Attentional Load Effects on Emotional Content in Face Working Memory

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Abstract

This study investigated the role of attentional resources in processing emotional faces in working memory (WM). Participants memorised two face arrays with the same emotion but different identities and were required to judge whether the test face had the same identity as one of the previous faces. Concurrently during encoding and maintenance, a sequence of high-or-low pitched tones (high load) or white noise bursts (low load) was presented, and participants were required to count how many low-tones were heard. Experiments 1 and 2 used an emotional and neutral test face, respectively. Results revealed a significant WM impairment for sad and angry faces in the high load vs low load condition but not for happy faces. In Experiment 1, participants remembered happy faces better than other emotional faces. In contrast, Experiment 2 showed that performance was poorer for happy than sad faces but not for angry faces. This evidence suggests that depleting attentional resources has less impact on WM for happy faces than other emotional faces, but also that differential effects on WM for emotional faces depend on the presence or absence of emotion in the probe face at retrieval.

Keywords: visual working memory; attention; face recognition; emotion.

Attentional Load Effects on Emotional Content in Face Working Memory

The evaluation of emotional situations in everyday life is essential to planning and predicting behavioural responses and making decisions to avoid or escape dangerous or stressful environments. For instance, the ability to decode emotional facial expressions is critical for quickly acting on a threat (Pollak, Cicchetti, Hornung, & Reed, 2000) or engaging in satisfying interactions with partners (Elfenbein & Ambady, 2002).

Previous studies have investigated how the decoding of emotional faces is affected by cognition, particularly to which extent the processing of emotional expressions seems to be dependent on attentional resources (Leyman et al., 2007; Phelps et al., 2006). Various studies reported that preferential processing of emotional faces requires focused attention (Pessoa, 2009; Pessoa, Kastner, et al., 2002; Pessoa, McKenna, et al., 2002; Yates et al., 2010). In support of this view, studies have shown that processing of emotional faces occurs when attentional resources are available to direct attention to the salient emotional stimuli (Acunzo et al., 2019; Yates et al., 2010).

In line with this argument, researchers have extended this debate to whether there is an attentional cost to processing emotional faces when this information is held in a temporary memory system, such as working memory (WM). WM is assumed to be a temporary and limited capacity storage system that maintains and manipulates information, underpinning a complex thought process (Baddeley & Andrade, 2000; Baddeley & Hitch, 1974). WM capacity for faces, in particular, has been shown to be limited to around two faces, significantly lower than the capacity limit of 3-4 simple colours (Jackson & Raymond, 2008). In addition, there are some small WM capacity variations for faces with different emotional expressions, where WM for the identity of angry faces was found to be better than for happy and neutral faces (Jackson et al., 2008, 2009, 2014; Thomas et al., 2014).

Given the limited capacity of WM, studies have investigated how attention is involved in the priority storage of previously encountered emotional stimuli in WM (Gupta & Srinivasan, 2014; Lee & Cho, 2019; Plancher et al., 2018; Srinivasan & Gupta, 2010; Srivastava & Srinivasan, 2010; Van Dillen & Derks, 2012; Van Dillen & Koole, 2009). Some argue that preferential processing of emotional faces depends on the availability of attentional resources in WM (Gupta & Srinivasan, 2014; Simione et al., 2014; Srinivasan & Gupta, 2010; Tsouli et al., 2017). Strong evidence comes from studies that manipulated competition for WM resources in a dual-task paradigm (Van Dillen & Derks, 2012; Van Dillen & Koole, 2009), visual search (Lee & Cho, 2019) and divided attention tasks (Gupta & Srinivasan, 2014). Studies using event-related potential (ERP) measures have also given hints that facilitated processing of emotional faces depends on attentional WM resources (Holmes et al., 2014; Van Dillen & Derks, 2012).

Although these studies show that competition for attentional resources in WM interferes with the processing of emotional faces, some report different patterns of attention allocation, more specifically between positive and negative faces (Lee & Cho, 2019; Van Dillen & Koole, 2009). For example, Van Dillen and Koole (2009) explored the interaction between attentional resources in WM and emotion in a dual-task paradigm. Participants judged the gender of angry and happy faces in the presence or absence of a concurrent math task (Study 1) or in conditions of low or high concurrent WM digits load (Study 2). In both studies, slower response times for angry than happy faces were observed in the gender-naming task only when WM resources were available (i.e., in the low load condition), whereas response times were equally slow for angry and happy faces in the high load condition. In support of these findings, electrophysiological research found evidence of high cognitive control under high WM load, and for this reason the task-irrelevant angry facial expressions no longer impacted gender-naming response times (Van Dillen & Derks, 2012).

Likewise, Gupta and Srinivasan (2014) have also found a different allocation of attention toward negative and positive faces in a recognition task. In their study, participants performed a low or high load letter-identification task with a circular array of six letters presented against a happy, sad or neutral face background. Following the letter task, participants were asked to recognise the identity of the face that appeared in the final trial. The results showed only an interaction between attention load and emotional faces (e.g., happy and sad) but not for neutral ones. More interesting, the results showed a better identification of happy faces compared to sad faces under both load conditions, whereas sad faces were only enhanced under low load when more attentional resources were available. In sum, this evidence suggests that attention resources in WM are allocated to prioritise emotional stimuli compared to neutral, though negative faces might elicit more attentional capture than positive ones (Gupta & Srinivasan, 2014; Lee & Cho, 2019; Van Dillen & Koole, 2009).

A third alternative supported by previous studies argues that emotional stimuli are processed automatically, independently of WM resources (e.g., Hermans et al., 2000). That is, selective attention relies on WM functions in similar ways for positive and negative valenced or nonvalenced information. For example, Pecchinenda et al. (2007) found that emotional face distractors (e.g., happy *vs.* angry *vs.* neutral) did not interfere in response to target words regardless of WM load, suggesting automatic processing of faces independently of the availability of resources. In addition, a recent review (Schweizer et al., 2019) reports findings that support the view that competition of perceptual or WM resources (i.e., executive function) from valenced distractors have a small and nonsignificant impact on WM performance compared to neutral distractors.

