Horizontal eye movements foster approach to negative pictures but do not change emotional valence: A dopaminergic regulation hypothesis

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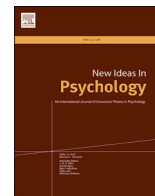R. Hans Phaf [*], Merel E. Hermans, Alexander Krepel, Ricardo L.R. Lieuw-On, Charlotte B. Mulder, Sabine Weijland

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ABSTRACT

A new dopaminergic regulation hypothesis is proposed based on two experiments exploring eye-movement effects. In the Eye Movement Desensitization and Reprocessing (EMDR) and Saccade-Induced Retrieval Enhancement (SIRE) domains, eye-movement mechanisms are mainly studied with explicit measures. Here implicit and explicit measures of emotion and memory for positive and negative pictures were investigated after eye movements or fixation in extreme right-handers. Eye movements enhanced explicit recognition predominantly for negative pictures. The absence of implicit repetition priming in both experiments supported a dissociation between implicit and explicit memory. Motivational eye-movement effects emerged but implicit and explicit affect remained unchanged. Experiment 2 revealed, after initial freezing to negative pictures, an acceleration, particularly of approach responses. Eye movements are postulated to foster approach towards negative memories, and promote, though dopaminergic pathways from the Superior Colliculus, enhanced explicit memory and active emotion regulation, primarily in persons with a collateralization of eye and dopamine dominance.

1. Eye-movement effects on emotion and memory

1.1. Two domains

Eye-Movement Desensitization and Reprocessing (EMDR) therapy strives to modify emotional experiences associated with anxious, often traumatic, memories (Shapiro, 1989, 2002). EMDR mostly requires the client to perform large horizontal eye movements by following the back-and-forth motion of the therapist's hand, while visualizing their anxious memories. In the more cognitively oriented memory-research domain, Saccade-Induced Retrieval Enhancement (SIRE; Lyle & Martin, 2010) predominantly involves investigating explicit memory performance (e.g., free recall, recognition) for affectively neutral material as a function of eye movements (e.g., Brunyé, Mahoney, Augustyn, & Taylor, 2009; Christman, Garvey, Propper, & Phaneuf, 2003; Lyle & Edlin, 2015; Lyle, Hanaver-Torrez, Hackländer, & Edlin, 2012; Lyle, Logan, & Roediger, 2008; Matzke et al., 2015; Nieuwenhuis et al., 2013; Parker & Dagnall, 2007). Initial SIRE studies acknowledged the link between clinical therapy and cognitive memory research (Christman et al., 2003; Propper & Christman, 2008), but subsequently the domains

bifurcated into distinct research specializations and theoretical accounts (also see Phaf, 2017). The rift between the two domains is perhaps well illustrated by the contrasting findings in false-memory studies, with the SIRE side reporting a reduction in false memories by eye movements (e. g., Kelley & Lyle, 2020; Lyle & Jacobs, 2010; Parker, Buckley, & Dagnall, 2008; Parker & Dagnall, 2007), and the EMDR side a tentative increase (e.g., Houben, Otgaar, Roelofs, & Merckelbach, 2018; Kenchel, Domagalski, Butler, & Loftus, 2020; but see; Calvillo & Emami, 2019; van Schie & Leer, 2019).

Treatment studies on patients dominate but there exist also a relatively small number of laboratory studies in the EMDR domain, which focus more than in the SIRE domain on the emotional aspects of the memories. Lee and Cuijpers (2013), for instance, included in their meta-analysis on EMDR ten lab studies comparing emotional self-reports in eye-movement and no eye-movement conditions. For these studies, Lee and Cuijpers found that eye movements reduced the reported emotional distress and vividness concerning negative autobiographic memories with moderate-to-large effect sizes. These subjective measures could be called explicit due to their direct reference to the emotion context. By contrast, implicit emotion measures, reflect changes in

behavior that can be attributed to one's emotional state but are independent of the conscious awareness for that state (cf, Berridge & Winkielman, 2003). Implicit and explicit emotional reactions are probably dissociated (e.g., with fear; LeDoux, 1996). Arguably, it would be possible that fear remains dormant implicitly after EMDR, despite diminished self-reports after eye movements. The EMDR and SIRE domains thus mainly address explicit measures; and, moreover, diverge on the emotional role of eye movements. It seems worthwhile to extend the laboratory eye-movement research into more implicit affective measures. This primarily theoretical paper first briefly discusses the four leading accounts in the two domains and then puts forth a new hypothesis based on two exploratory experiments. The unexpected findings from the present experiments broadly supported attentional engagement accounts but also necessitated modification and further elaboration into the dopaminergic regulation hypothesis.

1.2. Theoretical accounts

A large gap exists between the theoretical accounts for EMDR and SIRE. Some experimental studies note that their results may apply to both domains, but ignore theoretical cross-connections (e.g., Matzke et al., 2015; Roberts, Fernandes, & MacLeod, 2020). The artificial division between EMDR and SIRE will be cast aside in the present paper and similarities and contrasts between hypotheses from the two domains are discussed briefly. The currently prevailing hypotheses on EMDR mechanisms are the working memory (WM) hypothesis (Andrade, Kavanagh, & Baddeley, 1997) and the orienting response (OR) hypothesis (Armstrong & Vaughan, 1996; MacCulloch & Feldman, 1996), whereas dominant hypotheses on SIRE are the interhemispheric interaction hypothesis (IHI, Christman et al., 2003) and the top-down attentional control hypothesis (TDAC, Edlin & Lyle, 2013; Lyle & Edlin, 2015; Lyle & Martin, 2010).

The WM hypothesis posits that eye movements load the visuo-spatial sketchpad and compete with concurrently active, specifically visual, memories for limited WM capacity (see Andrade et al., 1997). If the eye movements and the emotional images load WM sufficiently, the resulting distraction would reduce emotionality, vividness, and retrieval of memories, as is purportedly found with EMDR therapy. According to the OR hypothesis, eye movements result in a visual scanning for danger, engaging attention to potential threats, and increasing arousal (Armstrong & Vaughan, 1996; MacCulloch & Feldman, 1996). If no danger is detected (e.g., during therapy), a safety reflex ensues resulting in a down-regulation of fear and arousal. In the SIRE domain, a somewhat related attentional account emerged, the TDAC hypothesis (Edlin & Lyle, 2013; Lyle & Edlin, 2015), not only addressing memory performance for mostly neutral material but also other cognitive phenomena, such as letter matching (Lyle & Martin, 2010), face recognition (Lyle & Orsborn, 2011), and creativity (Shobe, Ross, & Fleck, 2009). Eye movements would activate the bilateral frontal eye fields and/or intraparietal sulcus. The attentional control exerted by this frontoparietal network would enhance retrieval, particularly of weak memories. In contrast to the OR account, TDAC makes no specific claims about emotional memories. Both assert that eye movements foster attentional processing, in a bottom-up and a top-down fashion, respectively.

The WM and OR (and also TDAC) hypotheses contrast with respect to explicit memory performance, at least when items are also retrieved during the eye movements (cf, Phaf, 2017). The former expects a weakening of explicit memory performance, due to the distraction, and the latter enhanced retrieval, particularly of negative memories, due to the greater attentional engagement. In the SIRE domain, memory enhancement has been obtained primarily with affectively neutral material and only for consistent handers (i.e., extreme right or left-handers, preferring the same hand for performing different tasks) but not clearly for mixed handers (e.g., Lyle et al., 2008, 2012). To our knowledge, lateralization has not been investigated in the EMDR domain. The handedness effects in SIRE initially gave rise to the IHI hypothesis

(Christman et al., 2003), which claims that eye movements improve the cooperation between left and right hemispheres, primarily in consistent handers. However, IHI has been discredited by stronger intra-hemispheric than inter-hemispheric influences of eye movements (Lyle & Martin, 2010), by EEG research (Samara, Elzinga, Slagter, & Nieuwenhuis, 2011), and by fMRI research (Petit et al., 2015). Initially, similar effects of vertical and horizontal eye movements, also contradicting IHI, have been reported (e.g., Gunter & Bodner, 2008; Lyle et al., 2008; van den Hout & Engelhard, 2012) but the findings here seem more variable (for negligible effects with vertical eye movements, see Brunyé et al., 2009; Christman et al., 2003; Parker, Relph, & Dagnall, 2008). Although currently no satisfactory account for lateralization effects exists, only extreme right-handers are included in the present experiments.

