



Emotional distraction in working memory: Bayesian-based evidence of the equivalent effect of positive and neutral interference

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ABSTRACT

Evidence has shown that negative distracting stimuli are most difficult to control when we are focused in a relevant task, while positive and neutral distractors might be equally overcome. Still, recent meta-analytic evidence has pointed out that differences in the ability to cope with positive or neutral distractors may be difficult to detect in healthy people and in laboratory sets. Here we re-analyse memory performance in four already published working memory experiments in which affective and non-affective distractors were used. We focused on the positive versus neutral contrast, which did not reveal differences in the original analysis, with the aim of quantifying evidence for the null hypothesis using a Bayesian approach. Bayes factor (BF) estimates show substantial evidence in favour to the absence of differences in three out of four datasets. Further, BF aggregated from the four studies shows stronger evidence for the null hypothesis. Results from this analysis show that WM performance after positive and neutral interference can be considered equivalent, suggesting that positive distractors can be overcome to the same extent as neutral ones.

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Affective information can capture attention in a preferential manner because of their biological relevance (Öhman et al., 2001; Vuilleumier, 2005). This prioritised access is often associated with adaptive behaviours, although it may impair working memory (WM) performance when emotional stimuli are not relevant for the ongoing task (Dolcos et al., 2011). Previous evidence has shown that negative stimuli are more difficult to ignore than non-affective distractors. Cognitive control mechanisms may be recruited to mitigate the interfering effect of such distractors and improve WM performance (see Iordan et al., 2013 for a review). This effect has also been described at the brain activity level, as negative distractors are able to modulate interactions between dorsal and ventral areas of the brain. Coping with neutral interferences is associated with larger recruitment of dorsolateral

prefrontal cortices (dlPFC), which are related with different aspects of executive functions and cognitive control, including inhibition. Contrary, negative distractors have been reported to de-activate those regions while they increase the activation of ventral structures, including the ventrolateral prefrontal cortex (vlPFC) and the amygdala. These structures are related with affective processing so that it seems reasonable that the appearance of emotionally negative stimuli trigger larger responses over them, even when we try to override the attentional response towards them. Indeed, vlPFC is thought to reflect cognitive control over affective responses and thus it is associated to successful WM performance under emotional distraction (Dolcos et al., 2006; Iordan et al., 2013).

The effect of positive affective distractors has, however, received less attention. Positive stimuli also

represent biologically salient information (e.g. foraging or seeking a mating partner), in such a way that they are also prioritised in the attentional response. Positive stimuli have been most frequently reported as capturing attention to the same extent than do negative ones, although some evidences suggest a mild superiority of negative stimuli (see Carretié, 2014 for a review and meta-analytic evidence). Accordingly, one would expect positive stimuli to interfere WM more than neutral ones, if not as much as do negative distractors. The literature in this regard is scarce and their results are inconclusive. An early study conducted by Kellermann et al. (2012) reported a slight advantage of positive distraction in WM performance in comparison with a control condition. Other experiments have however reported no differences between positive and neutral distractors (García-Pacios, Del Río, et al., 2015; García-Pacios, Garcés, et al., 2015; Mano et al., 2013; Mullin et al., 2012). Moreover, a recent meta-analysis conducted by Schweizer et al. (2019) has highlighted that the effect of affective distraction on behavioural measures of WM is difficult to see, particularly in healthy samples.

But, even tentatively admitting that positive distractors in WM can be controlled as effectively as non-affective interferences, such possibility does not imply that neurocognitive mechanisms for coping with positive and neutral distractors are the same. Successful WM performance under negative distraction is associated with greater activation of vIPFC (Jordan et al., 2013) so it may be the case that similar brain dynamics could operate under positive distraction allowing the individual to cope with it as well as with neutral distractors. This would result in an absence of differences at the behavioural level that would however be achieved at a higher neurocognitive cost for the case of positive distraction. This issue has been studied in a magnetoencephalography (MEG) study in which positive, negative and neutral distractors were presented during the maintenance of a delayed-recognition WM task (García-Pacios, Garcés, et al., 2015). MEG combines excellent temporal precision with fairly good spatial resolution and therefore allows to characterise the unfolding brain response over different brain regions. Results from the event-related field (ERF) analysis identified two main latencies that revealed differences in the brain mechanisms implicated in coping with affective and non-affective distractors. At very early latencies (70–130 ms), prefrontal mechanisms were engaged for the rapid detection of negative and

