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Running with emotion: When affective content hampers working memory performance

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This study tested the hypothesis that affective content may undermine rather than facilitate working memory (WM) performance. To this end, participants performed a running WM task with positive, negative and neutral words. In typical running memory tasks, participants are presented with lists of unpredictable length and are asked to recall the last three or four items. We found that accuracy with affective words decreased as lists lengthened, whereas list length did not influence recall of neutral words. We interpreted this pattern of results in terms of a limited resource model of WM in which valence represents additional information that needs to be manipulated, especially in the context of difficult trials.

Keywords: Working memory; Emotion; Running memory task.

Although many studies have recently begun investigating the interaction between working memory (WM) and emotion (e.g., Martin & Kerns, 2011), it is often difficult to draw specific conclusions about the processing of emotional information in WM and the direction of emotional influence on WM tasks. One reason lies in the definition of WM per sé. In fact, the ability to maintain a limited amount of information active in WM in order to use it during a cognitive task implies a variety of functions such as capacity, inhibition, updating and binding—to cite only few. In particular, WM capacity limitations mean that some features will be processed at the expense of others since only a limited quantity of information can be held in WM. This limited capacity, however, can be increased by grouping or "chunking" items as a collection of concepts that have strong associations between each other. The functions of selection and inhibition in WM involve paying attention to some of the perceptual features and/or some of the cognitive details while ignoring others. Moreover, selection and inhibition will allow only relevant features to be processed in WM. Finally, rehearsal in WM is crucial to remembering since rehearsing serves to preserve features and to enrich an event as well to preserve the correct serial recall order or the activated memory trace.

Furthermore, affective information has differential effects on these functions. For example, a study by Mitchell and Phillips (2007) yields a complex picture in terms of emotional modulation of executive functions. In fact, their results show how emotions sometimes hamper and sometimes boost WM performance. More recently, Baddeley introduced a new component within his classic WM model, the so-called hedonic detector, to acknowledge the fact that emotion holds a special and complex status in WM (e.g., Baddeley, Banse, Huang, & Page, 2012).

Another complementary reason for this complex pattern of data is the fact that no single existing task taps all WM functions. In fact, a variety of WM tasks, from simple span measures to complex inhibition and binding tasks, have been described in literature. This renders the interpretation of data intricate. One interesting WM task, recently returned to limelight, is the running memory task (Broadway & Engle, 2010; Mammarella & Fairfield, 2006). In this task, participants are presented with a series of lists of items of unknown length and are asked to recall the last 3 or 4 items. This task is assumed to reflect both storage capacity (Broadway & Engle, 2010; Cowan, 2005) and updating or, more generally, executive functions (for a detailed discussion see Bunting, Cowan, & Saults, 2006).

However, beyond the discussion about which function is actually measured better by this task that is not the aim of our study, we believe that running memory is a suitable for studying the interaction between WM and emotion for different reasons. First, given its span format, it helps shed light on the interaction between the deployment of WM resources and emotion. By using this task, we can evaluate

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whether WM performance is enhanced or undermined by emotional information at different levels of task requests. Second, running memory has recently been described as a predictive measure of fluid intelligence (e.g., Broadway & Engle, 2010). Thus, it may represent an important index of our general ability to manipulate information, relevant to the on-going task, online. Consequently, studying whether emotion facilitates or undermines running memory performance may be relevant for better explaining success or failure in other complex cognitive abilities. In particular, in this study, we examined the effect of emotional content on running WM performance. As far as we know, only a few studies have addressed the role of emotions in running WM. For example, Martin and Kerns (2011) highlighted how mood can have differential effects on cognition. In particular, they found that positive mood hampered WM storage capacity but had no effect on predominant response inhibition. However, since this study compared positive mood with a neutral condition but not with a negative condition, it may be possible that these results only partially account for the effects of emotional mood in WM. In addition, the authors adopted a mood induction technique rather than manipulating the affective valence of the information in WM as we did in our study. In another study by Greenberg, Tokarev, and Estes (2012), the authors found that affective orientating tasks at encoding influenced running memory performance in a recognition-based task. That is, participants recognised negative words better when they previously judged these words as negative. The same happened for positive words. Although this study did not adopt a typical WM procedure, it highlights the fact that emotional manipulations can influence running memory performance. More specifically, concerning Martin and Kerns (2011)'s results, data are coherent with Baddeley's hypothesis (Baddeley et al., 2012) that considers affective information as another type of information that WM has to process. Accordingly, when task requests increase by adding emotional content, WM performance decreases. Our study aimed to investigate this hypothesis. We asked our participants to complete a running WM task that varied in terms of the valence of the emotional content. Some of the words were positive, some negative and others were neutral. Our prediction was that emotional content would decrease running WM performance and especially as task requests increased. Differently, performance with neutral words may be unaffected and even more so with a blocked study design. In fact, when valence presentation is blocked, neutral and emotional items may create a sort of trade-off in WM to the extent that the absence of emotions per sé increase WM performance, independently of list length, by freeing WM capacity and lightening rehearsal requests. Specifically, our hypothesis is that neutral items may be generally unaffected by list length unless emotional trials are presented first. This may be due to the fact, that when participants studied emotional trials, all WM resources are directed towards valence processing leaving few resources available for the task per sé, especially with the more difficult trials. Consequently, when participants study neutral trials, in which more resources are available, performance is unaffected by list length. Differently, when participants are presented with neutral trials first, we expect to observe a typical decrease in WM performance with longer lists as shown with valenced items.