To clarify these mixed findings, we investigated whether this priority of emotional information in WM may depend on attentional resources and how attention is allocated to positive and negative faces. A major issue of studies reviewed so far is the manipulation of WM resources in the methodological designs. In previous studies, there was no direct interference of attention during the encoding and retention of affective information (e.g., Gupta & Srinivasan, 2014; Lee & Cho, 2019). For instance, participants performed a WM task with a concurrent attentional task (e.g., math task; Van Dillen & Koole, 2009; letter-identification task; Gupta & Srinivasan, 2014) or without a concurrent task, but with the manipulation of sequential spatial attention during stimuli presentation (Lee & Cho, 2019).

In our study, we measured for the first time whether a concurrent attentional load task (Kaiser, 2015) conducted during the encoding and maintenance of emotional faces in WM (happy, angry, and sad faces) modulates WM retrieval accuracy for these face identities. To explore the influence of attention on face WM, we employed a dual-task paradigm with a main face recognition task and a concurrent auditory attentional task involving tone counting. In the main task, the participants had to memorise the identity of two faces that displayed the same emotion but were of different identities. After a brief WM maintenance interval, the participant answered whether a single test face matched or not in identity with either of the previous faces seen at encoding. Two attentional load conditions were manipulated. In the high-load condition, participants heard a sequence of low and high tones during face WM encoding and maintenance and counted the number of low tones for the report at the end of the trial. In the low-load condition, participants heard white noise bursts during face WM encoding and maintenance and had nothing to count (they reported zero).

The dual-task paradigm was intended to manipulate the availability and the allocation of attentional resources during the processing and memorisation of emotional faces. Thus, if the processing of emotional information in face WM depends on attentional resources, it is to be expected that WM accuracy for emotional faces would be impaired in the high-versus no-load condition. Otherwise, if the processing of emotional stimuli is automatic, it would not be impaired when attentional resources are depleted. In case the attention allocation to negative and positive faces differs, we would expect an impairment of WM for negative faces in the high-versus no-load condition (Van Dillen & Derks, 2012; Van Dillen & Koole, 2009) with little or no such dual-task impairment for happy faces (Gupta & Srinivasan, 2014; Srinivasan & Gupta, 2010).

Furthermore, in contrast to some studies (Van Dillen & Derks, 2012; Gupta & Srinivasan, 2014), we measured the interference of attention in a strongly conceptualized WM task, a face recognition task, controlling and measuring the perceptual feature processing. Two experiments of this nature were conducted. In Experiment 1, the test face showed the same emotional expression as at encoding (as per Jackson et al., 2009). The attentional load task was engaged during encoding when emotional expression information was present and not during retrieval, and thus any effects of attentional load on emotional WM could be assumed to be linked to the emotions seen during the encoding phase. However, there is the possibility that the presence of expression at retrieval may modulate recall by serving as a particular emotional cue. In addition, emotional test faces were identical images to those seen at encoding and therefore recall may be based on low-level feature matching rather than higher-level face recognition per se (see Chen et al., 2015; Jackson et al., 2014). Therefore Experiment 2 aimed to replicate the findings of Experiment 1 but with a neutral test face shown at retrieval (as per Jackson et al., 2014). For both experiments, participants were required to answer whether the test face was of the same or different identity from one of the previously presented faces, regardless of the emotional expression of the face. Previous studies have found the same emotion-specific effects on memory regardless of whether the test face is emotional or neutral (e.g., Chen et al., 2015, Jackson et al., 2014), so we expect to replicate our findings across experiments here.

Method

Participants

A total of 78 participants (46 females) aged 18-35 years (*M* = 24.44 years, *SD* = 5.46), with normal or corrected normal vision and normal hearing, voluntarily participated in the Experiment 1 (n = 40) and in Experiment 2 (n = 38). The sample size for each experiment was estimated considering the main effect (η^2_p = .12) of emotional expressions on memory for face identity as reported by D'Argembeau and Van der Linden (2011), which manipulated emotional and neutral expressions in the study and test. The power analyses were performed in G*Power (Faul et al. 2007) for repeated measures, within-factors ANOVA, considering the effect size $f(U)$ = .37 (η^2_p = .12 as in SPSS), power $(1 - \beta) = .80$, $\alpha = .05$, with four measures (emotional expressions) in Experiment 1 and three measures (emotional expressions) in Experiment 2. The estimated sample sizes were 29 participants for the first experiment and 38 for the second.

The Research Ethics Committee of the Faculty of Philosophy, Sciences and Letters at Ribeirão Preto (University of São Paulo) approved the project, and all participants signed consent forms. The participants were evaluated with the Beck Anxiety Inventory and the Beck Depression Inventory to control for potential influences of mood. The participants were compensated for their transportation to the laboratory with an amount equivalent to US$ 2.50.

Materials and stimuli

The stimuli for the faces WM task were extracted from the Karolinska Directed Emotional Faces database (KDEF) (Goeleven et al., 2008). We conducted a pilot study to ensure the KDEF stimuli could be used in Brazil with equivalent ratings of facial expressions (see the supplemental material for the details), and the results revealed similar valence and arousal ratings to the original study (Goeleven et al., 2008). For both experiments, the stimuli were male greyscale faces without hair, cropped into an oval, and were subtended approximately 8 × 11 degrees of visual angle (at a 60 cm on average distance from the screen), or 303 × 423 pixels in a 23-inch widescreen monitor with 1920 × 1080 pixels of resolution. We selected faces from eight males displaying four emotional expressions (neutral, happiness, anger, and sadness), a total of 32 stimuli. The stimuli were displayed in four randomised locations within an 18° × 25°, or 18 x 25 cm grid to counterbalance any potential effects of vertical/horizontal positioning. Since we used two faces at encoding per trial, the other locations within the grid were filled with scrambled faces that were created by segmenting a face into 19 squares and then randomly rearranging them. The composite image was cropped into an oval pattern to maintain a face-like outline. The stimuli of the tone counting task (TC) were a low-pitched tone (200 Hz), a high-pitched tone (1500 Hz) or white noise bursts. The tones were presented through headphones for 250 ms each and were generated using the program Audacity.

