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RELATIONS BETWEEN EMOTION AND WORKING MEMORY: EVIDENCE FROM BEHAVIOURAL AND PSYCHOPHYSIOLOGICAL STUDIES.

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ABSTRACT. Baddeley (2007) proposed the Hedonic Detection to explain the connection between emotion and working memory (WM). This review aimed to systematize evidence of the influence of emotion on performance of WM tasks and its association with the Hedonic system on current studies. We carried out a database research that generated 103 papers in a restricted period (2007 - 2017). Ten papers combining behavioural tests with psycho-physiological measures and ten papers using strictly behavioural tasks were selected. In all approaches were observed that the type of cognitive request underlying the task is crucial to understand how WM performance is influenced by emotion. Besides, was possible to detect a trend in the literature to focus on executive process related to a neural model for WM, since just only one behavioural paper explained the results based on Hedonic Detector system.

Key-words: Emotion; working memory; systematic review.

RELAÇÕES ENTRE EMOÇÃO E MEMÓRIA OPERACIONAL: EVIDÊNCIAS DE ESTUDOS COMPORTAMENTAIS E PSICOFISIOLÓGICOS.

RESUMO. Baddeley (2007) propôs o Detector Hedônico para explicar a relação entre as emoções e memória operacional (MO). Esta revisão teve como objetivo sistematizar evidências da influência das emoções no desempenho em tarefas de MO a partir de artigos atuais e sua associação com o sistema Hedônico. Para isso, foi realizada uma pesquisa em variadas bases de dados que gerou 103 artigos em um período restrito (2007 - 2017). Foram selecionados dez artigos combinando testes comportamentais com medidas psicofisiológicas e dez artigos utilizando tarefas estritamente comportamentais. Em todas as abordagens foi observado que o tipo de demanda cognitiva subjacente à tarefa foi crucial para entender como o desempenho da MO é influenciado pelas emoções. Além disso, foi possível detectar uma tendência para explicação dos resultados com base no processamento executivo relacionado a um modelo neural da MO, visto que apenas um artigo comportamental explicou os resultados com base no sistema de detecção Hedônica.

Palavras-chave: Emoção; memória operacional; revisão sistemática.

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RELACIONES ENTRE EMOCIÓN Y MEMORIA OPERATIVA: EVIDENCIA DE LOS ESTUDIOS CONDUCTUALES Y PSICOFISIOLÓGICOS.

RESUMEN. Baddeley (2007) ha propuesto Detector Hedónica en un intento de explicar la conexión entre emoción y memoria operativa (MO). En la presente revisión se tuvo como objetivo sistematizar a partir de artículos actuales la influencia de las emociones en la performance de tareas de MO a partir de artículos actuales y su asociación con el sistema Hedónico. Para ello, llevamos a cabo una búsqueda exhaustiva que generó 103 artículos con un período restringido (2007-2017). Se seleccionaron 10 artículos conductuales combinados con medidas psicofisiológicas y otros 10 utilizaron solo medidas conductuales. En ambos abordajes se observó que el tipo de demanda cognitiva presente en la tarea es crucial para comprender cómo la ejecución en la tarea es influenciada por la emoción. Además, fue posible detectar una tendencia en la literatura a centrarse en el proceso ejecutivo relacionado con un modelo neural de MO; ya que solo un estudio conductual explicó sus resultados con base en el sistema de Detector Hedónico.

Palabras clave: Emoción; memoria operativa; revisión sistemática.

Introduction

Working memory (WM) is a short-term storage system under attentional control that supports the capacity for multifaceted thought (Baddeley & Hitch, 1974; Baddeley, 2003). Baddeley and Hitch's first WM model included the central executive, the phonological loop, and the visuospatial sketchpad components: the central executive is related to selection, initiation, and ending of processing routines. The other two components are responsible for storing and manipulating verbal and visuospatial information: the phonological loop and the visuospatial sketchpad, respectively. The fourth component, the episodic buffer was included by Baddeley (2000) in an attempt to explain the integration of information among the other WM components and long-term memory.