In our study, we manipulated WM content rather than inducing positive or negative mood. In fact, we believe that it is important to investigate how different emotional dimensions are elaborated in WM and it may be that online manipulation of valence is more resource demanding per sé, and thereby leaves fewer resources for the task at hand as it becomes more difficult.

METHODS

Participants

Forty right-handed adults (22 female) participated as volunteers in the experiment. Participants ranged from 18 to 29 years of age ($M_{age} = 22.1$, $SD = 2.6$), with normal or corrected normal vision, no colour blindness or weakness, no history of mental illness or neuropathy. None of the participants were undergoing medical treatment and declared to have not consumed coffee, alcohol or other substances during the 12 hours prior to the experimental session. All participants were administered the Positive and Negative Affective Scale (PANAS, Watson, Clark, & Tellegen, 1988) to assess current mood ($M_{positive}$ score =27.7, $SD = 5.6$; $M_{negative}$ score = 24.7, $SD = 5.0$).Before beginning the experimental session, all participants signed informed consent forms.

Stimuli

We selected 60 words (20 positive, 20 negative and 20 neutral) from the Italian adaptation of the Anew (Montefinese, Ambrosini, Fairfield, & Mammarella, 2013). Word characteristics are presented in Table 1. We developed lists of 5, 6, 7 and 8 items. Each participant saw 2 lists for each length (5, 6, 7 and 8 items long) for positive, negative and neutral words for a total of 24 trials. Words had 6.37 mean number of characters and ranged from 5 to 8 characters. Finally, none of the trials contained semantically related words (e.g., party, birthday) in order to avoid chunking effects that could aid recall.

Procedure

In each trial, participants saw a fixation "+" for 1500 milliseconds in the center of the screen that indicated the onset of the trial, followed by sequentially

TABLE 1
Word characteristics

	Positive	*Negative*	*Neutral*
Valence	7.80 (0.48)	2.21 (0.44)	5.37 (0.34)
Arousal	6.71 (0.38)	6.83 (0.24)	4.75 (0.45)

Note: Standard errors are in brackets. Values range from 1 (*very negative*) to 9 (*very positive*).

presented valenced words in the center of the screen for 1000 milliseconds each. The number of words presented varied between 5 and 8 words for each trial. The list lengths were randomised but valence was blocked so that participants saw all trials from one valence before going to the next. The blocks of valence were randomly intermixed across participants. Finally, a question mark appeared in the center of the screen, and participants were instructed to verbally list the last three words of each trial in a sequential order.

We chose to create lists from 5 to 8 items long because pilot studies carried out in our lab showed that lists of this length avoided ceiling and floor effects that can be considered as indexes of task difficulty. In fact, before carrying out this study, we created in a series of trials constructed to determine the most informative task length. We presented participants with lists of valenced words that varied in length from 3 to 10 words using the same criteria used to construct our experimental task lists. Results showed how running WM task performance was at ceiling for lists that were 3 and 4 items long while all participants below chance performance for lists that were 9 or 10 items long.

RESULTS

To better highlight the effects of emotion on running WM performance, we examined accuracy scores on 5 and 6 item trials pooled together (short and easier) vs. scores on 7 and 8 item trials pooled together (long and more difficult).

We conducted a 2×3 repeated-measures analysis of variance (ANOVA). List length (short vs. long) and valence (positive, negative and neutral) were manipulated within-subjects. Results evidenced a significant two-way interaction, $F(2, 78) = 3.37$, $p < .05$, partial $\eta_2 = .08$ showing how valence did not affect performance with shorter lists, whereas participants did better on neutral trials with longer lists (Figure 1).