Procedure

At the beginning of the session, each participant was evaluated with the Beck Anxiety Inventory (BAI; Beck et al., 1988) and the Beck Depression Inventory (BDI; Beck et al., 1961). The participants received instructions about the tasks and performed six practice trials for the face recognition task alone, six practice trials for the tone counting task alone, and then six practice trials for the complete dual-task WM procedure.

The participants performed the face WM task adapted from Jackson et al. (2009, 2014) concurrently with the tone counting task. In each trial, after the presentation of a fixation point for 1000 ms and a white screen for 250 ms, the encoding array of two faces was presented for 2000 ms. The faces in the encoding array had the same emotional expression but different identities. After a maintenance interval of a blank screen for 1500 ms, a test face with the same expression as at encoding (Experiment 1) or a neutral expression (Experiment 2) was presented in the centre of the screen until response. In half of the trials, the test face shared identity with one of the faces presented in the encoding array (i.e., was the same image). On the other half, it did not share identity (i.e., the expressive face was from a different person). The task was to respond "yes" (left mouse button) if the test face was present in the encoding array or "no" (right mouse button) if it was not. The participant was instructed to respond as quickly and accurately as possible to the test face, but there was no response time limit.

The concurrent tone counting task (TC) comprised a sequence of six low- and high-pitched tones in the high-load condition or a sequence of six white noise bursts in the low-load condition. The participants were required to count the number of low-pitched tones presented in the trial, which varied from two to five tones in randomised order or zero in the low-load condition. The tones were presented through headphones during both encoding and maintenance and started simultaneously with the presentation of the encoding face array, each tone lasting 250 ms with approximately 333 ms interval between tones (i.e., five intervals of 333 ms and one interval of 335 ms). The response to the test face was followed by a scale with five numbers in the centre of the screen (i.e., 0, 2, 3, 4, 5), and the participants were required to indicate the tone counting response option. The main components of the trial sequence for each experiment are shown in Figure 1.

In Experiment 1 there were 160 trials in total, 80 trials per attentional condition, and in each condition there were 20 trials for each of the four emotional expressions. In Experiment 2 there were 120 trials in total, 60 trials per attentional condition, and in each condition there were 20 trials for each of the three emotional expressions. All the trials conditions were presented in random order.

[Figure 1 near here]

Data Analyses

Performance in the face WM task was measured by the discrimination index *d'* and the response bias parameter *c* derived from the signal detection theory and calculated as follows: $d' = Z(H) - Z(FA)$ and $c = 0.5 \times [z(H) + z(FA)]$, where *H* and *FA* are adjusted hit and false alarm rates, respectively (Snodgrass & Corwin, 1988). Regarding the criterion *c*, positive values indicate a conservative criterion (i.e., a bias towards responding 'no'), and negative values indicate a liberal criterion (i.e., a bias towards responding 'yes'), with the neutral criterion with values closer to zero. Performance in the tone counting task was measured by the proportion of correct answers. These measures from each experiment were analysed separately using repeated measures 2 × 4 ANOVA (Exp.1) and 2 × 3 ANOVA (Exp. 2), considering the attention load and emotional expression as within-subject factors.

Subsequently, the *d'* and *c* data of experiments 1 and 2 were cross-analysed by using repeated measures 2 × 3 × 2 ANOVA considering experiment (emotion-probe and neutral-probe groups) as between-subjects factor, and attention load and emotional expression (happiness, angry, and sadness) as within-subject factors. The trials of neutral emotion type in the emotion-probe group were disregarded in these analyses to facilitate the comparison between the two probe-groups. As a first step, these analyses were carried out preliminarily by inserting BAI and BDI scores as covariates for controlling for the effects of the participants' levels of anxiety and depression. We also analysed performance in the tone counting task for verifying the participants' engagement in the concurrent task. Note that the main WM face analysis was computed using all trials and not restricted to correct tone trials only, as this would have meant an imbalance in the number of trials considered in each WM load condition within and across experiments (because tone counting accuracy differed as a function of WM load condition). The same rationale was applied to analysis of tone counting performance (face WM accuracy differed as a function of both emotion and WM load). However we also ran the analyses again from correct concurrent task trials only and report these in footnotes (the pattern of results remained similar in both cases).

For all the analyses, the significance level was set at .05, partial eta squared (η^2_p) effect sizes were computed, and post-hoc analyses and *t*-tests using Bonferroni's correction were carried out as necessary. The sphericity assumption was assessed by the Mauchly's test, and no violations of sphericity were observed ($p > .327$).

Results

Preliminary analyses

We considered the data from 77 participants, since our preliminary analyses indicated that one participant had low performance in both low attention (*M* = .52, *SD* = .13) and high attention (*M* = .20, *SD* = .13) conditions. The overall performance in tone counting was satisfactory (*M* = .84, *SD* = .20), and it was higher in low-load (*M* = .986, *SD* = .034) than high-load trials (*M* = .681, *SD* = .162), $t(76) = 17.3$, $p < .001$.

Preliminary analyses indicated that the sample's mean scores in the BAI (*M* = 9.3, *SD* = 9.4) and the BDI (*M* = 8.8, *SD* = 8.2) did not have significant effects on performance (*d'*) in the WM task, as revealed by the ANCOVA including BAI scores, $F(1, 73) = 1.04$, $p = .31$, $\eta^2_p = .014$, and BDI scores as covariates, $F(1, 73) = 1.78$, $p = .19$, $\eta^2_p = .024$, so these variables were subsequently disregarded. The response bias *c* also was not significantly influenced by BAI scores, $F(1, 73) < 1$, $p = .96$, $\eta^2_p < .001$, and BDI scores, $F(1, 73) < 1$, $p = .65$, $\eta^2_p = .003$, nor was performance in the concurrent tone counting task significantly influenced by BAI scores, $F(1, 73) < 1$, $p = .35$, $\eta^2_p = .012$, and BDI scores, $F(1, 73) < 1$, $p = .54$, $\eta^2_p = .005$.

