an increase in WM accuracy for novel versus familiar targets for the Korean group (88.2% correct vs. 84.5% correct, respectively). In contrast, WM accuracy did not differ between the familiarity conditions for the English group (80.8% correct for both, novel and familiar targets). The analysis of WM capacity estimates indicated a similar effect with a trend for a significant interaction between familiarity and group, $F(1, 40) = 3.05$, $p = .088$. WM capacity was higher for novel than familiar targets in the Korean group ($k = 1.46$ for novel targets, $k = 1.32$ for familiar targets), whereas there was no difference between the two conditions in the English group ($k = 1.17$ for novel targets, $k = 1.18$ for familiar targets). As expected, response accuracy was higher for load 1 (86.4% correct, $k = 0.73$) than load 3 (80.8% correct, $k = 1.84$), main effect of WM load, $F(1, 40) = 25.59$, $p < .001$, $\eta^2 = .39$. Overall, WM accuracy was slightly better for the Korean group (86.4% correct) compared to the English group (80.8% correct), $F(1, 40) = 3.52$, $p = .07$. Interactions between load and group, load and familiarity, and between all three factors were not significant (all *F*-values < 0.4, all *p*-values > .53).

Overall, RT did not differ between the two groups, $F(1, 40) = 0.10$, $p = .75$. Consistent with the accuracy data, RTs increased from WM load 1 (974.71 ms) to WM load 3 (1172.16 ms), significant main effect of WM load, $F(1, 40) = 65.21$, $p < .001$, $\eta^2 = .62$. The main effect of target familiarity was not significant (1071.13 ms in the familiar condition and 1075.74 ms in the novel condition), $F(1, 40) = 0.11$, $p = .74$, nor did the interaction between the factors WM load and familiarity reach significance, $F(1, 40) = 0.04$, $p = .83$. The lack of a main effect of familiarity or a familiarity-by-load interaction on RTs indicates that the findings for response accuracy were not a result of speed–accuracy tradeoffs. Interactions between load and group, familiarity and group, and between all three factors were not significant (all *F*-values < 0.17, all *p*-values > .68).

Together, the accuracy and RT results indicate that presenting the target upside-down versus upright improved spatial WM performance in the Korean group who had experience with the character that was presented, but not in the English group, who were unfamiliar with the stimulus. This difference in the effect of target orientation on WM performance between the two groups suggests that it is familiarity based and not driven by changes in low-level features of the stimulus.

Confidence rating—In the Korean group, about 86% of the correct trials were true memories (74.0% of all trials), and about 14% of the correct responses were given without being confident (12.92% of all trials). In the English group, about 79% of the correct trials were true memories (63.7% of all trials), and about 21% of the correct responses were given without being confident (17.0% of all trials). In both groups, about half of the errors were false memories (7.0% and 9.0% of all trials for the Korean and the English group, respectively) and incorrect/not confident responses (6.7% and 10.2% of all trials for the Korean and the English group, respectively) (see Figure 5). Overall, WM performance was slightly higher in the Korean group compared to the English group. This difference was based on a higher percentage of true memory responses, $F(1, 40) = 4.37$, $p < .05$, $\eta^2 = .10$, and a lower percentage of incorrect/not confident responses, $F(1, 40) = 6.12$, $p < .05$, $\eta^2 = .13$, for the Korean versus the English group. The amount of correct/not confident responses and false memories did not differ between groups (all F-values < 2.2, all p-values > .14).

An effect of target familiarity was found on the percentage of true memories and the percentage of correct/not confident responses. Across WM load conditions, both Korean- and English-speaking participants gave more true memory responses in the condition of novel versus familiar targets, ANOVA, main effect of target familiarity, $F(1, 40) = 6.10$, $p < .05$, $\eta^2 = .13$, no significant interaction between familiarity and group, $F(1, 40) = 0.38$, $p = .54$. There was a significant interaction between target familiarity and group on the percentage of correct responses that were given without being confident, $F(1, 40) = 10.12$, $p < .01$, $\eta^2 = .20$. This interaction effect reflected a higher percentage of correct/not confident responses for novel versus familiar targets only in the Korean group. The English group showed the opposite pattern, i.e., a higher percentage of correct/not confident responses for familiar compared to novel targets.