Although Baddeley and Hitch's model is the most quoted one, others WM frameworks have been developed. For example, an embedded-processes model proposed by Cowan (1988), in which performance is determined according to temporary activation, which triggers representations in long-term memory and is controlled by attentional processes. In this concept, the information is not preserved within storage buffers, but attentional resources will temporarily activate a subset of information in long-term memory to maintain current goals (Cowan, 1999).

Currently, it is possible to observe in the field of neuroscience the prevalence of Cowan's model, mainly because the concept of different storage components implies, in neural terms, transferring information from one part of the brain to another, which suggest nonspecific activation during encoding, regardless of its modality of representation (D'Esposito, 2007). Focusing on a specific relation between WM tasks and encephalic areas, authors assume that the material is encoded into WM through the allocation of attention to internal representations of long-term memory (D'Esposito & Postle, 2015).

Some studies argued that visual updating tasks are highly correlated with complex visual span (Schmiedek, Hildebrandt, Lövdén, Lindenberger, & Wilhelm, 2009). However, a recent meta-analysis by Redick and Lindsey (2013) showed that span and n-back tasks are weakly related, and the authors pointed out that they cannot be used interchangeably as measures of WM since these two tasks engage different cognitive processes. In fact, in complex span tasks, participants must generate and manipulate a sequence of stimuli presented on a given trial, whereas n-back tasks require participants to recognize a current item as an item that was recently presented in the correct serial position (Wilhelm, Hildebrandt, & Oberauer, 2013).

Apart from this discussion, Baddeley (2007) posit a new component in his model that relates emotions to WM: The Hedonic Detector. This component is suggested to be responsible for evaluation and processing of the emotional information. It has a neutral point for comparison of positive and negative valences of stimuli and establishes an average value between stimuli in the environment and information retained in WM. The combinations of these valences produce a hedonic signal that allows the individual to calibrate future choices while a failure in the neutral point could resemble psychopathological traits such as depression and anxiety.

Since malfunctioning of Hedonic Detector system was supposed to have a central role in depression (Baddeley, 2007), Baddeley, Banse, Huang, and Page (2012) carried out two experiments aiming to test the influence of emotion on cognition, considering the ability to evaluate word valences after being positively and negatively induced by two different procedures. They showed that negative mood states produced a lower hedonic rating of word valence, suggesting that the induced mood could influence a following hedonic judgment. Results seem to demonstrate that participants who are negatively mood induced are less able to suppress intrusive negative thoughts; consequently; ruminant thoughts will influence the attention, so decreasing WM task performance (Baddeley, 2007).

According to Kensinger and Corkin (2003), most research using positive and negative mood induction has shown that induced mood can indeed affect WM performance (Gray, 2001; Mather, et al., 2006). Mather et al. (2006) used a visual short-term source-monitoring task to investigate if memory performance would decrease as a function of arousal levels (high, medium, or low). Participants had to remember the location of four different pictures from the corresponding subset of positive or negative emotional arousal, and the authors concluded that negative high arousal pictures recruited more attention, hence disturbing WM processing capacity.

Moreover, the disruptive influence of negative stimuli on WM performance seems to be caused by the narrowing of the attentional focus due to emotional content. This is suggestive of a trade-off in the processing of information because individuals prioritize emotional processing, decreasing the resources that should be allocated to the behavioural task (King & Schaefer, 2011).

In contrast, Gray (2001) found the performance on a visual 2-back task to be enhanced by negative mood induction and found the opposite pattern for the verbal 2-back task, arguing that this is a signal of the selective effect of emotion on the components of cognitive control. According to these results, performance in WM tasks appears to be related not only to the emotional content but the type of cognitive request and modality underlying the task (Kensinger & Corkin, 2003). Therefore, emotional stimuli seem to affect WM differently in span tasks and updating tasks.

In fact, the results above reinforce the modality specificity proposed by the independent modules (e.g., verbal or visual) within Baddeley's WM model. In contrast, these unrelated results between visual and verbal modalities would not be possible on Cowan's model which suggested a general domain, a central executive that, in turn, can activate networks for many modalities of information stored in long-term memory, in which codification is independent of the form of representation (Morrison, 2005).