Experiment 1

Tone counting task

The 2 × 4 repeated measures ANOVA on the proportion of correct answers revealed a significant effect of attention load, $F(1, 39) = 151.47$, $p < .001$, $\eta^2_p = .795$, given the higher performance in low-load (*M* = .99, *SE* = .001) than in high-load trials (*M* = .74, *SE* = .021). The main effect of emotional expression, $F(3, 117) = 1.19$, *p* =

.32, η^2_p = .030, and the interaction between the factors, $F(3, 117) = 1.40$, $p = .25$, η^2_p = .034, were not significant.[2]

Face WM accuracy (d')

Figure 2A shows the interaction between attention load and emotional expression for Experiment 1. The 2 × 4 repeated measures ANOVA on discrimination index *d'* revealed a significant main effect of attention load, $F(1, 39) = 71.10$, $p < .001$, η^2_p = .65, where participants performed better in the low-load condition (*M* = 2.43, *SE* = .07) than in the high-load condition (*M* = 1.78, *SE* = .09). The results revealed a significant main effect of emotional expression, $F(3, 117) = 3.12$, $p = .029$, η^2_p = .07, but Bonferroni corrected *t*-tests with adjusted *p*-values for the number of comparisons (i.e., 6) showed no significant difference in performance between happy faces and neutral faces, $t(39) = - 2.34$ ($p = .14$), happy faces and sad faces, $t(39) = 2.56$ ($p = .08$), happy and angry faces, $t(39) = 2.74$ ($p = .054$), neutral faces and angry faces, $t(39) = - .13$ ($p = 1$), neutral faces and sad faces, $t(39) = - .09$ ($p = 1$), and angry faces versus sad faces, $t(39) = - .20$ ($p = 1$).

[Figure 2 near here]

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[2] An additional analysis of tone counting when the participants have answered correctly to the WM task revealed the same pattern of results, that is, a strong effect of attention load ($p < .001$, η^2_p = .795) and non-significant effects of emotional expression ($p = .64$, η^2_p = .014) and interaction ($p = .62$, η^2_p = .015), further supporting that tone counting performance was not influenced by the emotional facial expressions of memory stimuli.

The interaction between the factors was significant, $F(3, 117) = 2.89$, $p = .038$, $\eta^2_p = .07$. To further explore this interaction, Bonferroni corrected *t*-tests with adjusted *p*-values for the number of comparisons (i.e., 4) were carried out for comparing performance between low- and high-load conditions for each emotional expression. The results revealed significantly poorer WM in high- than low-load conditions for neutral, $t(39) = 6.86$, angry, $t(39) = 4.90$, and sad faces, $t(39) = 5.48$ (all $ps < .001$), but the difference for happy faces only approached significance, $t(39) = 2.70$, $p = .050$[3].

Face Response Bias (c)

Table 1 shows the *c* values for the two attentional conditions and the three emotional faces. The 2 × 4 repeated measures ANOVA on the response bias criterion *c* revealed a significant effect of attention load, $F(1, 39) = 4.17$, $p = .048$, $\eta^2_p = .096$, where *c* was closer to zero in the low-load condition ($M = -.034$, $SE = .03$) than in the high-load condition ($M = -.127$, $SE = .05$), indicating that participants were slightly more liberal in the high-load condition. The effect of emotional expression, $F(3,117) < 1$, $p = .41$, $\eta^2_p = .024$, and the interaction between the factors, $F(3,117) < 1$, $p = .41$, $\eta^2_p = .024$, were not significant.

[Table 1 near here]

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[3] This pattern of results was also observed in an additional analysis of the proportion of correct answers in the WM task when the participants had answered correctly to the tone counting task, that is, the low- vs. high-load difference for happy faces was not significant, $t(39) = 2.41$ ($p = .08$), whereas significant differences were observed for the neutral, $t(39) = 6.03$ ($p < .001$), angry, $t(39) = 4.77$ ($p < .001$), and sad faces, $t(39) = 4.39$ ($p < .001$).

Interim Summary

The main aim of Experiment 1 was to assess whether the processing of emotional information in WM demands attentional resources. The results showed that performance was impaired by a high attention load, and this effect varied across emotional expressions. WM for neutral, angry and sad faces was significantly impacted by high attention load, but happy faces were less impacted. This pattern of results was further supported by an additional analysis of WM performance restricting to trials in which the participants performed the tone counting task accurately to ensure they were effectively engaged in the concurrent task. Thus, our analyses support the view that the concurrent task significantly impacted WM performance differentially according to emotional facial expressions.

We also analysed whether performance in the concurrent task was conversely influenced by the WM task, especially by the emotional facial expressions of memory stimuli. Our results are in line with previous findings that reported no effect of emotion on concurrent task performance (e.g., a math task or digit recognition) (Dillen & Derks, 2012; Van Dille & Koole, 2009). These findings can be explained by the multicomponent WM model (Baddeley & Hitch, 1974), taking into consideration that in these studies the concurrent tasks associated with memory tasks had a substantial auditory and/or phonological component, while the main memory tasks involved visual stimuli. Thus the concurrent tasks were mainly processed by different WM components (i.e., phonological/auditory and visuospatial) but competed for common attention resources, which is associated with impairment in WM performance (Baddeley & Hitch, 1974). There is evidence, however, that concurrent task performance involving emotional judgment may be impacted by the combination of high WM load coupled with emotional distractors. For example, Lim et al. (2014) found that the perceptual judgment of faces as neutral or fearful was influenced by a visuospatial WM task under conditions of high load and the presence of distracting words of emotional content. Thus, in our study the concurrent and WM tasks required common attention resources without requiring the processing of stimuli sharing perceptual or emotional features.