GENERAL DISCUSSION

The current study was designed to investigate the relationship between target familiarity and the encoding of information into spatial WM. Experiment 1 revealed that increasing the novelty of the targets presented during WM encoding improved performance in the spatial WM task. Experiment 2 suggested that this effect was due to the faster and more efficient allocation of attentional processing resources. Using a cross-cultural approach in Experiment 3, we ruled out that the effect of target novelty was due to differences in low-level stimulus features. These findings converge with previous studies demonstrating that target salience can increase the efficiency of visual WM encoding (Fine & Minnery, 2009; Schmidt et al., 2002). Previous studies manipulated salience based on sensory stimulus features or the sudden-onset of stimuli (Fine & Minnery, 2009; Schmidt et al., 2002), and through the foreknowledge of the target's location (Schmidt et al., 2002) and identity (Vogel et al., 2005). Here, we used a paradigm that varied the novelty of the targets to be encoded into WM and show a similar facilitation effect. Thus, our findings indicate that novelty is a factor that increases target salience and in turn facilitates visual WM encoding.

The beneficial effect of target novelty on spatial WM performance observed in this study is in sharp contrast to previous studies that used faces or complex stimuli and showed the opposite effect, i.e., better WM for familiar versus novel stimuli (Curby & Gauthier, 2007; Curby, Glazek, & Gauthier, 2009; Jackson & Raymond, 2008). For instance, Curby and Gauthier (2007) found that when subjects were given adequate encoding time, WM capacity was significantly larger for upright faces than for inverted faces. Similarly, Jackson and Raymond (2008) reported better WM for famous versus unfamiliar faces. This discrepancy is most likely due to the biological significance of the face stimuli that might override the novelty effect from the inverted face (Jiang, Costello, & He, 2007; Wang, Zhang, He, & Jiang, 2010) and/or the high complexity of the stimuli that might influence the encoding strategies. For instance, it has been shown that increased familiarity or expertise enhances the configural or holistic processing of complex stimuli (Curby & Gauthier, 2007; Curby et al., 2009). In line with the notion that faces represent special stimuli due to their ecological validity, search asymmetries for novel (upside-down) versus familiar (upright) stimuli have been consistently found for simple stimuli (Frith, 1974; Reicher et al., 1976; Shen & Reingold, 2001; Wang et al., 1994; Wolfe, 2001) but not for face stimuli (Kuehn & Jolicoeur, 1994; Nothdurft, 1993b). Indeed, there might be a visual processing advantage for upright/famous faces versus inverted/unfamiliar faces as indicated by studies on humans (Purcell & Stewart, 1986; Tong & Nakayama, 1999) and nonhuman primates (Tomonaga, 2007). In contrast, there is very little evidence that high familiarity or expertise enhances performance in visual WM tasks using simple stimuli (Chen, Eng, & Jiang, 2006; Olson & Jiang, 2004; Pashler, 1988). In addition, the present task differed from those used in previous studies (Curby & Gauthier, 2007; Jackson & Raymond, 2008) in that subjects were asked to store the location of the letter rather than the attribute for which they had expertise (the identity of the letter). There is some evidence that the beneficial effect of familiar faces on WM storage is due to improved precision of the WM representations rather than increasing the number of the stored faces (Scolari, Vogel, & Awh, 2008). Thus, expertise might influence the precision with which the familiar attribute can be stored, but would not necessarily predict any change in the ability to store its location.

It is important to note, that the tasks in the present study were designed to minimize the influence of low-level physical features on target salience. In Experiment 1, novel and familiar targets differed only with regard to a local change in orientation, whereas in Experiment 3 both global and local basic stimulus properties were kept physically identical. Although effects of stimulus-driven factors cannot entirely be ruled out in Experiment 1, we believe that the novelty effect can be best understood in terms of top-down expectations that result from a previously formed concept stored in long-term memory. The results suggest that if the presented stimulus does not match this concept, it will be categorized as novel and processed with higher priority. This finding is highly consistent with the visual search asymmetries for novel versus familiar stimuli reflecting high-level visual processing (Frith, 1974; Reicher et al., 1976; Shen & Reingold, 2001; Wang et al., 1994; Wolfe, 2001). A role of conceptual factors in controlling target salience has also previously been demonstrated in studies investigating the perception of natural scenes. For instance, subjects attend preferentially to objects that are not expected within a specific scene than scene-consistent objects (Gordon, 2004). In addition, changes in a visual scene are detected faster and with higher accuracy when the changes are made to objects that are inconsistent with the scene than when they are made to scene-consistent objects (Stirk & Underwood, 2007). Interestingly, the knowledge about categories of objects has also been used to define top-down saliency in computational models (“discriminant saliency”; Gao & Vasconcelos, 2005). We thus conclude that top-down conceptual processes may have been critically involved in the processing of target salience in our task.