Despite several studies in the area, no consensus has been reached regarding the precise effect of emotion on WM, in other words, if positive or negative stimuli in healthy participants decrease or increase WM performance. Therefore, the aim of this review is threefold: (1) to describe and analyse methods and approaches related to the influence of emotional valences and arousal on WM performance (i.e. studies combining behavioural and brain functioning measures or electrodermal measures and conversely strictly behavioural measures); (2) to discern the effects of emotion on WM processes and modalities; and finally, (3) to detect the WM models that have been referenced in papers in this area since the Hedonic Detector has been proposed.

Method

Eligibility criteria

Inclusion criteria were: (1) papers had to include the main goal of the effects of emotion valences (positive or negative versus neutral) and/or arousal on WM tasks (verbal or visual modality, or both), through mood induction or using emotional stimuli methodologies on healthy adult participants; (2) Date-restricted search, in which articles should be published between 2007 and 2017, that took into account the introduction of the Hedonic Detector concept in the literature in order to observe the influence of this new component on the explanation of findings related to the impact of emotion on WM performance; (3) the language of papers could be English, Spanish, or Portuguese. Exclusion criteria were: (1) review papers; (2) experiments with paediatric and geriatric samples; (3) sensorial modalities other than verbal and visual; (4) training-related studies; (5) expanded abstracts and theses.

Identification of relevant papers

Papers were identified by searching electronic databases; the search was applied to the following databases: Web of Science, MEDLINE, Scopus, and Scielo. Search terms included: "hedonic detector," ''working memory'', and ''emotion'', or "valence," or "arousal" present in the title, to increase the specificity of search strategy and to standardize the same search strategy to all databases since search fields vary among databases. The corresponding words in Portuguese and Spanish were also used: Portuguese - Detector Hedônico, memória operatória/memória operacional/de trabalho, emoção, valência, excitação; Spanish: Detector Hedónico, memória operativa/ memória de trabajo, emoción, valencia, excitación). The searches were carried out in February 2017.

Results

The search with the keyword “hedonic detector” revealed only one paper (Baddeley et al., 2012), which was not included in this review since it aimed to investigate the plausibility of the theoretical concept of the Hedonic Detector and the main purpose of this paper was to search for Hedonic Detector evidence.

Together a total of 103 papers were found using the keywords ‘‘working memory’’ and ‘‘emotion’’ or “valence” or “arousal,” from these papers sample, twenty papers met our criteria and were included in this systematic review (selected papers were marked with an asterisk in the references). Eighty-three studies were excluded: Studies which not focused on the effects of emotion on WM, such as emotion regulation or investigations related to WM capacity and emotions (22 papers), examined emotions on mood disorders samples (27 papers), sensorial modalities other than verbal and visual, such as facial touch and olfactory stimulation (3 papers), paediatric samples (7 papers), paediatric and geriatric samples (3 papers), geriatric sample (2 papers), the effect of WM training on emotions (6 papers). The other 13 exclusions were: Theses (1 paper), Review (1 paper), 2 Chapters, paper with the intent only to test neuroimaging reliability (1 paper), and expanded abstract (3 papers), Korean language (1 paper), papers not available for access on-line (3 papers).

From the 20 papers selected, ten papers used techniques for measuring brain activity such as electrophysiology, functional neuroimaging, near-infrared spectroscopy, and electrodermal measures to observe physiological changes during WM tasks and/or mood induction and ten papers used strictly behavioural tasks. Experimental design, characteristics, and results of these studies are summarized in Tables 1 and 2, respectively.

WM behavioural tasks of the psychophysiology papers

It was not the goal of this review to discuss the psychophysiological results gathered in the selected studies since its generalization could be unattainable due to the diversity of psychophysiological procedures. Therefore, only the results of the WM behavioural performance were analysed in this systematic review.