Experiment 2

Tone counting task

The 2 × 3 repeated measures ANOVA on the proportion of correct answers revealed a significant effect of attention load, $F(1, 36) = 185.26$, $p < .001$, $\eta^2_p = .837$, given the higher performance in low-load ($M = .976$, $SE = .008$) than in high-load trials ($M = .616$, $SE = .028$). The main effect of emotional expression, $F(2, 72) = 1.04$, $p = .36$, $\eta^2_p = .028$, and the interaction between the factors, $F(2, 72) < 1$, $p = .39$, $\eta^2_p = .026$, were not significant.[4]

Face WM accuracy (d')

Figure 2B shows the interaction between attention load and emotional expression for Experiment 2. The 2 × 3 repeated measures ANOVA on *d'* revealed a main effect of attention load, $F(1, 36) = 29.90$, $p < .001$, $\eta^2_p = .45$, where participants performed better in the low-load condition ($M = 1.30$, $SE = .11$) than in the high-load condition ($M = 0.92$, $SE = .10$), as in Experiment 1. The main effect of emotional

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[4] An additional analysis of tone counting when the participants have answered correctly to the WM task revealed the same pattern of results, that is, a strong effect of load ($p < .001$, $\eta^2_p = .845$) and non-significant effects of emotion ($p = .73$, $\eta^2_p = .018$) or interaction ($p = .80$, $\eta^2_p = .013$), further supporting that tone counting performance was not influenced by the emotional facial expressions of memory stimuli.

expression was also significant, $F(2, 72) = 3.21$, $p = .046$, $\eta^2_p = .082$, and Bonferroni corrected *t*-tests with adjusted *p*-values for the number of comparisons (i.e., 3) revealed that performance was poorer with happy faces compared to sad faces, $t(36) = -2.80$ ($p = .02$), but was not significant between happy and angry faces, $t(36) = -1.60$ ($p = .36$), and angry faces versus sad faces, $t(36) = -.75$ ($p = 1$).

The interaction between WM load and emotion was significant, $F(2, 72) = 7.71$, $p = .001$, $\eta^2_p = .18$. To further explore this interaction, Bonferroni corrected *t*-tests with adjusted *p*-values for the number of comparisons (i.e., 3) were carried out for comparing performance between low- and high-load conditions for each emotion. This revealed significantly poorer WM in high- than low-load conditions differences for angry, $t(36) = 5.82$, and sad faces, $t(36) = 3.64$ (both $ps < .001$), but this was non-significant for happy faces, $t(36) = -.066$, $p = 1$.[5]

Face Response bias (c)

The 2 × 3 repeated measures ANOVA on the response bias criterion *c* showed that the main effect of attention load was not significant, $F(1, 36) = 2.15$, $p = .15$, $\eta^2_p = .056$. The main effect of emotional expression was significant, $F(2, 72) = 3.32$, $p = .042$, $\eta^2_p = .085$, given the more liberal criterion (i.e. negative *c* values) observed for happy ($M = -.078$, $SE = .077$) and angry faces ($M = -.076$, $SE = .059$), and more conservative

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[5] A broadly similar pattern of results was also observed in an additional analysis of the proportion of correct answers in the WM task when the participants had answered correctly to the tone counting task, that is, the low- vs. high-load difference for happy, $t(36) = 1.54$ ($p = .40$), was not significant, and it was significant for angry faces, $t(36) = 5.00$ ($p < .001$), and sad faces, $t(36) = 3.33$ ($p = .006$).

criterion (i.e., positives *c* values) for sad faces (*M* = .043, *SE* = .057), although differences were nonsignificant regarding happy versus angry, $t(36) = -.04$ ($p = 2.90$), sad versus happy, $t(36) = -1.96$ ($p = .17$), and sad versus angry, $t(36) = -2.35$ ($p = .07$), as revealed by Bonferroni corrected *t*-tests. Finally, the interaction between the factors was not significant, $F(2, 72) < 1$, $p = .50$, $\eta^2_p = .019$.

Interim Summary

In Experiment 2, we investigated whether the results observed in Experiment 1 would be replicated using neutral faces at retrieval. In line with Experiment 1, the results revealed that attention load significantly impacted WM performance for angry and sad faces but not for happy faces. This pattern of results was mainly supported by an additional analysis of WM performance restricting to trials in which the participants performed the tone counting task accurately. In this analysis, WM performance for happy and angry faces was not significantly impacted by attention load, as it was observed for sad faces. Despite the discrepancy in the results with angry faces, the main analysis considering all the trials revealed a significant difference between attention load conditions. Overall, the results of Experiment 2 provide further support that WM for happy faces is less dependent on attentional resources compared to angry and sad faces. In addition, the results also provided further support that tone counting is not influenced by the emotional content of the WM stimuli.

Cross-Experiment Analyses

Tone counting task

The analysis revealed a main significant difference between groups in the tone counting task performance, $F(1, 75) = 14.56$, $p < .001$, $\eta^2_p = .16$, with higher performance in the emotion-probe group (*M* = .75, *SE* = .02) than the neutral-probe group (*M* = .62, *SE* = .02). The main effect of emotional expression was not significant, $F(2, 150) = 1.80$, $p = .17$, $\eta^2_p = .02$, with similar accuracy across happy (*M* = .69, *SE* = .02), angry (*M* = .70, *SE* = .02), and sad faces (*M* = .67, *SE* = .02), and there was a non-significant interaction between group and emotion, $F(2,150) < 1$, $p = .44$, $\eta^2_p = .01$.

Face WM accuracy (d')

The 2 × 2 × 3 repeated measures ANOVA on discrimination index *d’* revealed a significant main effect of group, $F(1,75) = 71.44$, $p < .001$, $\eta^2_p = .49$, with higher overall accuracy for the emotion-probe group (*M* = 2.12, *SE* = .08) than the neutral-probe group (*M* = 1.11, *SE* = .09). The results revealed a significant main effect of attention load, $F(1, 75) = 69.38$, $p < .001$, $\eta^2_p = .48$, where participants performed better in the low-load condition (*M* = 1.86, *SE* = .06) than in the high-load condition (*M* = 1.38, *SE* = .07). There was a non-significant main effect of emotional expression, $F(2, 150) < 1$, $p = .70$, $\eta^2_p = .005$.