The SIRE effect seemingly opposes the WM hypothesis, which predicts a memory weakening. The WM proponents would argue however, that verbal rather than visual WM is addressed by the words and autobiographical memories often used in SIRE studies (e.g., Christman et al., 2003; Lyle et al., 2012, 2008; Parker & Dagnall, 2010). In their view, an eye-movement induced memory weakening could resurface with visual material, provided that these images load visual WM sufficiently. In support of the WM account, van den Hout, Bartelski, and Engelhard (2013) found that emotional vividness and fragment recognition decreased for studied pictures that were re-imagined during eye movements, but not for those that were not. Conversely, an enhancement effect also has been reported for the recognition of visuospatial material (Brunyé et al., 2009; see also Lyle, 2018; Lyle & Jacobs, 2010; Parker, Relph, & Dagnall, 2008; using images of complex scenes). No concurrent loading of visual WM by the pictures may have occurred here, because participants were not explicitly instructed to retrieve studied pictures during eye movements. Next to the re-imagining during the eye movements, also other design factors may have played a role in these contrasting findings, such as the timing of the eye movements and the degree of WM loading. To give the WM account a fair chance, the present experiments investigated memory specifically for both positive and negative pictures, and contained the instruction to retrieve these pictures (i.e., load visual WM) both during eye movements and fixation.

The WM hypothesis does not differentiate between positive and negative memories and predicts a symmetrical decrease in emotionality due to eye movements (van den Hout & Engelhard, 2012; see also; Maxfield, Melnyk, & Hayman, 2008). The OR hypothesis conversely, assumes that attentional engagement only applies to negative memories and thus entails a specific reduction of negative affect (Armstrong & Vaughan, 1996; MacCulloch & Feldman, 1996). Initial SIRE demonstrations mostly concerned neutral material, not explicitly selected to have only a neutral valence however (e.g., Christman et al., 2003; Lyle et al., 2008, 2012), and may have contained some emotion words. Later studies revealed a larger retrieval enhancement for negative words than for neutral words (Phaf, 2017; Samara et al., 2011), whereas a replication study that selected only strictly neutral words failed to find SIRE (Matzke et al., 2015). The findings with emotional material narrow the gap between EMDR and SIRE but may not represent genuine affective processing. The larger enhancement for negative material may also result from preferential retrieval and increased elaborative learning during the eye movements of this material, due to its higher salience than of neutral material (cf, Kensinger & Corkin, 2003). This alternative, not necessarily affective, explanation becomes implausible, however, if the affective measures included in this study show a parallel down-regulation specific to negative affect.

1.3. The present experiments

This eye-movement study is one of the first to include implicit measures (i.e., not referring to the emotion or memory context), at least for emotion (for implicit memory measures, see Christman et al., 2003; Parker, Powell, & Dagnall, 2018). Particularly in emotions, implicit processing may play a prominent role (cf, Berridge & Winkielman, 2003;

Phaf & Rotteveel, 2012). The only other study to investigate implicit emotional variables was performed by Barrowcliff, Gray, MacCulloch, Freeman, and MacCulloch (2004). In line with the OR hypothesis, they found a reduction of electrodermal arousal by eye-movements only for negative, but not for positive, autobiographical memories. Surprisingly however, subjective emotionality decreased for both negative and positive memories, which suggests a dissociation between implicit and explicit emotion measures (cf, Berridge & Winkielman, 2003). The authors explained this by the simultaneous action of WM-loading and physiological de-arousal mechanisms.

Subjective (i.e., experiential) self-reports on the emotional episode as explicit measures of emotion have been known to be notoriously inaccurate (Mauss & Robinson, 2009). A more reliable way to study emotional eye-movement effects may be with behavioral measures, such as in the speeded two-alternative-forced-choice evaluation task of positive and negative stimuli (i.e., a type of affective priming; see Fazio, Sanbonmatsu, Powell, & Kardes, 1986). In this task, participants reveal their affective state implicitly by differential speeds in evaluating positive and negative stimuli. If reactions to positive stimuli are relatively faster and to negative stimuli relatively slower after the eye movements than before, this would indicate a shift towards more positive affect (i.e., the eye movements serve as affectively positive primes). Affective priming represents a generalization of memory priming to emotion research. A previous presentation of parts, or the whole, of the stimulus can serve as prime in memory experiments. Any type of preceding stimulus exerting an affective influence (e.g., color-incongruent Stroop stimuli; Dreisbach & Fischer, 2012), including eye movements, can act as prime in emotion experiments.

Not only reaction times of evaluating affectively laden target stimuli (Experiment 1), but also latencies of approach-avoidance action tendencies (Experiment 2) were determined in this study. A general finding in approach-avoidance tasks is that positive affect accelerates approach and slows down avoidance, and vice versa for negative affect (see Phaf, Mohr, Rotteveel, & Wicherts, 2014). The assessment of reaction times in the two experiments also enabled the concurrent gauging of repetition priming (i.e., response acceleration to repeated pictures), which is considered an implicit memory measure (cf, Schacter, 1987). In addition, explicit mood and arousal were assessed by administering the nonverbal Self-Assessment Manikin (SAM, Bradley & Lang, 1994), before and after the eye manipulation, which allows participants to indicate their mood and arousal states on 5-point rating scales with figures drawn to illustrate the respective states at the points (i.e., the manikins). The global-local focusing task (Gasper & Clore, 2002) was also included in Experiment 1 as a tentative measure of affect but will not be discussed further here. We investigated whether eye movements relative to fixation enhance memory specifically for negative pictures, whether eye movements weaken the affective strength of these pictures, and whether avoidance tendencies of these negative images may be weakened and possibly even be redirected into the opposite approach-oriented processing.

We follow recent calls to retire statistical significance entirely (Amrhein, Greenland, & McShane, 2019). Alarmingly high levels of false positives (Ioannidis, 2005), and false negatives (e.g., Hartgerink, Wicherts, & van Assen, 2017), even in the absence of bias, invalidate all attempts at null-hypothesis significance testing. Research moreover, should focus not on rejecting that nothing is there (i.e., the null hypothesis), supporting an infinite number of alternative theoretical hypotheses, but on estimating the extent of an effect. No test statistics are reported and the new-statistics recommendations of Cumming (2014) to report effect sizes (ES; for the different types, see Lakens, 2013) and confidence intervals (CI) are followed. The CIs do not serve as a sort of significance test, whether they include zero or not, but provide an uncertainty measure by indicating plausible lower and upper values for the point estimate. According to Cumming (p.26): "I strongly suggest that the best plan is simply to go cold turkey, omit any mention of NHST, and focus on finding words to give a meaningful interpretation of the ES estimates and CIs that give the best answers to your research questions."

2. Experiment 1

Implicit and explicit measures of emotion (i.e., affective evaluation vs. self-report) and memory (i.e., repetition priming vs. recognition) for negative and positive pictures were investigated in extreme right-handers after horizontal eye movements and after fixation. To maximize the opportunity for re-imagination, as required for EMDR, relatively long periods were chosen for the eye manipulation. SIRE usually involves shorter periods of eye movements but no detrimental effects of including longer periods are expected. Speeded evaluation (Fazio et al., 1986) before (i.e., baseline performance) and after the eye manipulation served as implicit measures of both affect and memory. The order of tasks in Experiment 1 (see Fig. 1) was initial self-report of mood and arousal, practice evaluation trials, first evaluation task (i.e., the study phase), eye manipulation, second evaluation task, explicit recognition task, and final self-report of mood and arousal. Similar to previous SIRE findings, we expected that only explicit but not implicit memory would be enhanced (see Christman et al., 2003; Parker et al., 2018). More importantly, eye-movement effects should be larger for negative than for positive pictures (cf, Phaf, 2017; Samara et al., 2011). With regard to emotion, the WM hypothesis would predict a weakening, irrespective of affective valence, and the OR hypothesis a conversion of negative into more positive affect as a consequence of the eye movements.