The task most used to assess WM performance was the n-back, it was included in 6 papers (Choi et al., 2013; Grimm, Weigand, Kazzer, Jacobs, & Bajbouj, 2012; Kessel et al., 2016; Li, Ouyang, & Luo, 2010b; Luo et al., 2014; Ozawa, Matsuda, & Hiraki , 2014), this task is related to Cowan’s model. Regarding the influence of emotional effects, three papers (Grimm et al., 2012; Li, Chan, & Luo, 2010a; Ozawa et al., 2014) did not identify behavioural effects of emotional stimuli and valence on WM performance. Two of them used verbal n-back tasks (Grimm et al., 2012; Ozawa et al., 2014). However, Grimm et al. (2012) used emotional words as a target of the task, while Ozawa et al. (2014) explored the neural processing underlying the cognitive control of emotions induced by emotional pictures before a verbal 1- and 3-back task. Furthermore, Li et al. (2010a) investigated the effect of negative induced emotion on different processing periods in spatial and verbal delayed matching-to-sample task.

The following papers demonstrated significant differences in WM performance as a function of valence of stimuli and arousal: Erk, Kleczar, and Walter (2007) investigated verbal capacity with a delayed matching to sample task with two load conditions (participants should remember one or six letters) revealed that performance was better after emotional induction (negative and positive) compared to neutral induction, increased WM performance was also found by Levens and Phelps (2010) which established that proactive interference in WM was lower for positive and negative stimuli compared to neutral stimuli, in other words, the recent emotional words were remembered in major quantity than neutral ones.

Regarding effects on n-back tasks, Kessel et al., (2016) using an emotional 3-back task demonstrated that emotional stimuli (emotional faces) were updated preferentially when compared to neutral ones, in other words, negative and positive emotional matching seems to be easier recognized, similar results were found by Luo et al. (2014) which verified that participants performed better in 2-back task with fearful faces compared to neutral ones. Related to arousal, Choi et al. (2013) verified that relaxed and then tense emotional states decreased results in 3-back WM compared to a neutral state. Impaired results were found by Osaka Yaoi, Minamoto, and Osaka (2013) and Li et al. (2010b), for negative emotional reading span task performance and negative emotional 2-back task, respectively.

In regards to the WM concept used, it was possible to observe that none of these papers cited the Hedonic Detector component.

Table 1. Summary of papers that have investigated emotional stimuli and their influence on WM according to techniques used.

(Continued)

Paper	Technique	Participants n (mean age)	Modality	Valence or/ and arousal	Tasks	Effects of emotion on WM tasks
Choi et al. (2013)	Electrodermal Measures	20 (25.10)	verbal	Neutral/ relaxed/ tense	3-back task	Impairment
Erk et al. (2007)	fMRI	12	verbal	Neutral/negative/ positive and low and high arousal	Delayed matching-to-sample	Facilitation
Grimm et al. (2012)	fMRI	20 (23.5)	Verbal	Positive/ negative /neutral	Emotional 2-back	No findings
Levens & Phelps (2010)	fMRI	27 (18.0)	Verbal	Positive/ negative /neutral	Recency probes proactive interference task	Facilitation
Li et al. (2010a)	ERP	15 (25.0)	Spatial and verbal	Neutral and negative	Delayed matching-to-sample	No findings
Li et al. (2010b)	ERP	20 (24.0)	Spatial and verbal	Positive/ negative /neutral	Emotional 0-back and 2-back	Impairment in Spatial WM task
Luo et al. (2014)	fMRI	25 (23.1)	Visual	Fearful and neutral	Emotional 0-back and 2-back	Impairment in 0-back Facilitation in 2-back
Osaka et al. (2013)	fMRI	26 (23.5)	Verbal	Positive/ negative /neutral	Reading Span	Impairment

(Conclusão)

Paper	Tech-nique	Participants n (mean age)	Modality	Valence or/ and arousal	Tasks	Effects of emotion on WM tasks
Ozawa et al. (2014)	NIRS	20 (19.4)	Verbal	Neutral /negative	1-back and 3-back	No findings
Kessel et al. (2016)	ERP	23 (22.4)	Visual	Positive/ negative /neutral	3-back	facilitation