Why did target salience in terms of novelty lead to an improvement in WM performance in our task? To elucidate the underlying mechanisms, we compared the distribution of the different types of responses in the novel versus the familiar target condition. Findings from the confidence rating in Experiment 1 revealed that target novelty not only increased the percentage of true memories, but also decreased the percentage of false memories.[4] The

[4]This finding was not replicated in the Korean group who showed no difference in the percentage of false memories between novel and familiar targets. Compared with the English group, the salience effect was predominantly driven by a higher percentage of correct/not confident responses for novel versus familiar targets. The lack of a salience effect on the percentage of false memories might be due to the overall higher performance in this group. Thus, the percentage of false memories was considerably low, making it more difficult to detect any performance differences in response to target salience.

amount of correct/not confident and incorrect/not confident responses did not change. False memory errors most likely reflect a failure in the selection of the items to be encoded into WM. Thus, subjects successfully encode, maintain, and retrieve information from WM, albeit the wrong information. The present results suggest that, by increasing target salience in terms of its novelty, the selection of the relevant information for WM encoding and/or the inhibition of nonrelevant information was facilitated and consequently led to higher WM performance. This is consistent with the finding that the ability to efficiently select relevant items and adeptly ignore irrelevant items varies across individuals and is predicted by the individual WM capacity (Vogel et al., 2005). Also many theories of attention propose that attention is the process that determines which perceptual representations are transferred into WM (Bundesen, 1990; Duncan & Humphreys, 1989). In line with these theories, we found a perceptual processing advantage for novel versus familiar targets when presenting the same stimuli in a task that required engagement of attentional mechanisms for target detection. Interestingly, in the present study the facilitation effect occurred even in the absence of distractors, indicating that it was more likely due to an improvement in the process of selecting the relevant information rather than to the inhibition of the irrelevant information. Another process that might have been performed more efficiently when the targets were salient is the formation of a memory representation of the target positions itself. WM consolidation takes time and is resource demanding (Jolicæur & Dell'Acqua, 1998) and therefore might promote strategies that can increase its efficiency. Specifically, the higher percentage of true memory responses in the condition of novel versus familiar targets might reflect the more efficient encoding of the target location as dictated by the precision with which the memory representation was formed (Bays, Catalao, & Husain, 2009; Bays & Husain, 2008; Ma & Huang, 2009). In conclusion, we suggest that the beneficial effect of target novelty on WM performance likely resulted from a modulation of the processes associated with the encoding phase, including perceptual processing of the presented stimuli, attentional selection, and/or consolidation, rather than reflecting a direct effect on WM storage. Future studies will be needed to disentangle the contribution of each of these processes.

The salience effect appeared to be similar when participants encoded either one or three target locations. This is in contrast to the study by Fine and Minnery (2009) who reported that the effect of target salience on WM performance was more pronounced when WM load was increased. This discrepancy might be explained by the differences in task difficulty. In the present task, WM demands were well within its capacity limit (Cowan, 2001; Luck & Vogel, 1997), whereas it was exceeded in the task used by Fine and Minnery (2009). Thus, it is likely that WM encoding is increasingly facilitated by target salience as the capacity limits of WM are reached, reflecting an efficient strategy of the memory system to deal with its limited resources.

Furthermore, the impact of visual attention on WM encoding likely depends on the specific attention and memory subsystems that are involved. Our findings demonstrate an important interaction between visual attention and spatial WM encoding. However, given that target novelty exerted control over the allocation of attention such that it was drawn to a target stimulus presented at a specific location, it is difficult to distinguish between spatial and object-based attention in the present task. Further research will be needed to investigate whether the interaction between visual attention and WM encoding generalizes from the spatial to other domains (e.g., visual object or auditory WM) and whether it occurs in situations in which attention and memory processes address the same (e.g., spatial attention and spatial WM) or different domains (e.g., spatial attention and visual object WM). Also on the neural level, it is not clear whether the interaction of salience and WM encoding is mediated by domain-specific or domain-independent substrates. There is large evidence that the storage of information in WM is organized in a domain-dependent fashion within the lateral prefrontal cortex (e.g., Courtney, 2004; Goldman-Rakic, 1987; Munk et al., 2002; Smith et al., 1995) and the posterior cortex including lateral posterior parietal and inferior temporal regions (e.g., Miller & Desimone, 1994; Munk et al., 2002; Wager & Smith, 2003). The posterior parietal cortex is also a key region in the control of visual attention, although the evidence for a domain-specific organization is less clear (e.g., Shomstein & Behrmann, 2006; Yantis & Serences, 2003). With regard to the present experiment, we thus suggest that the posterior parietal cortex is a candidate region for localizing the interaction of salience and spatial WM encoding.