2.1. Method

2.1.1. Participants

Fifty-three students from the University of Amsterdam signed informed consent after being informed that shocking images would be presented. Exclusion criteria were previous participation in EMDR therapy, uncorrected visual impairment, and proneness to dizziness and/or nausea. Only extremely right-handed individuals were included (+10 on the van Strien, 1993, 2003, questionnaire, which is a standardized variant of the Edinburgh Handedness Inventory adapted to the Dutch language and culture; see also Edlin et al., 2015). Participants scoring more than 15% errors on the easy evaluation task were excluded from analyses. Random assignment resulted in approximately equal group sizes (eye movement: N = 27; fixation: N = 26).

2.1.2. Design

The evaluation task had a 2 × 3 × 2 mixed factorial design with manipulation (bilateral eye movement vs. fixation) as between-participants independent variable, and picture status (Pre-New, Post-Old vs. Post-New) and picture valence (positive vs. negative) as within-participants independent variables. The recognition task had a 2 (bilateral vs. fixation) x 2 (Post-Old vs. Post-New) x 2 (positive vs. negative) mixed factorial design. For recognition, proportion of 'old' responses served as the dependent variable. Recognition performance was analyzed with the two-high threshold model (Snodgrass & Corwin, 1988), which separates true recognition (*Pr*) from response bias (*Br*). For evaluation, reaction times (RT) were calculated over correct responses of the valenced pictures. Outliers (3.6%) were removed with the SPSS boxplot method (>1.5 interquartile range from the median). Repetition priming is shown by a successive shortening of evaluation RTs to studied pictures. Affective priming is shown by differential speeds in evaluating positive and negative stimuli before and after the eye movements, as measured with the affect index. The affect index was calculated by subtracting RTs for positive pictures from RTs for negative pictures. With positive affect, relatively faster responses are given to positive than to negative stimuli (i.e., resulting in more positive indices), and vice versa with negative affect (i.e., resulting in more negative indices). Errors of evaluation were not further analyzed due to their low level (7.9%).
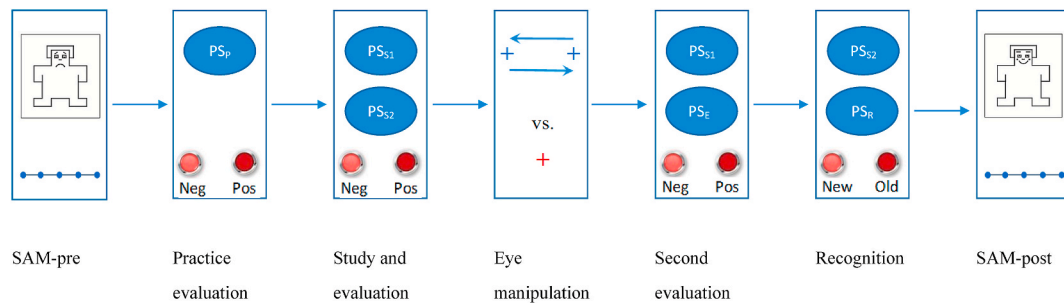
Fig. 1. Timeline of tasks and picture sets in Experiment 1. SAM-pre and SAM-post: mood and arousal scales of the Self-Assessment Manikin at baseline and after the eye manipulation. The evaluation and recognition tasks concerned two-alternative forced choice Neg-Pos and New-Old decisions. Only in the evaluation tasks reaction times were measured. PS_P: practice picture set; PS_{S1} and PS_{S2}: picture sets studied in the evaluation task; PS_E and PS_R: non-studied picture sets used in evaluation and recognition.

2.1.3. Material and apparatus

Stimuli were presented against a grey background in a dimly lit room on a 23″ Asus VG246HE monitor (resolution 1920×1080 pixels; 100 Hz refresh rate). Participants were comfortably seated in a height-adjustable chair with their head on a chin rest 30 cm from the screen. RTs and old/new responses were measured with a two-button response box operated with the right index finger. For evaluation, left and right buttons always represented negative and positive responses, respectively, for recognition always new and old responses, respectively. Bilateral eye movements were induced for 5 min by alternating a white fixation cross (+, Arial font, size 32) on a dark background between left and right positions on the screen 30 cm apart ($53°$ visual angle). With fixation the cross changed color from red to green to blue, every half second, for 5 min.

One-hundred and eight positive and 108 negative pictures (1024×768 pixels; $48°$ wide) with moderate valence (positive $M = 6.57 \pm 0.31$; negative $M = 2.82 \pm 0.37$) and arousal (positive $M = 4.80 \pm 0.56$; negative $M = 5.49 \pm 0.52$) scores were selected from the IAPS database (Lang, Bradley, & Cuthbert, 1999). After selecting 16 practice pictures, the remaining pictures were divided into four sets of 50 containing 25 negative and 25 positive pictures. Two sets were presented in the study phase, and one old and a new set in the post-eye-manipulation evaluation task (see Fig. 1). In the subsequent recognition task the other old set and the remaining new set were shown. Pictures in evaluation and recognition tasks were presented one-by-one for 500 ms with a jittered intertrial interval between 1200 and 2000 ms. Participants were instructed to evaluate the pictures as quickly and accurately as possible. Recognition decisions were made as accurately as possible but before the next picture appeared. Presentation order of pictures within phases and the order of sets over phases was determined randomly (without replacement) by the computer.

2.1.4. Procedure

Participants were informed that effects of eye movement or fixation on emotion and memory were being investigated. The five-point mood (1 negative right pole, 5 positive left pole) and arousal (1 aroused right pole, 5 calm left pole) scales of the self-assessment manikin (SAM; Bradley & Lang, 1994) were first administered on paper. A practice session (16 trials) of the evaluation task was then performed. They were instructed that memory for the pictures from the study phase (100 trials) would later be tested. After a short break, the eye manipulation followed, in which participants were explicitly instructed to re-imagine the studied pictures as much as possible. Subsequently, the second evaluation task, and the old-new recognition task were performed. The experiment ended with a second SAM administration and an exit interview. Participants were asked for impressions and strategies during the experiment, compliance to instructions, and whether they thought eye movements would enhance or reduce memory.

2.2. Results

Six participants were excluded due to evaluation errors exceeding 15% and two for not following instructions (i.e., reported switching buttons; no re-imagination during eye manipulation). Twenty-two participants (age 22.4 ± 1.7 yr, 13 female) remained in the bilateral condition and 23 (age 22.1 ± 2.0 yr, 14 female) in the fixation condition. No participant reported knowledge about whether eye movements would enhance or reduce memory and which emotional effects would be expected. Mood and arousal reports did not show effects of eye manipulation (see Table 1).

2.2.1. Repetition priming and affective evaluation

RTs (see Table 2) revealed repetition priming, but no meaningful changes in affective evaluation. Neither implicit memory performance nor implicit emotional processing were influenced by the eye movements. Overall, faster responses were made to negative ($M = 793 \pm 112$ ms) than positive pictures ($M = 835 \pm 111$ ms; 95% CI M_{diff} [20, 64]; Cohen's $d_z = 0.574$). This is probably due to most participants resting their index finger on the left, negative button, and needing more time to reach the right, positive button. Repetition priming, irrespective of eye condition, was evidenced by RTs being shorter for Post-Old ($M = 756 \pm 95$ ms) than Pre-New ($M = 850 \pm 118$ ms; 95% CI M_{diff} [67, 121]; Cohen's $d_z = 1.050$) and Post-New pictures ($M = 837 \pm 103$ ms; 95% CI M_{diff} [59, 103]; Cohen's $d_z = 1.122$). As expected, there were no clear

Table 1

For Experiment 1 are shown Mood and Arousal reports (*SD*) on the Self-Assessment Manikin as a function of measurement phase (Pre vs. Post) and eye condition, and discrimination measure *Pr* (*SD*) and bias measure *Br* (*SD*) according to the two-high threshold model as a function of picture valence and eye condition. For all differences 95% Confidence Intervals (CI) and effect sizes (Cohen's *d*) are given in the right columns.