positive distractors, while the effective control of emotional interference took place later in the processing (360–455 ms). At this latency, negative interference engaged vIPFC, along with sections of medial prefrontal cortex (mPFC), orbitofrontal cortex (OFC) and dIPFC, to a greater extent than did positive and neutral distractors. Indeed, activity in these regions while coping with the interfering item positively correlated with successful performance at the subsequent recognition stage of the WM task. Critically, this effect appeared only for negative distractors, with no differences in the contrast between positive and neutral distractors (García-Pacios, Garcés, et al., 2015). This absence of differences would suggest that, despite of their attentional salience (as indexed by early detection mechanisms), coping with positive distractors does not require from additional brain resources than those implemented for controlling neutral interferences. However, a subsequent study using whole-brain functional connectivity analysis revealed that the control of positive distraction at that same latency required from greater functional coupling between prefrontal cortices (including vIPFC) and posterior regions, than for neutral distraction. Indeed, this study suggested that these differences would begin even earlier, at around 250 ms (García-Pacios et al., 2017). This particular result is in accordance with the conclusions drawn by Schweizer et al. (2019) who noted that, while differences between affective and non-affective distractors are difficult so see at the behavioural level, brain imaging may be able to track some of them.

With the aim of clarifying whether positive and neutral distractors has equivalent or differential interfering effects on WM maintenance, here we explore more in depth the nulls results found in this particular contrast in four WM experiments previously published by our group, including behavioural performance in a neuroimaging study (García-Pacios, Garcés, et al., 2015). In the first experiment (García-Pacios, Del Río, et al., 2015; Exp. 1) we asked participants to complete a delayed-recognition WM task in which neutral faces were used as task-relevant stimuli. During the maintenance of this information, affective, either positive or negative, and neutral distractors were presented. Negative and positive distractors were selected to be high arousing, although the former tended to be significantly more arousing than the latter (see Table 2). Given that both sort of affective stimuli should capture more attention than neutral stimuli, we initially expected to see a mainly arousal-driven

effect on WM performance. Since negative were more arousing than positive distractors, and some evidence suggested that their attentional capture may be larger than the one for positive stimuli (Carretié, 2014), we considered that best WM performance would occur for neutral distractors, followed by positive and finally by negative distractors. Contrary to this a-priori hypothesis, results showed no differences in performance after positive and neutral, while negative stimuli were associated with impaired WM performance. Even though positive stimuli convey biologically salient information that tends to capture attention, it would have been the case that the less arousing positive distractors in that experimental set could not have made the difference from the neutral distractors.

In a second experiment (García-Pacios, Del Río, et al., 2015; Exp. 2) we attempted to confirm whether the equivalent performance after positive and neutral distractors would remain after matching positive to negative distractors in arousal (Table 2). Less important for our purpose here, we also included a fourth condition where no distractor was presented in order to assess whether neutral interferences had an effect beyond a no-distraction scenario. According to the pattern observed in Experiment 1, negative distractors impaired WM more than did positive and neutral ones. But more important, positive distractors were controlled as well as neutral ones, even being as high arousing as were negative.

Still, it might have been possible that participants were voluntarily paying less attention to neutral and positive than to negative distractors. Even unlikely, this possibility could not be discarded without having a direct measure of what volunteers were doing during the appearance of the distractor. Therefore, in the third experiment (García-Pacios, Del Río, et al., 2015; Exp. 3) we implemented the experimental task from Experiment 2 but we asked participants to report whether the scene represented in every single distractor took place indoors or outdoors, so that we could have a measure of whether they differentially paid attention to the three types of distractor. Results replicated the pattern observed in experiments 1 and 2 and discarded a potential effect of a voluntary attentional bias towards any of the distractors. Further, the absence of differences in WM performance after positive and neutral interference was replicated in a subsequent MEG study (García-Pacios, Garcés, et al., 2015, described above).

Overall, these four experiments suggested that not every sort of emotional distractor can interfere WM