Overall, the current findings add to the growing body of evidence from behavioural (Awh et al., 1998; Oh & Kim, 2004; Pashler, 1994; Theeuwes et al., 2011; Woodman & Luck, 2004) and neuroimaging studies (Awh & Jonides, 2001; Corbetta, Kincade, & Shulman, 2002; Lepsien & Nobre, 2007; Mayer et al., 2007; Nobre et al., 2004) indicating that the attentional mechanisms that operate on visual perception may influence the processing of stimuli at multiple stages of processing such as WM encoding, maintenance, and retrieval (Awh et al., 2006). Our results demonstrate that target novelty enhances the processes required for WM encoding. Understanding the processes that are capable of improving WM may lead to new approaches in the search of remediation strategies for patients suffering from WM impairments such as patients with schizophrenia.

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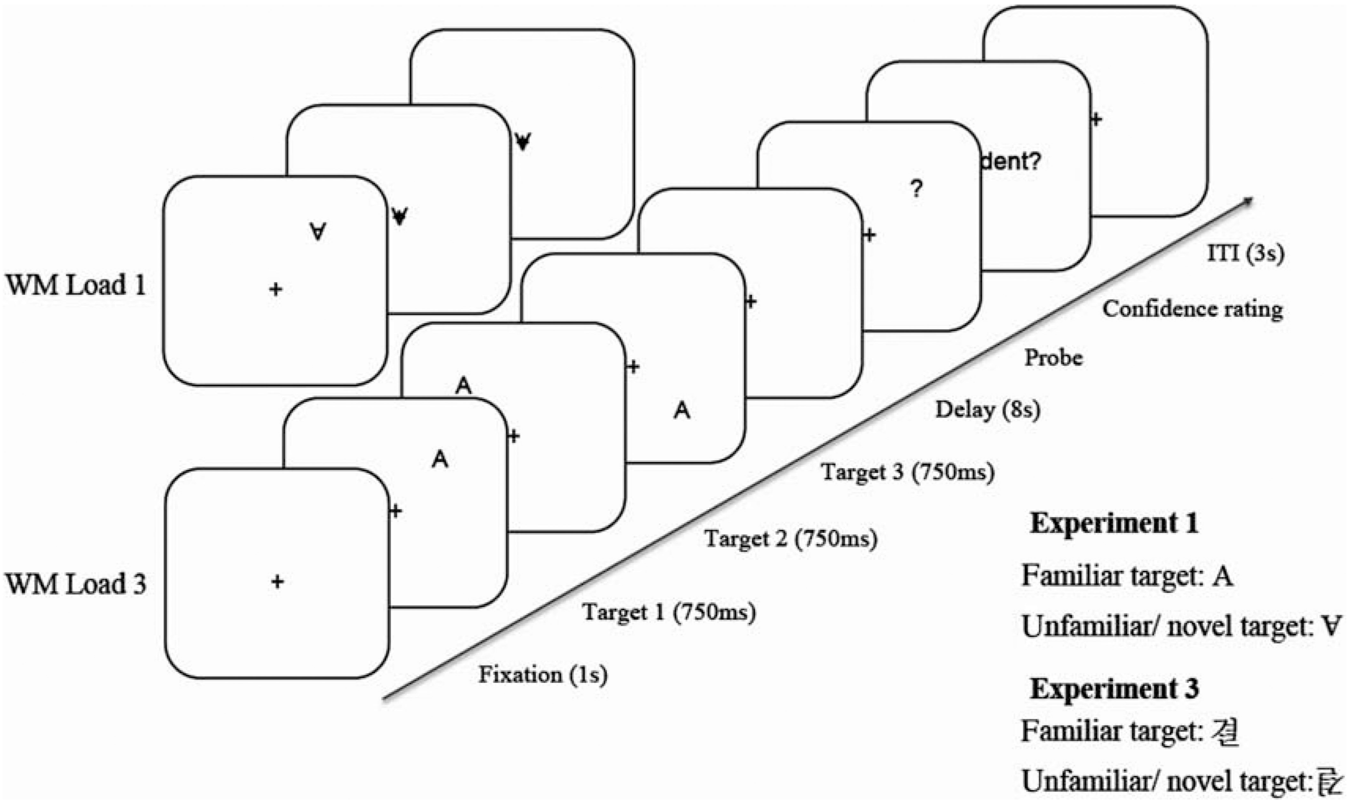