		Bilateral (N = 22)	Fixation (N = 23)	95% CI Upper	M_{diff} Lower	Cohen's *d*
Mood	Pre	4.05 (0.58)	4.22 (0.60)	−0.52	0.18	−0.29
	Post	4.00 (0.67)	4.00 (0.67)	−0.40	0.40	0
Arousal	Pre	3.68 (0.95)	3.91 (1.00)	−0.82	0.36	−0.24
	Post	3.91 (1.02)	4.00 (0.91)	−0.67	0.49	−0.10
Pr	Positive	0.82 (0.11)	0.81 (0.10)	−0.05	0.08	0.14
	Negative	0.73 (0.12)	0.62 (0.13)	0.03	0.18	0.88
Br	Positive	0.33 (0.31)	0.46 (0.28)	−0.31	0.05	−0.44
	Negative	0.27 (0.21)	0.28 (0.18)	−0.77	0.76	−0.00

Table 2
Average reaction time (*SD*) in ms for Experiment 1 as a function of picture status (Pre-New, Post-Old, and Post-New), valence, and eye condition and Affect Index (*SD*) in ms as a function of picture status and eye condition.

		Bilateral (N = 22)	Fixation (N = 23)	95% CI Upper	M_{diff} Lower	Cohen's *d*
Pre-New	Negative	840 (118)	802 (98)	−47	83	0.17
	Positive	888 (127)	870 (117)	−56	92	0.15
	Affect index	−48 (66)	−69 (73)	−21	63	−0.31
Post-Old	Negative	750 (107)	718 (78)	−36	99	0.29
	Positive	782 (101)	772 (85)	−46	66	0.11
	Affect index	−33 (73)	−54 (77)	−24	66	−0.29
Post-New	Negative	841 (133)	812 (84)	−38	96	0.27
	Positive	864 (97)	832 (93)	−25	89	0.35
	Affect Index	−23 (114)	−20 (73)	−61	55	0.03

indications that repetition-priming was modulated by eye manipulation or picture valence (all $|d| < 0.25$).

With respect to the affect indices (see Table 2), positive affect increased over the course of the experiment, irrespective of eye condition, particularly for Post-New pictures ($M = −22 \pm 94$ ms) relative to Pre-New pictures ($M = −59 \pm 69$ ms; 95% CI M_{diff} [6, 68]; Cohen's d_z = 0.36). In absolute terms, there was also somewhat more positive affect, again irrespective of eye condition, with Post-Old pictures ($M = −44 \pm 75$ ms) than before the manipulation (95% CI M_{diff} [-10, 40]; Cohen's d_z = 0.18). The largest difference between eye-manipulation groups was found before the actual manipulation in the evaluation of the Pre-New pictures (see Table 2). The manipulation itself did not result in appreciable shifts of evaluation speed.

2.2.2. Recognition

Eye movements elevated true recognition (see Table 1), particularly for negative pictures. Aggregated over positive and negative pictures, memory performance was higher after eye movements ($Pr = 0.78 \pm 0.12$) than after fixation ($Pr = 0.72 \pm 0.15$; 95% CI M_{diff} [-0.02, 0.14]; Cohen's $d = 0.45$). Recognition was overall higher for positive ($Pr = 0.82 \pm 0.10$) than for negative pictures ($Pr = 0.68 \pm 0.14$; 95% CI M_{diff} [0.10, 0.19]; Cohen's $d_z = 0.94$), but this could be due to the specific material selected. More relevant to the present hypothesis was that eye movements raised recognition much more for negative (Cohen's $d = 0.88$) than for positive pictures (Cohen's $d = 0.14$; see also Table 1).

For bias we had no specific expectations, but here a valence effect emerged. Positive pictures ($Br = 0.40 \pm 0.31$) were subject to a more liberal bias than negative pictures ($Br = 0.27 \pm 0.19$; 95% CI M_{diff} [0.04, 0.23]; Cohen's $d_z = 0.41$). Eye movements seemed to reduce bias for positive pictures (Cohen's $d = −0.44$) to more conservative levels, almost to the level of bias for negative pictures, which in turn was not affected by the eye manipulation (Cohen's $d = −0.004$; see also Table 1).

2.3. Discussion

Explicit recognition, but not implicit repetition priming (cf, Christman et al., 2003; Parker et al., 2018), of negative pictures that were actively re-imagined during the eye manipulation was enhanced by the eye movements. The presence of SIRE in recognition but the absence of an enhancement in repetition priming may constitute a single dissociation between implicit and explicit memory performance (cf, Schacter, 1987). Particularly when priming involves a simple identification process, but not the production of multiple response alternatives, a dissociation as a function of attention level is a common finding (see Spataro, Cestari, & Rossi-Arnaud, 2011). The memory dissociation thus strengthens an attentional regulation account for the eye-movement effects.

Despite the specific loading of visual WM by pictures, memory strength was not reduced but even increased by the eye movements, which is difficult to reconcile with the WM hypothesis. It remains possible however, that WM was not sufficiently taxed by these negative

pictures, which certainly are not as strong as actual traumatic memories. In contrast moreover to the WM hypothesis that would predict similar distraction effects on positive and negative pictures (cf, van den Hout & Engelhard, 2012), retrieval enhancement was larger here for negative than for positive pictures. It cannot be excluded however, that the selective SIRE for negative material (e.g., Phaf, 2017; Samara et al., 2011) is not a genuine affective process, but is due to a higher salience and preferential retrieval of negative material during eye movements when mixed with other material. In sum, attentional engagement and elaboration, possibly through an OR, of memories retrieved during eye movements seem a more likely candidate for explaining these results than the WM distraction hypothesis.

For the emotional part, the regulation hypothesis did not seem supported by a reduction of implicit or explicit negative affect. The experiment however, focused only on the affective component of emotion (i.e., core affect; positive or negative valence; pleasure or pain; hedonic tone; cf, Phaf & Rotteveel, 2012), but did not investigate motivational constituents (i.e., action tendencies, such as approach, avoidance, inhibition, dominance, rejection, submission, exuberance, helplessness, and many others), which according to standard emotion theory are also crucial emotion components (e.g., Frijda, 1986). Although positive affect often is accompanied by approach tendencies and negative affect by avoidance tendencies (cf, Phaf et al., 2014), also other constellations can occur, even in the most basic emotions. In the emotion anger, for instance, negative affect can be coupled to approach, instead of to avoidance, as is the case in fear (e.g., Carver & Harmon-Jones, 2009). We conjecture here that eye movements may modulate motivational aspects but not the core affect of emotional memories. Eye movements could even shift the action tendencies associated with the negative memories from avoidance to more approach, but leave their negative valence unchanged. Experiment 2 investigated whether eye movements modulated action tendencies in the approach-avoidance task (AAT; Phaf et al., 2014).

3. Experiment 2

After evaluating and studying valenced pictures and subsequently executing either eye movements or fixation (while re-imagining the pictures), recognition was tested with the two-alternative-forced-choice AAT, and the pictures were again evaluated. Reaction times were only measured in the AAT but not in the evaluation task, in which the binary positive-negative responses were replaced by a 7-point rating scale. In the vertical three-button-stand AAT upward arm-flexion (i.e., approach) and downward arm-extension (i.e., avoidance) movements are made (see Fig. 2), without requiring any self-referenced or object-referenced approach-avoidance interpretation (see Rotteveel & Phaf, 2004). The stand allowed for the implicit measurement of the speed of approach and avoidance tendencies, while concurrently assessing explicit recognition performance. The coupling of upper and lower buttons of the stand to old and new recognition decisions was rotated over two experimental blocks, so that both approach and avoidance responses could be
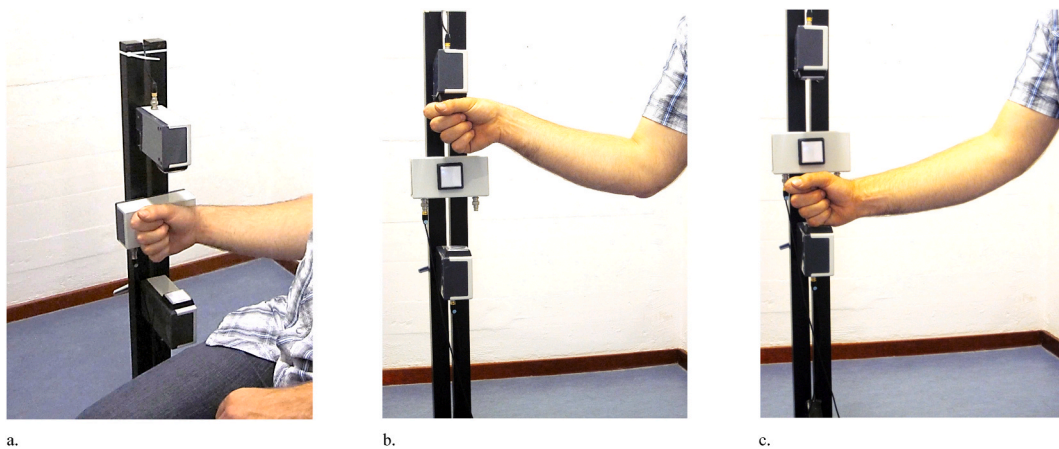
Fig. 2. The vertical button stand for the approach-avoidance task in Experiment 2. The stand has an upper, central, and lower button. a. The central button is kept pressed with the back of the hand between stimulus presentations and should be released only after stimulus onset. b. With a flexion instruction the upper button should be pressed as fast as possible with the fist after stimulus onset. c. With an extension instruction the lower button should be pressed as fast as possible with the fist after stimulus onset.