Strictly behavioural papers

Ten papers were found using only behavioural tasks to investigate emotional processing on WM. The n-back task was included in 2 papers (Lindström & Bohlin, 2011; Hur, Iordan, Dolcos, & Berenbaum, 2016). Other papers contemplated simple span tasks that measured short-term memory (Bergmann, Rijpkema, Fernandez, & Kessels, 2012; Fairfield, Mammarella, Domenico, & Palumbo, 2014; Esmaeili, Karimi, Tabatabaie, Moradi, & Farahini, 2011; Gotoh, 2012; Gotoh, Kikuchi, & Olofsson, 2010; Xie & Zhang, 2016), OSPAN (Storbeck & Maswood, 2015), and selective interference method (Levens & Phelps, 2008) linked to Baddeley´s model.

Four papers (Gotoh et al., 2010; Gotoh; 2012; Levens & Phelps, 2008; Lindström & Bohlin, 2011) showed increased WM performance using emotionally valenced stimuli and one paper using emotional induction (Esmaeili et al., 2011). More specifically, Levens and Phelps (2008) indicated that positive and negative emotion, regardless of how it is elicited (by words or pictures), facilitates proactive interference resolution within WM, which was not observed in the list of neutral words. While, Lindström and Bohlin, (2011) using an emotional 2-back task showed that emotional stimuli used as a target could facilitate WM performance, by way of positive and negative stimuli were associated with more hits, higher discriminability, and lower reaction time than neutral items.

Using colour discrimination and target detection task with affective words as spatial retro-cues Gotoh et al. (2010) found that negative cues yielded shorter response times compared with neutral and positive verbal cues. In another paper, Gotoh (2012), demonstrated that valenced words (negative and positive) were more recalled compared to neutral words in a trial in which words with negative, neutral, and positive affective valence were simultaneously presented on three different speakers. Esmaeili et al. (2011) paper, significant results were found by comparison between groups (positive vs. neutral) induced with video clips on total WM tasks scores composed by number-letter and spatial span tasks. Furthermore, Storbeck and Maswood (2015) observed that only positive valence influenced to higher spatial and verbal WM capacity score compared to negative and neutral valences, mainly because a positive mood seemed to enhance coordination between task goals. On the other hand, Xie and Zhang (2016) findings did not indicate quantitative effects; however Visual WM under negative emotion exhibited improved resolution compared with neutral and positive conditions.

Two papers showed impaired WM performance when stimuli were used as emotional mood induction (Bergmann et al., 2012; Fairfield et al., 2014) and one (Hur et al., 2016) as emotional stimuli was used as the target. More precisely, Bergmann et al. (2012) showed in a delayed matching to sample task, in which, five picture pairs, each pair consisted of one neutral and a valenced picture that pairs comprising low-arousal or two neutral stimuli were more probable to be appropriately processed than pairs consisting of high-arousal, moreover the arousal outcome was modulated by affective valence for the WM.

Fairfield et al. (2014) revealed a decrease in accuracy for positive and negative words only in longer lists indicating that task difficulty interacts with valence processing in WM. Moreover, Hur et al. (2016) observed that WM performance was poorer when the material already being held online and the new input was of matching emotions (e.g., both were negative), compared to when they were not.

Considering the conceptual framework that supports the results of the papers presented, two out of 10 papers (Fairfield et al., 2014; Xie & Zhang, 2016) discussed the results specifically according to Baddeley's model, and Fairfield cited the Hedonic Detector component. The others papers (Hur et al., 2016; Levens & Phelps, 2008; Lindström & Bohlin, 2011; Storbeck & Maswood, 2015; Gotoh, 2012; Gotoh et al., 2010) focused on executive processes, such as attentional control and updating, without specifying a model. Bergmann et al. (2012) did not define any WM model. Finally, Esmaeili et al. (2011) discussed their data based on neuroscience concepts (Specific brain areas).