maintenance to the same extent. Indeed, it seemed that cognitive control can cope with positive distractors as well as with neutral ones. Notwithstanding, the question of whether positive and neutral stimuli have equivalent effects in WM, i.e. concluding that there is no difference between responses to both types of stimuli, is difficult to address from the Null Hypothesis Significance Tests (NHST) paradigm (Dienes, 2011, 2014). A nonsignificant result cannot be taken as evidence for the absence of an effect (Fisher, 1935; Pardo et al., 2009) without additional information (Schuirmann, 1987; Westlake, 1972). In the last years, several authors have proposed the use of Bayes' factor (BF) to gain evidence to the existence of null effects (Aczel et al., 2018; Dienes, 2014; Lakens et al., 2020; Rouder et al., 2009). The BF is the ratio of the probabilities of the data under two different models (e.g. H_0 and H_1). When the BF value is close to 1 there is no evidence in favour of either hypothesis. As the value deviates from 1 the evidence grows towards one of the hypotheses (Dienes, 2014). When the odds of a hypothesis exceed a value of 3 (or the complementary $BF < 0.33$), it is considered to start receiving positive or substantial empirical support (Jarosz & Wiley, 2014). The objective of the present paper is therefore to evaluate the equivalence between WM performance after positive and neutral distractors in these four experiments and summarise the evidence from them altogether. To do this, we re-analyse WM performance from positive and neutral distraction conditions in these four experiments using a Bayesian approach.

Method

Participants

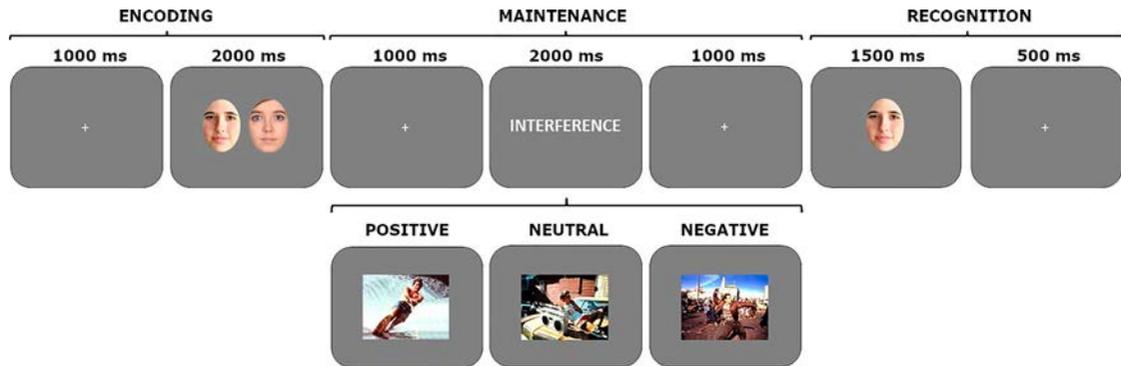
All participants in the four studies were healthy undergraduate students with ages ranging from 18 to 40 years (Table 1).

Materials and WM task

Items at encoding and recognition consisted of coloured neutral faces with an oval mask along the contours to remove any potential non-face cue. Participants were asked to encode two pair of faces that were displayed for 2000ms and hold them in memory. 1000 ms after the offset of the encoding faces, a distracting picture was presented for 2000ms, followed by another 1000 ms interval (a

Table 1. Age and gender distribution of volunteers in Experiments 1–4.

	Experiment 1	Experiment 2	Experiment 3	Experiment 4
Age range	18–30	18–40	18–28	18–29
Mean age	21	21.6	21.2	20.06
Gender	15 females, 15 males	24 females, 19 males	20 females, 6 males	7 females, 8 males

**Figure 1.** Diagram of the delayed-recognition WM task.

maintenance interval of 4000 ms total length). Next, a single face was presented for 1500 ms and participants had to decide whether it was part of the encoding set or not, by pressing one of two keys (Figure 1). Faces at encoding and recognition stages were counterbalanced across experimental conditions and participants. Distracting items were selected from the International Affective Picture System (IAPS) (Lang et al., 2005) to form three experimental sets (i.e. negative, positive and neutral). Positive and negative distractors were selected to not differ in arousal in Experiments 2–4, but they did in Experiment 1 (see Table 2 for mean normative values of stimuli used in Experiments 1–4). The presentation of distracting items along the task was pseudorandomized to prevent inducing long-lasting mood states (see García-Pacios, Del Río, et al., 2015 for a detailed description of materials and WM task).

Statistical analysis

The corrected recognition scores (CRS, hits rate – false alarms rate) for positive and neutral distractors were used as measures of WM performance in Experiments 1–4. CRS are commonly used in studies of recognition memory to account for potential response biases (e.g. Anastasi & Rhodes, 2005; Dolcos & McCarthy, 2006; Gopie & Macleod, 2009), ranging from 0 to 1 with 0 indicating chance performance. We first compared the response to each distractor by a paired samples *t*-test. Then we calculated the BF associated to each experiment by the Bayesian *t*-test proposed by Rouder et al. (2009). This BF compares the point null hypothesis that the standardised effect size is zero with the alternative that standardised effect size is not zero (Morey & Rouder, 2018). The alternative covers a range of standardised effect sizes given by a Cauchy distribution centred in zero. The spread of

Table 2. Mean normative values of stimuli used in Experiments 1–4.