measured for old and new pictures. Two dependent variables are derived from the button-stand RTs. The interval between stimulus onset and central-button release constitutes the initiation time (IT), representing the time needed for preparing approach or avoidance. The interval between central-button release and hitting the lower and upper button reflects the movement time (MT).

If eye movements increase attentional engagement, as proposed by the OR- and TDAC accounts, they can induce more approach towards negative pictures and enhance retrieval specifically of negative memories. A WM distraction model would predict a weakening of both negative and positive memories and emotions, but does not specifically address action tendencies. A modified regulation hypothesis might expect a conversion of motivational processes by eye movements, while leaving core affect unchanged. More extremely scoring positive and negative IAPS pictures were selected here than in Experiment 1, to approximate the strong negative valence of traumatic memories in EMDR more closely. The potentially shocking images (e.g., mutilated bodies) probably not only induce avoidance reactions but may also evoke freezing behavior, which may decelerate both flexion and extension responses (e.g., see Roelofs, Hagenaars, & Stins, 2010; Azevedo et al., 2005). In addition to facilitating regulatory approach tendencies, it is also expected that eye movements mitigate this freezing behavior. Only changes with respect to the method of Experiment 1 are discussed below.

3.1. Method

3.1.1. Participants

Sixty-two extremely right-handed students from the University of Amsterdam signed informed consent after being informed that shocking images were presented. The same exclusion criteria applied as in Experiment 1, except for the error limit being reduced to 10%, because evaluation of the extremely valenced pictures was easier here. Random participant assignment resulted in equal group sizes (eye movement N = 31; fixation N = 31).

3.1.2. Design

The AAT had a 2 (eye manipulation) x 2 (picture valence) x 2 (picture status) x 2 (action) mixed factorial design, and the evaluation task after the AAT a 2 (eye manipulation) x 2 (picture valence) x 2 (picture status) mixed factorial design. Bilateral eye movement vs. fixation served as between-participants independent variable, picture valence (positive vs. negative), picture status (old vs. new), and action (flexion vs. extension) as within-participants variables. Dependent variables were proportion

old in the AAT responses, and IT and MT for the flexion and extension responses. Outlier trials (12% of the trials) with too long or too short ITs and MTs were removed completely with the box-plot method (>1.5 interquartile range). For the evaluation tasks, scores on a 7-point scale, ranging from left (1 negative) to right (7 positive), served as the dependent variable.

Two matched stimulus sets were balanced over the old-new conditions (see Fig. 3). The AAT instructions (old-flexion, new-extension vs. old-extension, new-flexion) were rotated over participants in two consecutive experimental blocks. The coupling of pictures to a particular instruction was determined randomly by the computer (without replacement), with equal numbers of positive and negative pictures for the two instructions.

3.1.3. Material and apparatus

The button stand (see Fig. 2) was positioned to the participant's right at an individually set distance from a comfortable height-adjustable chair. The lower and upper buttons of the stand are positioned at a 10 cm distance of the central (rest) button. During the AAT-recognition task, the participant continuously presses the central button with the back of the hand, but when a picture is shown, should hit the upper or lower button as fast as possible with her fist. The resting position was set individually at an isometric 110° angle between under and upper arm, so that biceps and triceps muscles have about equal muscle tension. Participants only placed their head on the chin rest during the eye manipulation. Evaluations were made by mouse clicks on the 7-point scale, ranging from 1 (negative, left) to 7 (positive, right).

Forty-eight positive and 48 negative pictures with extreme arousal ratings were selected from the IAPS database (Lang et al., 1999). The pictures were divided equally over two stimulus sets, matched as closely as possible on stimulus type (e.g., humans vs. animals). For the negative stimulus sets, valence (Set 1: $M = 2.31 \pm 0.77$; Set 2: $M = 2.59 \pm 0.80$) and arousal (Set 1: $M = 6.62 \pm 0.29$; Set 2: $M = 6.60 \pm 0.35$) were at similar levels. Also for the positive stimulus sets, valence (Set 1: $M = 7.33 \pm 0.61$; Set 2: $M = 7.23 \pm 0.55$) and arousal (Set 1: $M = 5.05 \pm 0.96$; Set 2: $M = 5.01 \pm 1.01$) did not differ much. In the evaluation task, the pictures were presented centrally until response, and for 1s in the AAT.

3.1.4. Procedure

Participants were informed that the influence of eye and arm movements on memory for strongly emotional pictures was being investigated, but were not told which direction this influence should take. They then practiced AAT with famous and non-famous faces under the instruction to press the upper button for famous faces and the lower
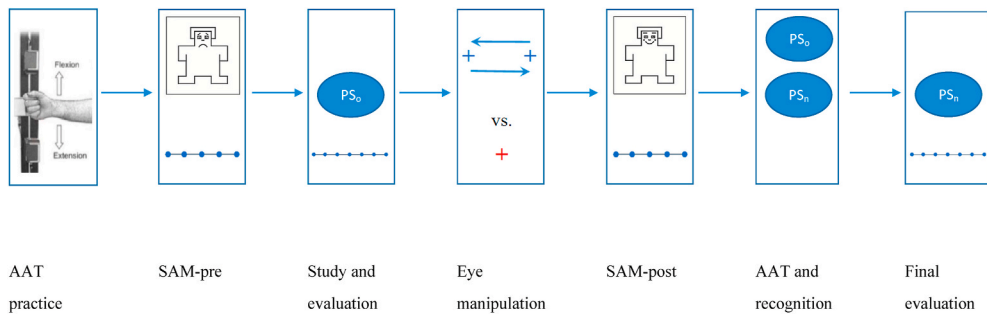
Fig. 3. Timeline of tasks and picture sets in Experiment 2. AAT practice: Approach-avoidance task practice with famous and non-famous faces. SAM-pre and SAM-post: five-point mood and arousal scales of the Self-Assessment Manikin at baseline and after the eye manipulation; PS$_O$: old, studied picture set; PS$_N$: new, nonstudied picture set. Study and test evaluations were performed on a seven-point rating scale. AAT and recognition were performed concurrently with old-new responses rotated over flexion-extension responses.

button for non-famous faces. After completing the first SAM scales (Bradley & Lang, 1994), they proceeded with the evaluation of the first picture set, in which they should carefully study the pictures for later memory testing. To prevent recency effects, a visual memory game was played for 5 min immediately after studying the pictures.

Participants were explicitly instructed to re-imagine the studied pictures as much as possible during the eye manipulation. No reference was made in this instruction to picture valence. After performing eye movements or fixation, they again completed the SAM scales. In the subsequent AAT phase, two experimental blocks (48 trials each, with the old-new and positive-negative pictures divided equally over blocks), separated by a 5 min break, were performed with complementary instructions. No explicit reference was made to approach or avoidance, flexion or extension, or the coupling of these arm movements to negative and positive emotions. Subsequently, all 96 pictures were again evaluated with the instruction to judge them intuitively while not trying to remember the first evaluations. In the exit interview, participants were asked explicitly whether they thought eye movements would weaken or strengthen memory. Compliance with instructions was also checked, and it was asked which pictures were re-imagined. Enquiries were made with an open question about encoding strategies while re-imagining during the eye manipulation. Making associations or categorizing the pictures were classified as active strategies, and just experiencing the pictures as passive. Multiple-strategy responses were recorded as variable. If a participant reported high distress levels as a result of the extremely negative pictures, the participant was calmed down and follow-up calls were made.