The interaction between attention load and emotional expression was significant, $F(2, 150) = 9.04$, $p < .001$, $\eta^2_p = .11$. To explore this interaction, Bonferroni corrected *t*-tests with adjusted *p*-values for the number of comparisons (i.e., 3) were carried out for comparing performance between low- and high-load conditions for each emotion. This revealed significantly poorer WM in high- than low-load conditions for angry, $t(76) = 7.56$, and sad faces, $t(76) = 6.47$ (both *ps* < .001), but not for happy faces, $t(76) = 1.91$, $p = .18$.

To further explore the interaction between attention load and emotional expression, we carried out additional ANOVAs for low and high attention conditions separately to better assess the difference between emotional expressions. The results revealed a significant difference between emotions only under the high-load attention condition, $F(2, 152) = 5.76$, $p = .004$, $\eta^2_p = .07$, where performance was better for happy faces in comparison with angry faces, $t(76) = 3.19$ ($p = .006$), and sad faces, $t(76) = 2.48$ ($p = .04$), with no difference between angry and sad faces, $t(76) = -.84$ ($p = 1$), as revelead by Bonferroni corrected *t*-tests. There were non-significant differences between emotions under the low-load attention condition, $F(2, 152) = 2.80$, $p = .06$, $\eta^2_p = .04$.

The interaction between emotion expression and probe-group was also significant, $F(2, 150) = 7.17$, $p = .001$, $\eta^2_p = .09$. To further explore this interaction, we carried out additional ANOVAs for each group separately to examine the difference across emotional faces. The results revealed a significant difference between emotions in the emotion-probe group, $F(2,78) = 4.31$, $p = .017$, $\eta^2_p = .10$, where performance was better for happy faces in comparison with angry faces, $t(39) = 2.74$ ($p = .027$), and sad faces, $t(39) = 2.55$ ($p = .04$), with no difference between angry and sad faces, $t(39) = -.206$ ($p = 1$), as revealed by Bonferroni corrected *t*-tests. In contrast, performance in the neutral-probe, $F(2, 72) = 3.20$, $p = .046$, $\eta^2_p = .08$, group was poorer with happy faces than sad faces, $t(36) = -2.80$ ($p = .02$), but there was no difference between happy and angry, $t(36) = -1.60$ ($p = .36$), and angry and sad faces, $t(36) = -.750$ ($p = 1$).

The other interactions between attention condition and probe-group and three-way interaction were non-significant ($F < 2$, $p > .10$).

Face Response Bias (c)

The 2 × 2 × 3 repeated measures ANOVA on the response bias criterion *c* revealed non-significant main effects of group, $F(1, 75) = .43$, $p = .51$, $\eta^2_p = .006$, attention load, $F(1, 75) = 3.71$, $p = .058$, $\eta^2_p = .047$, and emotional expression, $F(2,150) = .44$, $p = .64$, $\eta^2_p = .006$.

There was a significant interaction between emotional expression and probe-group, $F(2, 150) = 4.26$, $p = .016$, $\eta^2_p = .05$, and to explore this interaction, we carried out additional ANOVAs for each group to better access the effects of emotion. The results revealed non-significant differences across emotions in the emotion-probe group, $F(2, 78) = 1.31$, $p = .28$, $\eta^2_p = .03$. In contrast, in the neutral-probe group, a significant difference was found between emotions, $F(2,72) = 3.32$, $p = .042$, $\eta^2_p = .08$, indicating a more liberal criterion (i.e. negative *c* values) observed for happy (*M* = -.078, *SE* = .077) and angry faces (*M* = -.076, *SE* = .059), and more conservative criterion (i.e., positives *c* values) for sad faces (*M* = .043, *SE* = .057). However, Bonferroni corrected *t*-tests revealed a non-significant difference between happy and angry, $t(36) = -.04$ ($p = 1$), sad and happy, $t(36) = - 1.95$ ($p = .17$), and sad and angry, $t(36) = - 2.35$ ($p = .07$). The other interactions between attentional condition and emotion and the three-way interaction were non-significant (F < 1, $p > .57$).

Interim Summary

The cross-experiment analysis showed a higher overall performance for the emotion-probe group than the neutral-probe group, suggesting that performance is impacted by the type of probe, that is, the discrimination was less effective when the probes were neutral faces. This finding is not surprising and could be related to the fact that participants in Experiment 1 employed a pure picture-matching strategy since the probe faces were identical to one of the faces in the face array on match trials. As in the experiments considered separately, the main effect of WM load was significant, but in contrast, the main effect of emotion was not significant, which was due to a larger group discrepancy for happy faces than observed for angry and sad faces, as revealed by the interaction between group and emotional expression. In Experiment 1, performance was better with happy than other faces whereas it was worse in Experiment 2. In Experiment 2 at retrieval participants had to compare a neutral probe face with representations of prior emotional faces at encoding, and perhaps some emotional expressions are more perceptually similar to neutral faces than other emotional expressions. We discuss the potential role of perceptual similarity in more depth in the general discussion. But broadly speaking this does suggest that the presence or absence of emotion at retrieval may be a critical factor for efficient performance in the WM task. Finally, as in the experiments considered separately, attention load impacted WM differently according to the emotional expressions, being significant with angry and sad faces but not with happy faces.

General Discussion

The present study examined the influence of attentional resources required for processing emotional faces (angry, sad, and happy) in WM. In a dual-task paradigm, we analysed performance on a face recognition WM task with emotional faces at retrieval (emotion-probe group, Experiment 1) and neutral faces at retrieval (neutral-probe group, Experiment 2) under low- and high-load dual-task attentional conditions (white noise vs tone counting, respectively). To summarise across both experiments, we find that: (a) depleting attentional resources impairs WM for angry and sad faces but not happy faces regardless of whether the test face is emotional or neutral: this might have produced better WM for happy vs. sad and angry faces under the high load attention condition and no emotion effects under the low load condition; (b) In the emotion-probe group, when the test face is expressive, and thus the emotion seen at encoding remains at retrieval, WM is better for happy than angry and sad faces, and general performance is better than when test face is neutral. In contrast, in the neutral-probe group, in which the test face is neutral, and thus emotional information is no longer in view at retrieval, we conversely find better WM for sad than happy faces but not for angry. Each of these findings will be discussed in turn.