	Negative		Positive		Neutral	
	Valence	Arousal	Valence	Arousal	Valence	Arousal
Experiment 1	2.29 (0.70)	6.54 (0.70)	7.33 (0.33)	5.84 (0.33)	4.91 (0.35)	2.77 (0.35)
Experiment 2	2.39 (0.67)	6.23 (0.56)	7.34 (0.32)	6.23 (0.53)	4.91 (0.35)	2.77 (0.38)
Experiment 3	2.39 (0.67)	6.23 (0.56)	7.34 (0.32)	6.23 (0.53)	4.91 (0.35)	2.77 (0.38)
Experiment 4	2.48 (0.52)	6.16 (0.41)	7.42 (0.33)	6.16 (0.49)	4.93 (0.35)	2.71 (0.38)

Note: Standard deviations are shown in parenthesis.

the distribution can be adjusted with the scale parameter r , the interquartile range. The wider the Cauchy distribution the more the plausibility put on large effect sizes (Rouder et al., 2009; Schönbrodt et al., 2017). As the effect of affective information on behavioural measures seems to be of small size (Schweizer et al., 2019) we set the Cauchy on the medium-wide scale parameter ($r = \sqrt{2}/2$) considered adequate for an effect of that magnitude (Morey & Rouder, 2018; Schönbrodt et al., 2017). Nevertheless, we also quantified the evidential impact of the width of the Cauchy prior distribution on the robustness of the analysis by calculating the BF under the wide ($r = 1$) and ultrawide ($r = \sqrt{2}$) r -values (Aczel et al., 2020; Morey & Rouder, 2018; Wagenmakers et al., 2018).

Finally, we joined the evidence from the four experiments in a combined BF as proposed by Rouder and Morey (2011). The meta-analytic BF is calculated under a fixed effect model, assuming a common true effect size across experiments but not a common variance. This procedure has been used in recent years to synthesise the results of several experiments (e.g. Bostyn & Roets, 2017; Brown et al., 2018; Dessel et al., 2016). In all the analysis we report BF_{01} , the odds in favour to the null. Analysis were conducted in the BayesFactor package (Morey & Rouder, 2018) implemented in R programming language (R Core Team, 2018). To evaluate the degree of evidence we considered the following cut-offs for the BF: anecdotal (1–3), moderate (3–10), strong (10–30), very strong (30–100) and extreme (>100) (Jeffreys, 1961; Lee & Wagenmakers, 2013).

Results

Results from the Student t test between positive and neutral conditions found no differences in WM performance as indexed by CRS (Table 3). We found

Table 3. Summary of results from the analysis of the four datasets.

Experiment	n	Positive		Neutral		t-Student
		Mean	SD	Mean	SD	
Experiment 1	30	0.647	0.136	0.676	0.160	$t = 0.988$; $p = .331$
Experiment 2	43	0.647	0.164	0.669	0.195	$t = 0.715$; $p = .478$
Experiment 3	26	0.646	0.169	0.600	0.162	$t = -1.088$; $p = .287$
Experiment 4	15	0.537	0.140	0.536	0.121	$t = -0.022$; $p = .983$

Table 4. BF_{01} from Experiments 1–4 and aggregated BF in the different Cauchy specifications.

Experiment	$r = \frac{\sqrt{2}}{2}$	$r = 1$	$r = \sqrt{2}$
Experiment 1	3.29	4.43	6.10
Experiment 2	4.76	6.55	9.11
Experiment 3	2.83	3.77	5.15
Experiment 4	3.81	5.14	7.08
Total	8.77	12.29	17.29

moderate evidence for null hypotheses in Experiment 1 ($BF_{01} = 3.29$), Experiment 2 ($BF_{01} = 4.76$), and Experiment 4 ($BF_{01} = 3.81$). In Experiment 3, the evidence also leans towards the null, but in the anecdotal range ($BF_{01} = 2.83$). The combined results of the four experiments also gave moderate support to the null hypothesis ($BF_{01} = 8.77$).