3.2. Results

The results of one participant were removed from the analyses for the reversal of instructions in the first AAT Block, and of another for reporting not to have re-imagined the pictures during the eye manipulation. A participant who had seen the pictures in previous research and found it difficult to distinguish old and new pictures in the recognition task was also excluded. The data-file of a fourth participant was lost. This resulted in 28 participants (20.39 ± 1.85 yr, 25 female) in the bilateral group and 30 (22.1 ± 2.85 yr, 24 female) in the fixation group. Two further participants were removed only from the AAT-analysis due to slow reactions ($Zs > 3$ in one or more of the IT conditions), leaving 26 participants (20.23 ± 1.81 yr, 24 female) in the eye-movement group and 30 (22.1 ± 2.85 yr, 24 female) in the fixation group.

The bilateral group reported in the exit interview to have re-imagined more negative (42.9%) than positive pictures (10.7%, variable 46.4%). In the fixation group, the majority was less pronounced, but again more negative (23.3%) than positive (6.7%, variable 70%) pictures were re-imagined. More participants in the eye-movement group reported an active (53.6%) than a passive strategy (35.7%; variable strategy 10.7%). Conversely, more passive (53.3%) than active strategies (43.3%; variable 3.3%) were reported by the fixation group. Finally, 50% of participants had expected the eye movements to reduce memory performance. A smaller group (13.8%) expected an

Table 3

For Experiment 2 are shown Mood and Arousal reports (*SD*) on the Self-Assessment Manikin as a function of measurement phase (Pre vs. Post) and eye condition, and discrimination measure *Pr* (*SD*) and bias measure *Br* (*SD*) according to the two-high threshold model as a function of picture valence and eye condition. For all differences 95% Confidence Intervals (CI) and effect sizes (Cohen's *d*) are given in the right columns.

		Bilateral (N = 28)	Fixation (N = 30)	95% CI Upper	M$_{diff}$ Lower	Cohen's *d*
Mood	Pre	1.93 (0.47)	1.97 (0.62)	−0.32	0.25	−0.07
	Post	2.46 (0.64)	2.50 (0.78)	−0.41	0.34	−0.05
Arousal	Pre	3.79 (1.03)	3.73 (0.83)	−0.44	0.55	0.06
	Post	4.04 (0.79)	4.07 (0.74)	−0.44	0.37	−0.04
Evaluation Pre	Negative	1.83 (0.40)	1.91 (0.38)	−0.28	0.13	−0.19
	Positive	5.85 (0.46)	5.77 (0.50)	−0.18	0.33	0.16
Evaluation Post-Old	Negative	1.89 (0.44)	1.97 (0.35)	−0.30	0.12	−0.22
	Positive	5.74 (0.52)	5.68 (0.52)	−0.21	0.33	0.11
Evaluation Post-New	Negative	1.95 (0.43)	1.99 (0.34)	−0.24	0.17	−0.10
	Positive	5.76 (0.52)	5.57 (0.53)	−0.08	0.47	0.37
Pr	Negative	0.75 (0.11)	0.69 (0.16)	−0.01	0.13	0.46
	Positive	0.83 (0.12)	0.80 (0.15)	−0.04	0.10	0.23
Br	Negative	0.62 (0.29)	0.52 (0.23)	−0.04	0.24	0.38
	Positive	0.33 (0.35)	0.26 (0.25)	−0.09	0.23	0.23

enhancement, or had no idea (36.2%).

3.2.1. Evaluation and SAM

The evaluations of both positive and negative pictures and the SAM scores showed no clear eye-movement effects (see Table 3). Positive pictures were evidently evaluated much more positively than negative pictures in all experimental phases (all $d > 4.50$). In absolute value, evaluations tended to be more extreme in the bilateral than in the fixation group, even before the eye manipulation (see Table 3). Irrespective of eye manipulation, SAM valence declined to more negative moods from baseline (M = 1.95 ± 0.54) to post-measurement (M = 2.48 ± 0.71, Cohen's $d_z = 0.85$, 95% CI [0.37, 0.70]). Similarly, SAM arousal increased from baseline (M = 3.76 ± 0.92) to post-measurement (M = 4.05 ± 0.76, Cohen's $d_z = 0.40$, 95% CI [0.10, 0.48]), presumably due to the confrontation with the extremely valenced pictures.

Table 4
Average IT (SD) in ms with Flexion and Extension for Experiment 2 as a function of valence, eye manipulation, and picture status.

		Bilateral (N = 26)	Fixation (N = 30)	95% CI Upper	M$_{diff}$ Lower	Cohen's *d*
Flexion						
New	Negative	833 (164)	977 (295)	−270	−18	−0.60
	Positive	801 (176)	878 (240)	−189	35	−0.37
Old	Negative	783 (106)	886 (203)	−188	−18	−0.63
	Positive	786 (113)	822 (181)	−116	44	−0.24
Extension						
New	Negative	824 (201)	892 (206)	−177	41	−0.34
	Positive	766 (112)	796 (159)	−103	43	−0.22
Old	Negative	804 (142)	890 (236)	−189	17	−0.44
	Positive	790 (121)	863 (207)	−162	16	−0.43

Table 5
Average MT (SD) in ms with Flexion and Extension for Experiment 2 as a function of valence, eye manipulation, and picture status.

		Bilateral (N = 26)	Fixation (N = 30)	95% CI Upper	M$_{diff}$ Lower	Cohen's *d*
Flexion						
New	Negative	175 (93)	178 (95)	−52	48	−0.02
	Positive	194 (108)	158 (88)	−17	89	0.38
Old	Negative	201 (156)	181 (153)	−63	103	0.13
	Positive	188 (101)	158 (70)	−17	77	0.36
Extension						
New	Negative	161 (88)	145 (68)	−25	59	0.22
	Positive	168 (46)	142 (65)	−4	56	0.47
Old	Negative	179 (152)	191 (178)	−100	76	−0.07
	Positive	170 (124)	151 (77)	−36	76	0.20

3.2.2. Approach-avoidance task

The expectations concerned action tendencies, as reflected by IT (see Table 4), but not action execution (i.e., MT, see Table 5). Only ITs are, therefore, discussed below. A strong inhibition to negative pictures (i.e., freezing; see Roelofs et al., 2010), regardless of picture status (old and new), action (flexion and extension), and eye manipulation, was found. ITs averaged over status, action, and eye manipulation were slower for negative ($M = 865 \pm 193$ ms) than positive pictures ($M = 815 \pm 160$ ms; 95% CI M$_{diff}$ [35, 65], Cohen's $d_z = 0.87$).

Eye movements mitigated the freezing. Aggregated over valence,

picture status, and action, eye-movement ITs ($M = 798 \pm 131$ ms) were shorter than fixation ITs ($M = 875 \pm 205$ ms; 95% CI M$_{diff}$ [-168, 14]); (Cohen's $d = 0.44$). The accelerations were larger for negative than for positive pictures and with flexion than with extension (see Table 4). The freezing was counteracted most strongly by the eye movements in flexion. Most importantly, re-imagining of old pictures in the bilateral group even made flexion ITs for the old negative pictures somewhat faster than flexion ITs for the old positive pictures, whereas approach to non-studied negative pictures remained slower than to new positive pictures. A similar, but less pronounced, pattern of reduction in freezing can be discerned in the extension preparation of this group.

3.2.3. Repetition priming and recognition

When split into flexion and extension initiation, repetition priming differed sharply in extent and even sign (see Table 6). Flexion showed the expected repetition priming, but surprisingly extension even revealed inverted repetition priming (i.e., longer ITs to old than new pictures) for positive pictures. Particularly with flexion, the priming was larger after fixation than after eye movements, which may further indicate that it does not concern an implicit memory effect, but rather a shift in motivational tendencies towards the pictures. Eye movements speeded approach preparation to both old and new pictures, thus squashing the IT differences (i.e., apparent repetition priming) relative to fixation.