Lack of attentional load effect on WM for happy faces

Our core research question was whether and how depleting attentional resources by implementing a concurrent task during encoding and maintenance would impact WM for emotional faces. The lack of attentional load effect on WM for happy faces in both emotion-probe and neutral-probe groups suggests that the recognition of happy faces is particularly resource-efficient. Besides, the finding of better WM for happy vs angry and sad faces under a high-load attention condition is likely to have resulted from the lack of attentional load effect for happy faces only. In contrast, memory for angry and sad faces in both experiments was significantly impaired under the high- vs low-load attentional manipulations. Thus, we have evidence that memory for negatively valenced faces requires more attentional resources than happy faces and therefore are not as efficiently processed (Van Dillen & Derks, 2012; Van Dillen & Koole, 2009).

A large body of evidence has shown a preferential enhancement of visual attention to threatening stimuli (Huang et al., 2011; Feldmann-Wüstefeld et al., 2011), especially in studies using a divided attention paradigm (Pottage & Schaefer, 2012; Talmi et al., 2008). Previous studies using WM tasks have shown similar findings that negative faces attract more attention, influencing WM (Van Dillen & Derks, 2012; Van Dillen & Koole, 2009). However, in contrast to previous studies (Jackson et al., 2009, 2012, 2014; Sessa et al., 2011), our findings showed no WM enhancement of angry faces. The advantage of angry faces with schematic (Juth et al., 2005) and real faces (Jackson et al., 2009. 2012, 2014) suggests enhanced maintenance of threatening information and perhaps more allocation of WM resources to angry faces. Feasibly, the depletion of attention here may have resulted in impairment for angry faces in our study's high load condition and, therefore, the lack of this angry face enhancement.

Jackson et al. (2014) proposed a motivational approach to explain how angry faces might influence the competition for resources in WM. They suggested that angry faces have a greater motivational value and demand more resources from WM with a form of 'threat tag' applied. Indeed, the present findings indicate a detrimental effect on recognising angry faces when there is competition for attentional resources in WM. Our findings are consistent with other studies investigating attention modulation of emotional faces in WM (MacNamara & Hajcak, 2011; Van Dillen & Derks, 2012) which suggests that processing of threat faces depends on the availability of attention resources.

Interesting, there also was no enhancement of angry versus other faces WM in the low-load condition. An explanation for this contradictory result is that our paradigm manipulated attention resources with the low- and high-load conditions in randomized trials. A blocked fashion method provides a better prediction of the next trials, allowing different strategies and attention allocation from a randomized trials method. Furthermore, the concurrent task in the low-load condition (e.g., white noises sequence) perhaps required some level of attention processing, although it was much lower than the high-load condition where specific tones were to be counted. Previous studies (Jackson et al., 2009, 2014) found an angry benefit in WM when no other processes compete for resources. This might suggest that emotion processing depends on the strength of top-down guidance of attention (Pessoa et al., 2005; Yates et al., 2010).

Conversely, the lack of attentional effect in happy face WM recognition implies that fewer attentional resources are allocated to happy faces compared to other negative faces (Srinivasan & Gupta, 2010; Srinivasan & Srinivasan, 2010). Thus, it is possible to conceive that WM processes rely on the availability of attention resources and consequently the relative advantage of positive stimuli, with only happy faces prioritised for WM storage under more demanding attentional conditions. Previous findings that reported a happiness superiority effect relative to both angry (Becker et al., 2012; Curby et al., 2019) and sad faces (Gupta & Srinivasan, 2015; Srinivasan & Srinivasan, 2010) support these assumptions. For instance, Curby et al. (2019) demonstrated a WM cost (e.g., lower WM capacity) for fearful faces compared to neutral and happy faces, showing a WM advantage for happy faces (e.g., Experiment 4). Consistent with this, Gupta and Srinivasan (2014) found that happy faces are better recognised than sad faces in a high load condition, indicating that happy faces require less attentional resources to be processed compared to sad faces.

Our data suggest that happy faces also need to compete for processing resources, but they require less attentional weight that could bias an advantage processing in their favour. These results concur with findings that reported a "superiority effect of happy faces" (Becker et al., 2011; Gupta & Srinivasan, 2014; Sportono et al., 2018). According to Becker et al. (2011), the discrimination of happy faces might have an evolutionary advantage because they are less ambiguous than the other expressions and afford prosocial tendencies. In addition, previous characterization tasks where participants are asked to recognise the facial expression into a limited number of pre-existing categories have shown a distinctive benefit of happy faces (Calvo et al., 2016; Nummenmaa & Calvo, 2015). For instance, Nummenmaa and Calvo (2015) argued that happy expressions are well recognised from angry expressions, even when both contain an equal amount of expressive information.

Emotional vs Neutral face at retrieval

Our findings reported a better performance for happy vs angry and sad faces in the emotion-probe group when the test face was an emotional expression but showed an inverse pattern in the neutral-probe group. When the test face was neutral, WM for sad faces was better than for happy but performance did not differ between sad vs angry and happy vs angry. Likewise, the general WM performance for any emotional face was lower than the emotion-probe group. This fact tells us that the presence or absence of emotion at retrieval may be a critical factor in the degree of efficiency of WM processes according to overall task difficulty.