Table 2. Emotional stimuli and its influence in WM performance in strictly behavioural design studies. (Continued)

Paper	Experiments, participants (mean age)	Modality	Valence	Tasks	Effects of emotion on WM tasks
Bergmann et al. (2012)	43 (21.24)	Visual	Positive/ negative / neutral	Delayed matching-to-sample	Impairment
Fairfield et al. (2014)	40 (22.1)	Verbal	Positive/ negative /neutral	Running WM	Impairment
Gotoh et al. (2010)	Exp 1: 23 (19.0) Exp 2: 32 (19.50)	Visual	Positive/ negative / neutral	Colour discrimination task with valenced/ neutral cue	Facilitation
Gotoh (2012)	26 (21.30)	Verbal	Positive/ negative/ neutral	Word Recall	Facilitation
Levens & Phelps (2008)	Exp 1: 44 (>18) Exp 2: 45 (>18) Exp 3: 52 (>18)	Verbal and visual	Positive/ negative/ neutral	Recency-probes proactive interference paradigm	Facilitation
Lindström & Bohlin (2011)	55 (24.15)	Visual	Positive/ negative/ neutral	Emotional 2-back task	Facilitation

(Conclusão)

Paper	Experiments, participants (mean age)	Modality	Valence	Tasks	Effects of emotion on WM tasks
Storbeck & Maswood (2015)	Exp 1: 120 (20.62) Exp 2: 100 (20.66)	Verbal and visual	Positive/ negative/ neutral	Operation Span	Facilitation
Xie & Zhang (2016)	Exp 1: 18 (19.99) Exp 2: 19 (19.85) Exp 3: 18 (20.24)	Visual	Positive/ negative/ neutral	Color WM task Shape WM task	No findings
Hur et al. (2016)	131 (19.3)	Visual	Negative and neutral	Emotional n-back task	Impaired
Esmaeili et al. (2011)	60	Verbal and visual	Positive and Neutral	Number-Letter Spatial Span	Facilitation

Discussion

The aims of this review were threefold: (1) to scrutinize methods and approaches towards the influence of emotional valences and arousal on WM performance; (2) to disentangle emotion effects on WM processes and modalities, and (3) to identify the WM models that have been referenced in papers in this area. For this purpose, a review of various papers using different approaches was carried out.

Methods and theoretical models used in the reviewed literature

Regarding the first aim of this review we identified that the use of n-back tasks rather than other tasks is salient, since the use was observed in 8 out of 20 papers (seven studies that used techniques for measuring brain activity – Choi et al., 2013; Grimm et al., 2012; Kessel et al., 2016; Li et al., 2010b; Luo et al., 2014; Ozawa et al., 2014) and two strictly behavioural (Hur et al., 2016; Lindström & Bohlin, 2011). Moreover, most of the studies were focused on executive process related to WM, which seems to be the current trend in the literature, especially after the construction of a neural model of WM (D'Esposito, 2007; D'Esposito & Postle, 2015).

The influence of emotional stimuli on verbal and visuospatial WM tasks.

The second aim of this review was to discern the effects of emotional stimuli on WM tasks and modalities. In this context, the effects of emotional stimuli on verbal WM modality assessed by n-back tasks, three of four papers did not exhibit influence of intrinsic emotional words (Grimm et al., 2012), emotional pictures used as induction before the performance of n-back task (Ozawa et al., 2014), or with the emotional stimulus positioned before each letter of the verbal n-back task (Li et al., 2010b), the lack of behavioural finds for verbal n-back tasks could indicate modality effects. This means that negative emotions revealed to extract visuospatial attention, which could cause an attentional resource competition between visuospatial WM and negative emotions. This type of effect is less noticeable for verbal WM because its processing relies mainly on phonological components (Sakai & Passingham, 2004). In fact, only higher level of arousal (tensed emotional state) seems to reduce the performance on verbal 3-back WM task after a visual mood induction compared to neutral one (Choi et al., 2013).