Explicit recognition (Pr; see Table 3), irrespective of eye manipulation, was higher for positive ($M = 0.81 \pm 0.13$) than for negative pictures ($M = 0.72 \pm 0.14$, Cohen's $d_z = 0.60$, 95% CI [0.06, 0.14]). More important for the current hypotheses is that eye movements enhanced recognition performance relative to fixation (see Table 3). Memory enhancement by eye movements occurred in the Pr of negative pictures relative to fixation (M$_{diff}$ = 0.06, Cohen's d = 0.46, 95% CI [-0.01, 0.13]), whereas the gain for positive pictures appeared to be smaller (M$_{diff}$ = 0.04, Cohen's d = 0.23, 95% CI [-0.04, 0.10]). In agreement with our expectations, the results suggest a stronger SIRE effect for negative than for positive pictures.

Again no specific expectations were formulated for bias, but opposite effects to Experiment 1 seemed to emerge, which may be due to the more extreme valence scores here. Positive pictures (Br = 0.29 ± 0.30) showed a more conservative bias than negative pictures (Br = 0.57 ± 0.26; 95% CI M$_{diff}$ [0.17, 0.38]; Cohen's $d_z = 0.71$). After performing eye movements, participants were less cautious than after fixation in their recognition decisions for both negative and positive pictures (see Table 3).

Table 6
Average repetition priming ITnew-ITold (SD) in ms with Flexion and Extension for Experiment 2 as a function of valence, eye manipulation, and picture status. The vertical columns of effect sizes (*d*) and confidence intervals (95% CI M$_{diff}$) are associated with the individual repetition priming scores, the horizontal rows with the difference in repetition priming between bilateral eye movements and eye fixation.

				Bilateral (N = 26)	Fixation (N = 30)	95% CI Upper	M$_{diff}$ Lower	Cohen's *d*
Flexion								
	Negative			50 (107)	91 (190)	17	−99	−0.38
		95% CI	Upper	93	157			
		M$_{diff}$	Lower	7	25			
		Cohen's d_z		0.47	0.52			
	Positive			15 (106)	56 (127)	21	−103	−0.35
		95% CI	Upper	58	103			
		M$_{diff}$	Lower	−28	9			
		Cohen's d_z		0.14	0.44			
Extension								
	Negative			19 (121)	3 (132)	84	−52	0.13
		95% CI	Upper	69	51			
		M$_{diff}$	Lower	−29	−47			
		Cohen's d_z		0.17	0.02			
	Positive			−24 (70)	−66 (111)	−12	−34	0.45
		95% CI	Upper	−12	−25			
		M$_{diff}$	Lower	−34	−107			
		Cohen's d_z		−0.34	−0.60			

4. A new hypothesis

4.1. Motivation rather than affect

A coherent view that slightly modifies and integrates attentional regulation hypotheses, such as OR and TDAC, is suggested by these results. Affective valence, whether implicit or explicit, remained unchanged by the eye movements. The classical affective congruency pattern in the AAT (i.e., positive affect facilitates approach, negative affect avoidance; cf, Phaf et al., 2014) also did not emerge in Experiment 2. Rather than valence however, eye movements modulated action tendencies, particularly with negative pictures, and redirected these towards approach, regulation and also memory elaboration. Explicit recognition performance (but not implicit repetition priming; see also Christman et al., 2003; Parker et al., 2018) of negative pictures profited most from the enhanced elaboration enacted by the eye movements (cf, Graf & Mandler, 1984; Spataro et al., 2011). The eye movements, thus, induced approach tendencies and active processing of the negative memories. Conversely, re-imagining these memories without eye movements (e.g., with fixation) could aggravate fear by strengthening avoidance tendencies, while leaving the negative valence unchanged. Successfully having engaged the painful memories in EMDR therapy, may, similar to in this experiment, lead to regulatory approach and post eye-movement relief, and may explain why patients usually "… experience a state of very engaged and focused attention …" (p.23, Armstrong & Vaughan, 1996; see also MacCulloch & Feldman, 1996).

The extremely negative pictures in Experiment 2, which are better suited to emulate traumatic memories than the pictures in Experiment 1, elicited freezing in both approach and avoidance responses (Azevedo et al., 2005; Roelofs et al., 2010). Eye movements completely counteracted this freezing, at least for flexion on re-imagined pictures. Overall, approach (i.e., flexion) was accelerated more by eye movements than avoidance (i.e., extension). Eye movements also speeded flexion and extension for positive stimuli but to a lesser extent than for negative stimuli. Subjective reports in the exit interview revealed that eye movements induced more active strategies than fixation. Together, these results support the view that eye movements, rather than serving as passive distractors, induce active regulation. The results however, do not necessarily contradict distraction accounts. The mechanisms operating in EMDR therapy may differ from those in laboratory experiments, leaving open the possibility that both distraction and regulation hypotheses are valid. The neutral stimuli used in most memory studies may not load WM sufficiently to reveal detrimental memory effects. Arguably, in EMDR distraction and regulation effects may occur in tandem. A subtler version of the WM hypothesis was suggested by Lilley, Andrade, Turpin, Sabin-Farrell, and Holmes (2009). "..eye movements may help make treatment for PTSD more tolerable for clients with extremely stressing and uncontrollable memories" (p.311). Their finding that eye movements only resulted in short-term but not long-term reductions of vividness and emotionality of traumatic images may well indicate that complementary mechanisms to WM loading are required to account for lasting therapeutic effects.

To our knowledge, only one other study obtained a pattern of AAT results similar to the present study (Hoofs, Carsten, Boehler, & Krebs, 2019). The authors reported the enhancement of both approach and avoidance tendencies by their emotional cues, rather than the classical affective congruency pattern. Eye movements did not serve as the priming factor in the AAT here, but cues of upcoming valenced events (i. e., incentive valence) were embedded in the target stimuli. Valence was manipulated by providing monetary rewards for correct responses (i.e., the reward group), or monetary losses for incorrect responses (i.e., the punishment group). Reward or punishment was signaled in advance by color cues (i.e., the incentive valence cues), while approach-avoidance responses had to be given to irrelevant target orientations. To the surprise of these authors, positive and negative incentive valence cues facilitated both approach and avoidance. Seeking to prevent punishment even benefitted these responses somewhat more than pursuing rewards. Similar to the eye movements, incentive-value cues seem to possess a motivational, rather than affective, nature that can strengthen different kinds of emotional behavior. The results of Hoofs and colleagues, thus, further strengthen the idea that motivation can be modulated independently from core affect.

The contrast between these results and the classical affective congruency pattern in the AAT (e.g., Phaf et al., 2014) can be explained as a dissociation (e.g., Berridge, 1996) between "wanting" (or SEEKING, Panksepp, 1998) and "liking". The former, evolutionary prepared, behavior program stimulates behavior directed at a large variety of goals, such as food, shelter, sex, and also safety. According to the SEEKING hypothesis of Panksepp (1998), this motivational system, or affect program, is responsible for the affective urge that characterizes all exploratory and appetitive behaviors. "This system is obviously quite efficient at facilitating learning, especially mastering information about where material resources are situated and the best way to obtain them" (Panksepp, p.53). The urge is essentially nonhedonic. "This system operates in both positive and negative emotional situations (e.g., seeking safety when in danger)" and "when this system is severely damaged or profoundly dysfunctional, most other prototype states are compromised and difficult to activate with classic external elicitors" (p.392, Panksepp & Watt, 2011). For the regulatory part of the new hypothesis, the behavior ensuing from the eye movements is postulated to be part of the SEEKING or wanting repertoire. Further ideas about the underlying mechanisms can be derived from bringing together neuroscientific insights on eye movements, the OR, and SEEKING behavior.