In explaining this finding, we argue that in the neutral-probe group where participants have to abstract across expression to remember face identity, the task demands are more difficult, resulting in a poorer performance compared to the emotion-probe group. In our paradigm, participants were required to make identity judgments when faces matched or unmatched emotional expression. In the neutral-probe group, participants may have inhibited the expression process to focus on the face's identity. On the contrary, the face's emotional dimension did not need to be disregarded for matching the identity face in the emotion-probe group. In this case, the inhibition of the emotional expression could have led to a higher demand for processing, as previous studies found that face identity and expression processing are interconnected (Atkinson et al., 2005; Ganel & Goshen-Gottstein, 2004), in other words, these characteristics are processed together, and both contribute to decision-making in an identity matching task (Yankouskaya et al., 2012). For instance, Ganel and Goshen-Gottstein (2004) had participants categorize faces according to a relevant visual feature of the face (e.g., expression feature: "Is this person smiling or angry?") while another irrelevant dimension was held constant (i.e., person with identity A) or varied randomly (e.g., person with identity A and B). Thus, two blocks of identity or expression matching were administrated. Findings showed that irrelevant information from other face dimensions interfered in the matching judgment equally in the identity and emotional expression blocks. Therefore, the authors suggested that interconnected routes code facial expression and identity.

These assumptions concur with our findings of better WM performance for happy faces compared to the negative faces in the emotion-probe group. Strong evidence suggests that happy faces convey positive social cues (Becker & Srinivasan, 2014), which facilitate the encoding of facial expression (Silvia et al., 2006) and consequently enable more resources to process facial identity (D'Argembeau & Van Der Linden, 2011). On the other hand, this happy face advantage on WM disappeared in the neutral-probe group, and sad faces were better recognised on WM than happy faces. An explanation for this result is that participants might have prompted additional strategies, such as lower-level perceptual processing, to solve identity matching when the task demand was more difficult in the neutral-probe group. In other words, the neutral test at retrieval may have required additional face perception processes involved in deciding whether the given face was presented at encoding with different emotional expressions.

In terms of the potential impact of image similarity on emotion effects in our current study and in particular in Experiment 2, prior work has considered this in relation to perceptual matching performance. Chen et al. (2011) researched whether the face discriminability of physical features differs between neutral versus a range of emotional expressions in a face identity matching task where pairs of faces had the same emotion (Exp. 1) or different emotions (Exp. 2; i.e., emotional vs neutral). Findings showed that happy faces were not more efficiently matched than sad expressions when the pairs had the same expression (e.g., happy-happy, sad-sad) or when the test-face had a neutral expression. However, the pair's happy-neutral faces were matched quicker than the angry-neutral pair. This does not align with the finding of similar WM for happy vs angry faces in Experiment 2 here using a neutral test face, nor the overall sad vs happy benefit.

A more objective measure of image similarity was computed in the Structural Similarity Index (SSIM) algorithm (Wang et al., 2004), which showed that neutral faces were structurally more similar to their sad and angry counterparts compared to fear counterparts, and neutral-happy faces structures were the least similar. However, Chen et al. (2011) did not find that SSIM values modulated perceptual matching performance when added as a covariate. The SSIM output could potentially explain why WM for sad faces was better than for happy faces in Experiment 2 here. The response bias data we reported can help us confirm whether this could be the case. In experiment 2 (neutral probe face), if sad to neutral faces were structurally similar to one another, a liberal bias to respond ‘same’ would be expected, while a conservative bias to respond ‘different’ may be expected for happy to neutral faces if they are less perceptually similar when making an identity match judgement using WM. We found the opposite (a more ‘different’ bias to sad faces and a more ‘same’ bias to happy faces). However, there were non-significant differences in response bias values between emotions so there is little evidence to suggest perceptual similarity effects confounded emotion effects to any meaningful degree. Although a liberal bias has been linked to negative images (Miendlarzewska et al., 2013), the same pattern has not been found with schematic faces (Tamm et al., 2017), which showed a more liberal response bias to happy faces.

Interestingly, this change in the discrimination criterion did not influence the competition for attentional resources in processing emotional information and the high attention load impaired more the negative faces than happy faces as in the emotion-probe group. There has been a considerable debate over the requirement of attentional resources for the perception of emotional faces since some evidence suggests a central (Tomasik et al., 2009) and spatial attention (Pessoa et al., 2002) demand to process emotion, whereas other evidence suggests no requirement of attentional resources (Shaw et al., 2011). This hypothesis should be further investigated in future studies.

Conclusion

Our findings point to substantial evidence that competition for attentional resources in WM interferes with the processing of emotional faces. However, our findings also suggest different attention allocation patterns between positive and negative faces, more specifically, a high attention demand for angry and sad faces than happy ones. It is interesting to note that emotional face WM demands are sensitive to face WM difficulty (ie probe face expressive vs neutral). Futures studies should consider this effect when evaluating the WM recognition task of emotional faces. Taken together, it appears that the amount of available attention resources can modulate the priority storage of emotional faces.

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   Not Applicable

2. Disclosure of interest

   The Author(s) declare(s) that there is no conflict of interest

3. Data availability statement

   The authors confirm that the data supporting the findings of this study are available within its supplementary materials.

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Figure captions list

- **Figure 1**

  Sequences of events in Experiment 1 (emotional face test) and 2 (neutral face test). Illustration of one trial with the emotional expression of anger. Participants memorised two faces array with the same emotional expressions for 2000 ms. After a 1,500 ms retention interval, one test face was presented. A sequence of six high- and low-pitched tones or six white noise bursts were presented during the encoding and retention interval. Participants were required to judge whether the identity of the probe face was the same or different from the previous face array and to indicate the number of low-pitched tones presented in the trial. In Experiment 1, the test face was an emotional face and a neutral face in Experiment 2.

- **Figure 2**

  Mean WM accuracy across emotions as a function of high concurrent attention load (tone counting) versus low concurrent attention load (white noise bursts). A. General mean performance on high and low attention conditions across emotion (happy, neutral, angry and sad faces) in Experiment 1 (emotion-probe group), where the test face has an emotional expression. B. General mean performance on high and low attention conditions across emotion (happy, neutral, angry and sad faces) in Experiment 2 (neutral-probe group), where the test face has a neutral expression across emotion. Error bars indicate 1 standard error above and below the mean.