Changing the Cauchy width to larger values increased the evidence to the null. When considering $r = 1$, BFs increase to 4.43, 6.55, 3.77, and 5.14 respectively in Experiments 1–4. When considering $r = \sqrt{2}$, BFs increase to 6.10, 9.11, 5.15, and 7.08 in experiments 1–4. The aggregated values are $BF_{01} = 12.29$ and $BF_{01} = 17.29$ for wide and ultrawide specifications (Table 4). These results show that the evidence for the null hypothesis is robust to changes in the prior distribution considered.

Discussion

The main objective of this work was to evaluate whether the interfering effect of positive and neutral distractors in WM could be considered equivalent. Previous studies reported no differences in performance between these conditions (García-Pacios, Del Río, et al., 2015; García-Pacios, Garcés, et al., 2015; Mano et al., 2013; Mullin et al., 2012). In this situation we adopted a different approach based on Bayesian testing which allows to state evidence in favour to the null hypothesis, thus to distractor equivalence (Dienes, 2014; Rouder et al., 2009). Our results provide moderate evidence for the equivalence between positive and neutral distraction in three experiments, and also positive but anecdotal evidence in the remaining study. Also, the aggregated Bayes factor calculated from the four experiments, points moderately towards de null.

Studies comparing the interfering effect of positive and negative distraction in WM are scarce. Evidence from attention literature shows that positive stimuli are prioritised in the attentional response due to their biological relevance (Pool et al., 2016),

suggesting that they should interfere WM maintenance in much the same way do negative distractors. However, studies using WM tasks have shown reduced distraction by positive items in comparison with negative ones (Kellermann et al., 2012) or even no differences on the effect of positive and neutral interferences in WM, suggesting that the attentional capture triggered by them can be overcome to the same extent (García-Pacios, Del Río, et al., 2015; García-Pacios, Garcés, et al., 2015; Mano et al., 2013). Recent meta-analytic evidence has emphasised that detecting the effects of emotional distractors in WM may be difficult, particularly in healthy volunteers and in laboratory settings, due in part to the low affective significance of some of them (Schweizer et al., 2019; see also Pessoa, 2009). Thus, at the light of the literature, we adopted by default an intermediate value for the Cauchy prior width compatible with such small effect sizes. Meanwhile, it is important to note that the more reduced the width of the Cauchy distribution, the more the null and the alternative hypothesis do similar predictions, making difficult to gain evidence to one or another (Wagenmakers et al., 2018). When considering a wider Cauchy, as do on the robustness analysis, we found stronger evidence towards the null. Together all these results should be interpreted as moderate evidence towards the null when considering as alternative smaller effect sizes and stronger evidence when considering moderate or larger ones.

This result seems not to fully fit with the rationale that affective stimuli are prioritised in the attentional response. According to that logic, positive and negative distractors should interfere WM maintenance more than do neutral stimuli, given that they both are biologically salient. However, positive and negative stimuli differ in significance and are associated with different behaviours and intensity reactions (i.e. approaching and avoidance behaviours). It has been proposed that organisms tend to approach to appetitive stimuli at low motivational levels, which subserves orienting and exploratory behaviours. By contrast, aversive stimuli rapidly engage the defence system and usually trigger stronger reactions, since implications of potential threats (e.g. predators) are typically more severe than those associated with appetitive stimuli (e.g. mating partners) (Berntson et al., 1993; Cacioppo et al., 1997; see also Bradley & Lang, 2007). The higher intensity of reactions to negative stimuli seems to manifest also in the attentional domain, as suggested by a recent meta-analysis that

has reported a certain advantage of negative over positive stimuli in their priority to capture attention (Carretié, 2014). However, the implications may be different when the attentional capture by both negative and positive stimuli need to be overridden in favour of an ongoing relevant task which may result in benefits for the individual. In this case, cognitive control might be able to cope with positive distractors (e.g. a source of food or a potential mating partner) as effectively as with non-affective distractors, since the consequences of ignoring that information are less immediate and dramatic than ignoring negative stimuli (e.g. an approaching predator) (Cacioppo et al., 1997; Öhman et al., 2000).