Figure 1.
Schematic diagram of the procedure and stimuli in Experiments 1 and 3. Participants were presented with a sequence of As and asked to memorize their positions on the computer screen. In the unfamiliar/novel target condition, the As were presented upside-down; in the familiar target condition the As appeared upright. In the WM load 1 condition, participants memorized only the location of the first A; the second and the third As appeared at the centre position and could be ignored. In the WM load 3 condition, participants were instructed to memorize the positions of all three As. After a delay of 8 s, a question mark appeared as a probe and participants indicated whether the position of the question mark did or did not match one of the target positions. At the end of each trial, participants rated the confidence level for their response. In Experiment 3, the target was a Korean syllable block that was presented either upright (familiar target) or upside-down (unfamiliar/novel target). WM: Working memory, ITI: Intertrial interval.

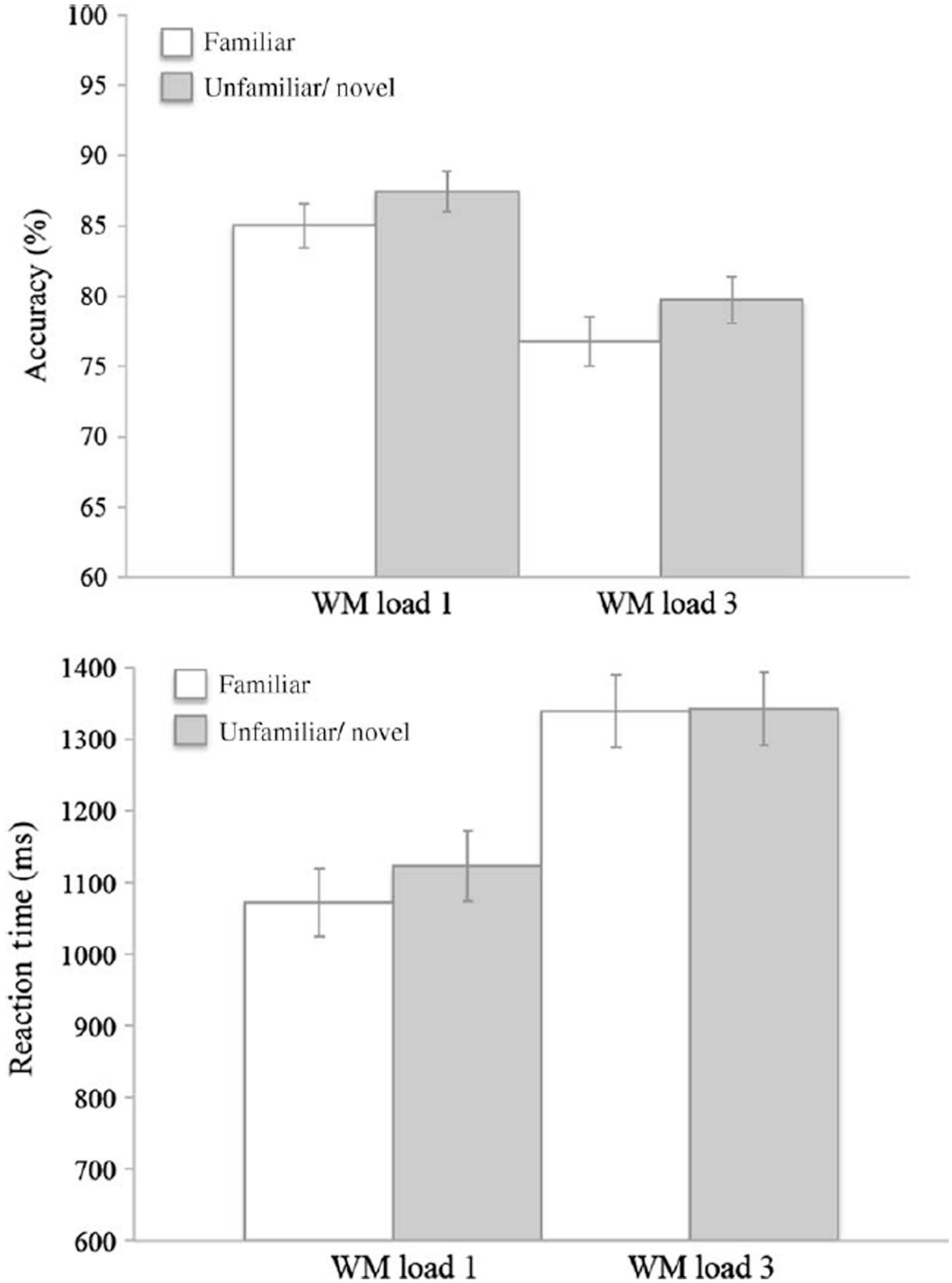

Figure 2.
Results from Experiment 1. Mean response accuracy and mean reaction time as a function of WM load (1 vs. 3) and target familiarity (familiar vs. unfamiliar/novel). Vertical bars represent the standard error of the mean.

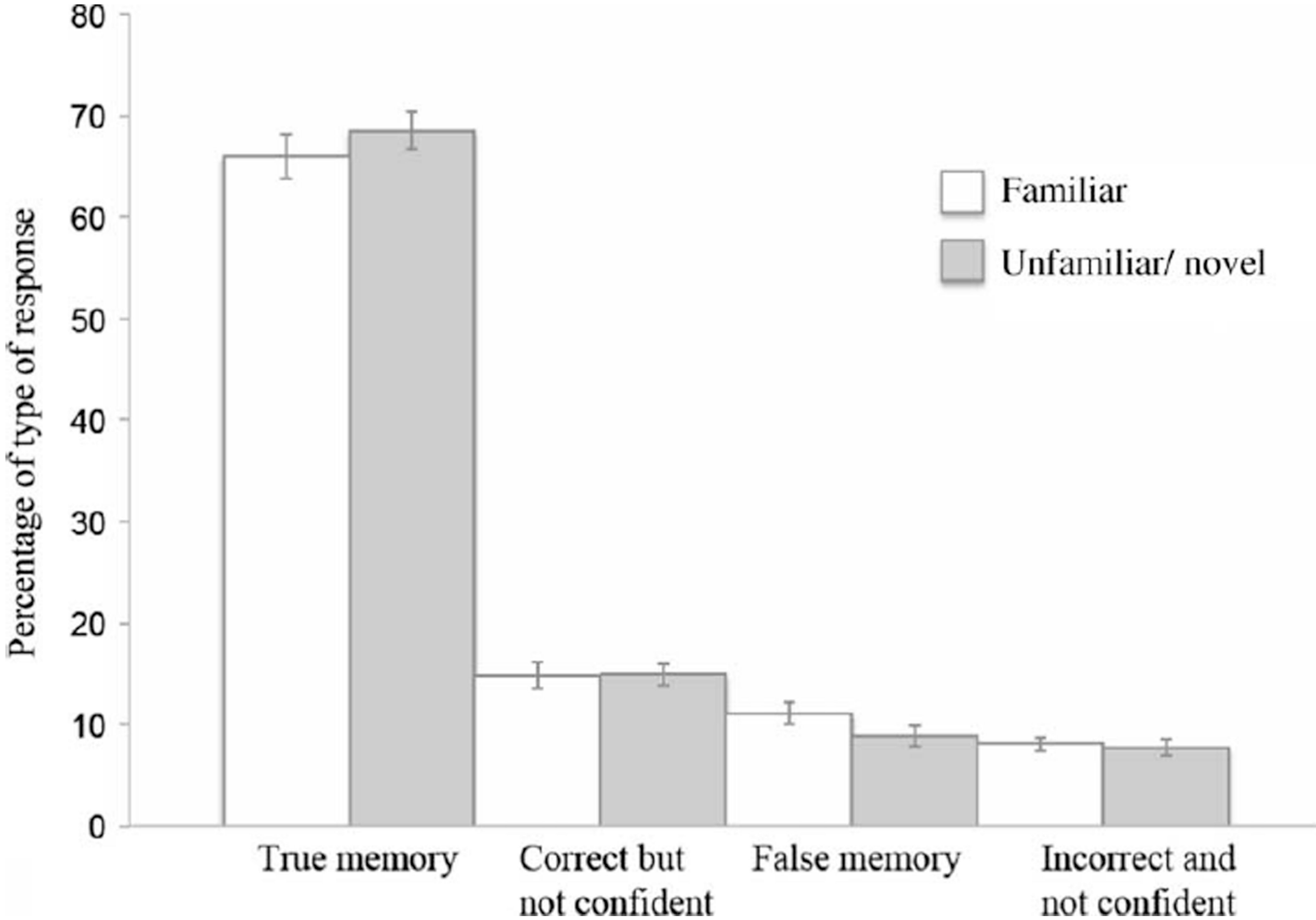

Figure 3.
Results from the confidence rating of Experiment 1. The percentage of each type of response is shown for the novel and familiar target condition across WM loads 1 and 3. We differentiated between four types of responses: True memory (correct and confident response), correct but not confident responses, false memory (incorrect and confident response), and incorrect and not confident responses. Vertical bars represent the standard error of the mean.