Other papers using visual n-back paradigm, the updating task most used, including emotional stimuli as the target of the task (Lindström & Bohlin, 2011; Hur et al., 2016; Kessel et al., 2016; Luo et al., 2014), in contrast to Li et al. (2010b). In which two of them, Kessel et al. (2016) and Luo et al. (2014), the first comparing emotional faces with negative valences, or both negative and positive, vs. neutral ones and the second comparing fearful faces vs. neutral ones, demonstrated similar results for higher cognitive load, in which emotional stimuli increased visual WM performance for negative valence compared to neutral one, probably because it was more distinctive stimuli. Similar evidence is presented by Lindström & Bohlin (2011), using emotional 2-back tasks, such as negative (violent death scenes), positive (sexual scenes), and neutral, showing that stimulus arousal facilitates the updating process when the stimuli are used as the target.

Differently, Li et al. (2010b) and Hur et al. (2016) verified decreased performance in a visual 2-back task with pictures as negative stimuli; however, in Li et al. (2010b) images were not intrinsic to the task. In fact, the stimulus was positioned before each letter composing the 2-back task to induce emotion, and in Hur et al. (2016) participants should indicate whether the colour (or emotion) of the picture in the present trial was the same as the one two trials before. Thus, it seems that in these cases visual stimuli impair only the capacity to update information.

Further task paradigms, such as delayed matching-to-sample tasks showed inconsistent results, for instance Li et al. (2010a), using an induction through aversive pictures before the performance on the tasks, did not show any emotional effect, one explanation argued by the authors was weakness of the aversive pictures to induce changes in behavioural WM performance. Congruently, Erk et al. (2007) did not found effects of emotional stimulation for low load condition, in other words, when only one item should be remembered, instead of when participants should remember six letters (highest load condition) performance was better for positive and negative stimulation compared to the neutral condition.

Controversially, Bergmann et al. (2012) found that visual WM performance was compromised for negative pictures with both low and higher arousals. Critical methodological differentiations of the first paper (Li et al., 2010a) could be observed, as such as, more of participants composing the sample and also the retention delay period, which was much longer in Bergmann et al. (2012) paper. Probably it led to an increase of attention on negative stimuli, thus generating a cost for the binding process.

Levens and Phelps (2010) and Gotoh (2012) assessed the effect of positive, negative, and neutral stimuli on interference paradigms assessing verbal WM. Results indicated that verbal valenced stimuli (positive and negative) were more distinctive than visual items, possibly because emotional stimuli have decreased familiarity signal strength. Reinforcing this point Storbeck and Maswood (2015) observed that positive valence induction increased performance on verbal WM capacity, regardless the WM domain (storage and processing). Moreover, this was the only paper that distinguished processing and storage in WM performance by using a WM span task (Operation Span); which is another theoretical aspect neglected in many studies. The authors argued that n-back task entails active maintenance and updating of information, whereas the WM span task requires greater demands on executive control compared to the first (Kane, Conway, Hambrick, & Engle, 2007), which is another argument hallmarking that these tasks are not equivalent measures of WM.

Also related to studies that investigated verbal WM performance, Osaka et al. (2013) demonstrated decreased results for verbal WM performance (Reading Span task) with negative stimuli compared to neutral stimuli. As well as, Fairfield et al. (2014) observed that accuracy with positive and negative words diminished as lists extended, although list length did not impact the recall of neutral words.

Discrepancies in the outcomes of behavioural tasks observed in the studies above could partially be explained by the way emotional stimuli are used to compose the task. In other words, participants who had to remember only emotional items themselves could have shown a distinctive process to emotional stimuli compared to neutral ones (Levens & Phelps, 2008; 2010; Lindström & Bohlin, 2011; Luo et al., 2014). In turn, when is required the maintenance of emotional content throughout the performance, and such stimuli is not totally related to the task than performance decreases at least for negative stimuli. This may be the case of several papers (Fairfield et al., 2014; Li et al., 2010b; Osaka et al., 2013) in that WM capacity drop off, corroborating with the observations of Kensinger and Corkin (2003). While, positive mood induction vs. neutral seems to enhance span WM tasks, such as number-letter and spatial span (Esmaeili et al., 2011).