Nonetheless, the reduced interfering effect of positive distraction might be alternatively explained without referring to cognitive control mechanisms. Positive emotions are known to enhance cognitive capacities by broadening the scope of attention (Fredrickson, 2001; Fredrickson & Branigan, 2005), an effect that has been linked to increases in dopamine release, particularly in the prefrontal cortex and the anterior cingulate (Ashby et al., 1999). It might therefore be possible that the undesired effect derived from the attentional capture by positive task-irrelevant stimuli would be compensated by the cognitive enhancement induced by the affect in the same stimuli. However, these beneficial effects reported on attention as well as on cognitive flexibility and controlled processing has been linked to more sustained positive mood, as such experimentally induced before the actual cognitive tasks (e.g. Nadler et al., 2010; Yang et al., 2013). It does not seem very likely that positive stimuli that briefly and transitorily appear during WM maintenance could trigger such effect. Instead, an interpretation based on the implementation of cognitive control mechanisms over an emotional distractor that is linked to less dramatic consequences seems more plausible. Indeed, several studies using other interference tasks have demonstrated that the recruitment of executive control during the interference trials results in reduced emotional interference (Cohen et al., 2010, 2012, 2016).

But the absence of differences in WM performance under positive and neutral distraction does not necessarily mean that the same brain dynamics are engaged during the processing of both types of distractors. It might be the case that additional brain resources were needed to override the effect of positive interferences. A previous MEG experiment by our

group has revealed that the detection of positive distractors is associated with greater activation of prefrontal areas, as much as negative distractors are (García-Pacios, Garcés, et al., 2015). Such early prefrontal response would serve as a mechanism for top-down facilitation of recognition (Bar et al., 2006) and would therefore allow the rapid detection of visual information of biological salience (Kveraga et al., 2007). The analysis of later latencies related with the effective control of the distracting items did not reveal differences between positive and neutral interferences (García-Pacios, Garcés, et al., 2015). These results would suggest that coping with positive affective stimuli would require from additional resources only to evaluate and detect them as biologically relevant, but not to block out their interfering effect, as long as they are not relevant for the ongoing task. However, whole-brain functional connectivity analysis on the same dataset revealed greater fronto-posterior coupling for positive stimuli at the same latencies than those previously described for the control of negative distraction, and even earlier. Moreover, the vIPFC, which is considered a key cortical region in coping with affective distraction (Jordan et al., 2013; see also García-Pacios, Garcés, et al., 2015), was the main section of the prefrontal cortex that increased its functional coupling with posterior cortices (García-Pacios et al., 2017). These findings reinforce recent conclusions derived from meta-analytic approaches and highlight that differences between some sort of affective distractors and non-affective ones may be difficult to see even at the brain level. In this particular case, ERF analysis would have been not sensitive enough to detect putative differences in local activity. Instead, functional connectivity measures do reveal differences between control mechanisms for positive and neutral distractors. This suggest that measures based on the dynamic interactions between anatomically distant regions are more sensitive to the demands posed by positive emotional stimuli as compared to neutral ones.

Still, it is worth noting that several types of items are traditionally included in the category of positive stimuli, varying in terms of arousal and specific individual's concerns. Erotic pictures capture attention as much as threat-related information (Sennwald et al., 2016) and attentional orientation towards food is modulated by hunger (Piech et al., 2010). Thus, further research is needed to clarify whether, in particular circumstances, specific positive stimuli

can gain significance for immediate survival and therefore interfere other cognitive processes to the same extent do threatening stimuli. Similarly, using different materials (e.g. verbal items) and even different WM tasks will be helpful to assess to what extent this effect is generalisable.

In summary, results from Bayesian analysis on four different datasets support the equivalence of WM performance after positive and neutral interference and suggest that positive affective distractors can be over-ridden to the same extent as neutral ones.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Appendix 1. R script used for the calculation of the Bayes Factor.

```

library(BayesFactor)
t<-c(.988,.715,-1.088,-.022)
n<-c(30,43,26,15)
SCL<-c(sqrt(2)/2,1,sqrt(2))
BF<-matrix(0,5,3)

for (i in 1:3) {
  Scl = SCL[i]
  BF[1,i]=ttest.tstat(t[1], n1=n[1], n2=0, nullInterval = NULL,
  rscale = Scl,
  complement = FALSE, simple = TRUE)
  BF[2,i]=ttest.tstat(t[2], n1=n[2], n2=0, nullInterval = NULL,
  rscale = Scl,
  complement = FALSE, simple = TRUE)
  BF[3,i]=ttest.tstat(t[3], n1=n[3], n2=0, nullInterval = NULL,
  rscale = Scl,
  complement = FALSE, simple = TRUE)
  BF[4,i]=ttest.tstat(t[4], n1=n[4], n2=0, nullInterval = NULL,
  rscale = Scl,
  complement = FALSE, simple = TRUE)
  BF[5,i] = exp(meta.ttestBF(t=t, n1=n,
  rscale=Scl)@bayesFactor$bf)
}
1/BF

```