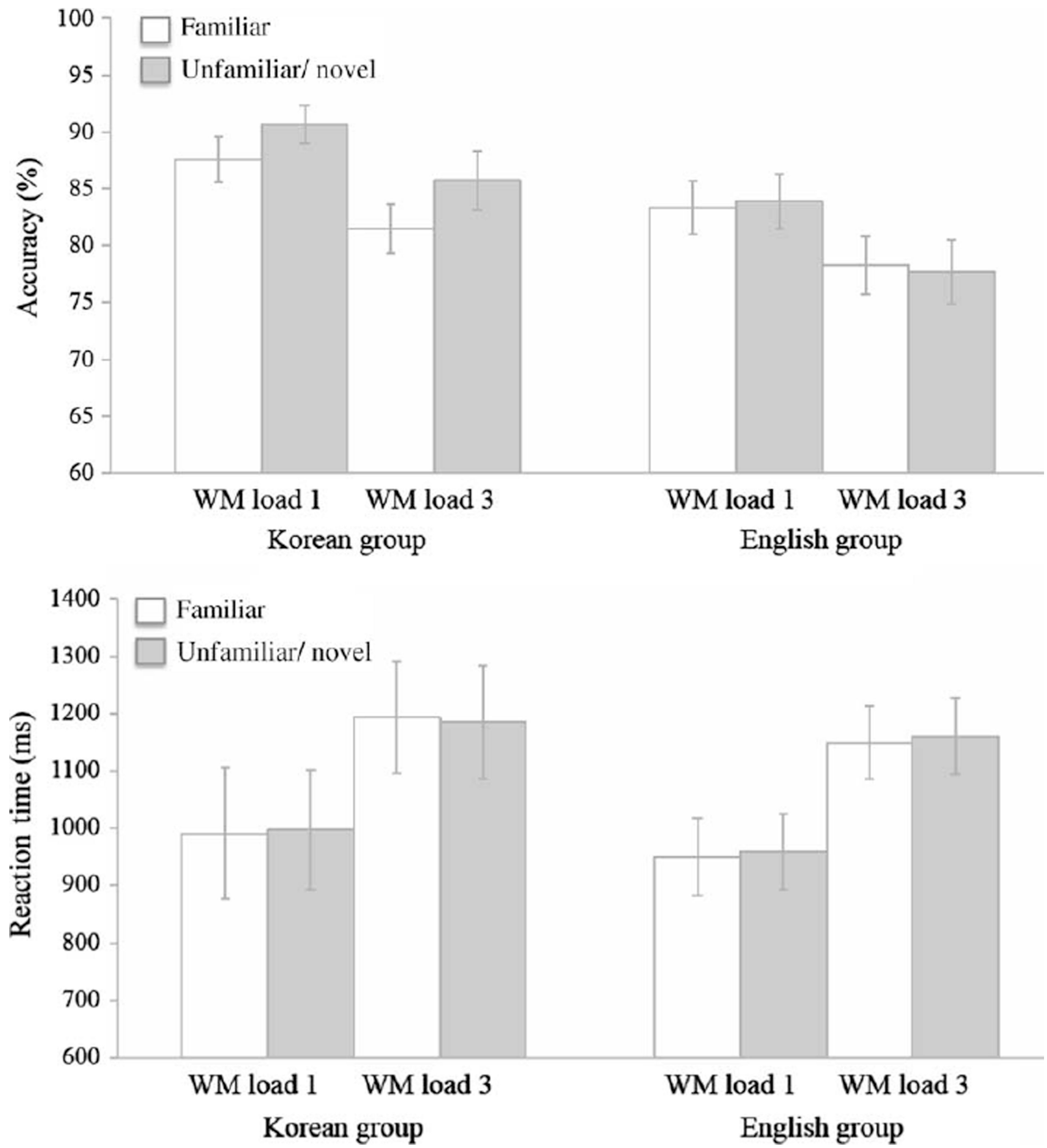

Figure 4.