Moreover, in case of Xie and Zhang (2016) which used negative emotion as induction previously of the WM tasks (participants tried to retain closed-contour shapes or colors) revealed to selectively enhance the qualitative aspect of internal representations in visual WM, independent of its quantitative aspect, this result could be possible because images were not stronger enough to promote changes in attentional or storage aspects. Moreover, measuring the impact of affective words as spatial retro-cues in colour discrimination and target detection task Gotoh et al. (2010) found that negative cues produced shorter response times compared to neutral and positive verbal cues, showing an increase in the attentional focus in favour of negative stimuli.

Papers in this review showed that complex, simple span and n-back tasks seem to test different capacities, which could be observed, for example, in studies that used mood induction before the completion of the task, while positive and negative stimuli seem to decrease the span task performance. On the other hand, no effects were found for verbal n-back tasks.

Consequently, different processes seem to be implied in the performance (Kane et al., 2007). Therefore, studies on WM must consider how the lack of this connection affects the explanation of their outcomes and the studies of others due to the difference between tasks (Redick & Lindsey, 2013).

Emotional stimuli and WM: hedonic detector and its effect on the literature

In fact, emotional stimuli seem to influence the WM performance, as proposed by Baddeley (2007). However, most of the authors did not use the Hedonic Detector to discuss their results, for instance in our review only Fairfield et al. (2014) quoted the Hedonic Detector component to explain the emotional effects on a simple span task. Another study (Xie & Zhang, 2016) cited Baddeley (2012) but did not explain their results based on the hedonic system. Nevertheless, we detected that at least seven papers (Bergmann et al., 2012; Esmaeili et al., 2011; Li et al., 2010a; Li et al., 2010b; Osaka et al., 2013; Ozawa et al., 2014; Xie & Zhang, 2016) could benefit from this theoretical model, since they applied a methodology that included emotional induction and a comparison with neutral stimuli, which is coherent with Baddeley (2007) proposal. One explanation for the lack of citation could rely on the transition tendency from procedures that uses purely behavioural paradigms to those that also include neurosciences techniques, as quoted previously in this review. A significant difference in these paradigms are; the former implies a series of experiments to rule out the possible strategic interpretations of the data, while the latter, search for specific systems-level of neural mechanisms usually related to a control system (D'Esposito & Postle, 2015) and not to multiple components, which according to Baddeley (2003) would be infeasible in neuroimaging studies.

Moreover, although Baddeley et al. (2012) highlighted the association between emotion and WM, they did not specify how the Hedonic Detector could be integrated into the WM model. For instance, they also did not include WM tasks on this seminal paper and claimed to provide theoretical speculation that might allow researchers to develop an empirically fruitful model. Finally, another theoretical frame could explain the results, for instance, the somatic marker hypothesis, which suggests that when an emotional event is brought to WM, it could elicit a somatic state capable of affecting cognitive performance (Bechara & Damásio, 2005).

Overall, our review systematized a sufficient basis for developing better tests of emerging hypotheses about emotional modulation of WM, but overall there is little consistency across the researchers. Moreover, due to the methodological variations among studies (inductor type, modality and also WM processes assessed), a meta-analysis could not be performed. Lastly, the clarity about the used WM model seems to be crucial to explain results and even for future replication. Despite the fact that Baddeley's Model is the most widely-used definition of WM, discrepancies can be explained by the emergence of new neuroscience technologies that emphasize state-based models (D'Esposito & Postle, 2015), mismatching theory and cognitive tasks. Therefore, despite that almost all the studies seem to demonstrate the close relation and influence of emotion on WM performance, the new component the "Hedonic Detector" was slightly referred to.

Final considerations

In conclusion, we may argue that congruent results were observed for n-back in which intense emotional stimuli, such as fearful images, could increase the participant's updating performance, while negative mood induction before accomplishing storage, span, and complex WM tasks could reduce capacity. The opposite pattern is observed for positive mood induction, which seems to increase performance. Nevertheless, incongruent results were found among Delayed Matching to Sample tasks due to a wide variety of procedures used across papers. In general, the consequences of emotions appear to be related to how a task is built, and how it measures memory processes.

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