We conducted a second ANOVA in order to clarify our hypothesis about a trade-off between neutral and emotional items in WM. List length (short vs. long) and valence (positive, negative and neutral) were manipulated within-subjects while order of valence presentation (neutral first vs. emotional first) were manipulated between-subjects. Results showed how the two-way interaction between list length and valence remained

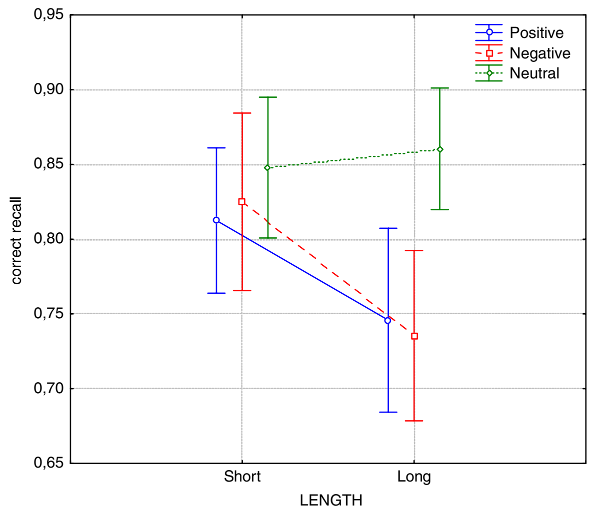

Figure 1. Proportions of correctly recalled words according to valence and list length.

significant only when emotional trials preceded neutral ones, $F(2, 22) = 3.28$, $p = .05$, partial $\eta_2 = .23$. Differently, when we considered data only from participants who saw the neutral trials first, the interaction was not significant, $F(2, 24) < 1$.

DISCUSSION

In this study of emotional WM, we found that emotional content undermined WM performance in a running WM task. However, this decrement only occurred with longer lists. Although previous studies have extended the so-called emotional enhancement effect to WM tasks (e.g., Mammarella, Borella, Carretti, Leonardi, & Fairfield, 2013; Mikels, Reuter-Lorenz, Beyer, & Fredrickson, 2008), our results suggest that there may be additional emotional effects that act at encoding stages that need to be addressed. In particular, we found a decrease in accuracy for valenced words with longer lists indicating that task difficulty interacts with valence processing in WM. This hypothesis is consistent with data by Schmeichel (2007) who highlighted the fact that contextual factors such as valence may reduce executive resources and consequently undermine WM performance. More specifically, in their study (Experiment 3), participants engaged in different tasks that varied in terms of difficulty (from maintenance to updating) and later asked to inhibit responses to an emotionally charged stimulus. Results showed that only participants who performed the updating task were less successful at inhibiting their emotional expressions. These results seem to support the hypothesis that with increasing effort, resources needed for emotion processing decrease. In this manner, task difficulty determined the impairment in valence processing. Our data suggests that emotion processing was only slightly impaired with shorter, and therefore easier, list lengths whereas with longer, and therefore more difficult list lengths, emotion processing was more heavily impaired. In addition, it is noteworthy that the observed WM decrement with longer lists was independent of the type of valence, as a similar pattern of results occurred for both positive and negative words. This may be, somehow, surprising since valence has been described to exert differential effects on WM performance (see Fredrickson & Branigan, 2005). For example, negative information has been shown to capture attention and increase recall on an item-by-item basis, whereas positive valence seems linked to better memory for semantic and core information or the global scene. One possibility is that given the nature of the task (e.g., span format, presentation rate, etc.) and the WM functions involved (storage, updating), the executive requirements of the shorter lists were not a decisive determinant of the running ability and participants performed equally well with different valenced information. However, when the task becomes more effortful, both positive and negative valence processing undermined the later executive control needed to correctly perform the task. This occurred independently of the valence of the information since both positive and negative dimensions are additional emotional information that needs to be processed. More precisely since valence across lists was blocked, our results may indicate that failures in emotion processing may be considered as an instance of generally reduced executive control resources. This pattern was also mirrored in the neutral condition which was positively affected since more resources were available for processing. In fact, neutral words that did not tap resources necessary for emotional processing, leaving more resources for later executive control, were unaffected by list length.

In conclusion, the current finding indicates that running WM processes for emotional information operate within a limited resource model showing that complex cognitive tasks that deplete the capacity of executive control per sé may be further negatively influenced by valence processing. Finally, our data may also underline a relationship between running memory performance and measures of fluid intelligence that needs to consider emotion.

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