Results from Experiment 3. Mean response accuracy and mean reaction time as a function of WM load (1 vs. 3) and target familiarity (familiar vs. unfamiliar/novel). Vertical bars represent the standard error of the mean.

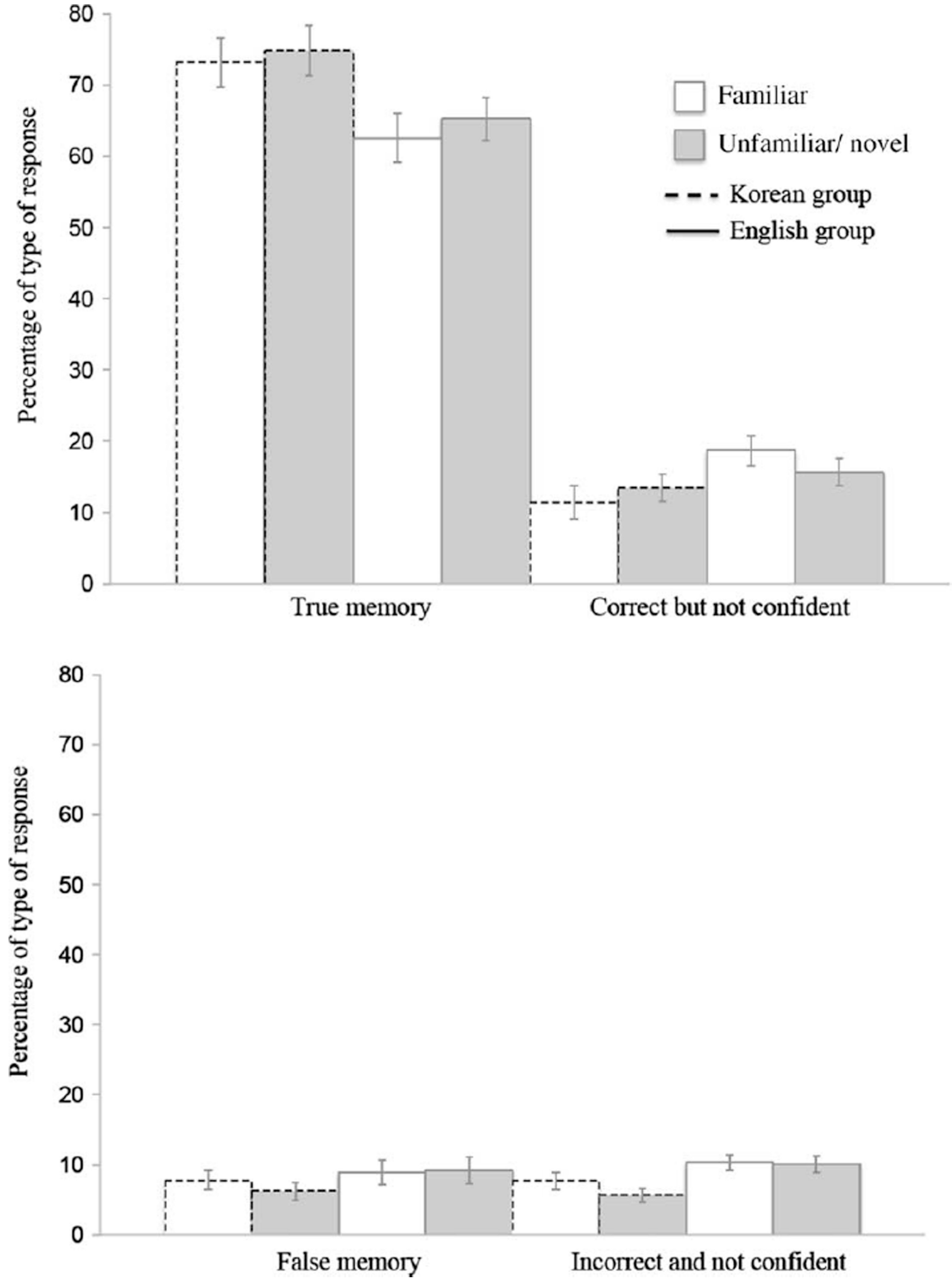

Figure 5.
Results from the confidence rating of Experiment 3. The percentage of each type of response is shown for the novel and familiar condition across WM loads 1 and 3 for the Korean and the English group. Vertical bars represent the standard error of the mean.