4.2. Dopaminergic regulation

Dopamine was identified by Panksepp (1998) as the main neuromodulator of the SEEKING (wanting; Berridge, 1996) system, and is proposed here to be a causal agent in the eye-movement effects. As part of the OR, unexpected visual events raise phasic dopamine levels through a mono-synaptic tectronigral connection from the superior colliculus (SC) to the substantia nigra (Redgrave & Gurney, 2006). Sokolov (1990) already allocated a central role to the SC in the eye-movement component of the OR. Saccades evoke a rapidly habituating transient visual response in the SC (Boehnke & Munoz, 2008), which can result in both defensive and regulatory behaviors associated with the OR. MacCulloch and Feldman (1996) called the latter "the positive investigatory or Safety Reflex", and "… a peripheral stimulus which does not identify any danger constitutes a safety signal and leads to a positive visceral response, de-arousal and an enabling of social/-exploratory behaviour." (p.576) Eye movements may thus derive their desensitizing effect, rather than from distraction and relaxation, from energizing regulation through dopamine, converting avoidance to approach.

Dopamine is associated with approach motivation, increased working memory capacity, and has a potent influence on synaptic plasticity (e.g., see Bromberg-Martin, Matsumoto, & Hikosaka, 2010), which can also account for the eye-movement effects found in this study. Dopaminergic effects may extend beyond the eye-movement phase but seem to decline to zero well within 2 h (cf, Endres et al., 1997). In the memory domain, this would imply that re-imagination during the eye movements is not an absolute requirement for SIRE effects to occur (see Phaf, 2017), but that without such re-imagination a dopaminergically induced enhancement may rapidly wane as a function of the interval between eye manipulation and retrieval. Dopamine neurons come in many different types and are connected with a number of distinct brain networks (i.e., there are at least nine major dopaminergic cell groups, excluding the retina; Björklund & Dunnett, 2007). The behavioral functions of dopamine may even be more diverse (e.g., Schultz, 2007) but we propose here that eye movements specifically stimulate, primarily in a bottom-up fashion, regulatory behavior (i.e., SEEKING) through targeted dopamine release (i.e., via tectronigral connections

from SC to substantia nigra; Redgrave & Gurney, 2006).

The translation of animal research into the human domain should be treated with caution, but two studies with optogenically manipulated mice provided further support for our dopaminergic regulation hypothesis (Almada et al., 2018; Baek et al., 2019). With this new optogenic technique the activity of individual neurons, which were genetically modified by viral injections, is controlled by pulsed lights in living animals. Almada and collaborators investigated the behavior of these mice in the "Beetle Mania Task", in which a threatening robo-beetle made erratic movements resulting in frequent encounters with the mouse. For control mice with ineffective viral injections, this always led to avoidance and flight responses. In contrast, when the nigrotectal pathways (i.e., between SC and Substantia Nigra) were stimulated optogenetically, the experimental mice began to actively explore and even chase the robo-beetle. The SEEKING behavior elicited by this stimulation is thus mediated by the same pathway as is responsible for the short-latency dopamine signal evoked by the eye movements.

Astonishingly, eye movements can even desensitize fearful memories in mice. In their optogenetic study, Baek and collaborators (2019) also demonstrated the causal involvement of the SC in the eye-movement effects. These researchers showed that bilateral alternating light sequences (i.e., to the eyes) reduced conditioned fear behavior (i.e., involving more extinction than would be due solely to the absence of the unconditioned stimulus) and increased the activities of SC and mediodorsal thalamus (MD). In addition, these activities were correlated positively with the extent of fear reduction. Optogenetic silencing of the SC-MD connections suppressed the reduction of fear behavior, which evidences that the SC is causally involved in the extinction due to the bilateral eye movements. If, moreover, the lights fired in a non-sequential manner, the additional extinction was not found, which can be seen to contradict distraction accounts.

4.3. Lateralized eye and dopamine dominance

A dopaminergic regulation hypothesis may account for the lateralization effects often obtained in eye-movement studies. Strong and consistent orienting biases (i.e., in the spatial direction of attention), probably representing an individual trait, occur towards the visual hemifield contralateral to the hemisphere that produces most dopamine (e.g., Mohr, Landis, Bracha, & Brugger, 2003; Tomer et al., 2013; Zozulinsky et al., 2014). Even within a group of right-handers, Tomer and colleagues obtained strong associations between right-hemisphere dominant dopamine binding and leftward orienting bias, and conversely between left-hemispheric dominance and rightward bias. In addition, Zozulinski and colleagues observed, also within a group of right-handers, that specific variants of dopaminergic genes predicted individual differences in orienting bias. Correlations between handedness and turning bias (see Mohr et al.) are in absolute value substantially smaller than correlations between dopamine dominance and turning bias (see Tomer et al.). This suggests that handedness probably is not the ideal laterality measure for optimizing SIRE and EMDR effects, if they involve attentional orienting.

Eye dominance (i.e., the preferred eye for tasks involving monocular vision) may act as a more fundamental determinant of asymmetries in visual and cognitive processing than handedness (e.g., Chaumillon, Blouin, & Guillaume, 2018), which certainly would make sense in an eye-movement context. Petit et al. (2015) conducted fMRI research on a very large group of participants into the lateralization of neural activity when saccades were guided by a white light that jumped randomly along the horizontal axis. A large variability was observed across the handedness groups, but strong left-handers, and to a lesser extent mixed handers, showed a rightward activation asymmetry, particularly in dorsal frontoparietal regions involved in spatial attention. Strong right-handers only had a small leftward asymmetry. The largest right-lateralization however, was obtained for strong left-handers with a

right eye dominance. Petit et al. noted that the latter is predominantly controlled through the ipsilateral occipital cortex (cf, Vergilino-Perez et al., 2012). The collateralization of hand and eye control, reflected by the largest asymmetries in neural activity, may confer benefits, as can be seen by the overrepresentation of strongly left-handed, and right-eye dominant, athletes in interactive sports such as tennis (see Petit et al.).

In individuals in whom the SCs implicated by eye dominance (e.g., Wang, Bianciardi, Chanes, & Satpute, 2020) and by dominant dopamine production (Redgrave & Gurney, 2006; Tomer et al., 2012) coincide, the largest effects of eye movements are expected. If saccades predominantly activate the SC on the side where the most dopamine is produced, they will influence attention, motivation, and memory more than when eye and dopamine dominance are located on different sides. Due to the positive correlations of eye and dopamine dominance with handedness, collateralized individuals will often also be (strongly) consistently handed. In addition, imperfect correlations of handedness with these other lateralization types may explain a good deal of variability in eye-movement effects (cf, Roberts et al., 2020). If the regulation in both EMDR and SIRE is indeed mediated by dopamine, activation by saccades of the SC on the side of dopamine dominance should reveal the largest effects.

4.4. Outline of the new hypothesis

The dopaminergic regulation hypothesis for emotional and memory effects of eye movements comprises behavioral functions, neuro-cognitive mechanisms, and consequences (i.e., optimization measures) for eye movement studies and therapies.

4.4.1. Functions

a) Longer-lasting effects of eye movements are attentional engagement, elaborative learning and the fostering of approach tendencies, particularly of affectively negative memories.
b) Freezing responses to extremely negative memories can be converted into approach responses by eye movements.
c) Eye movements can also have short-term distraction effects, provided that WM is loaded sufficiently by the negative memories.
d) The behavioral tendencies ensuing from the eye movements are postulated to be part of the SEEKING or wanting repertoire

4.4.2. Mechanisms

a) Eye movements are controlled by signals coming through and from the SC.
b) The activation of the SC raises a short-latency dopamine signal through a monosynaptic connection to the Substantia Nigra.
c) Many different neural pathways are modulated by dopamine but eye movements specifically target the dopaminergic pathway that is responsible for attentional engagement, memory enhancement, and a conversion from avoidance to approach (i.e., SEEKING tendencies).
d) Eye movements are predominantly controlled through the SC in one hemisphere. The lateralization of this SC corresponds to the ipsilateral lateralization of the eye that is preferred in monocular tasks (i.e., eye dominance).
e) Dopamine production is also lateralized (i.e., dopamine dominance) and induces a contralateral orienting bias.

4.4.3. Consequences

a) Persons with collateralized eye and dopamine dominance are the most sensitive to eye-movement effects.
b) Eye movements are most effective when memories are re-imagined during the bilateral stimulation.
c) A description of further optimization measures that, according to the dopaminergic regulation hypothesis, could be taken in both eye-

movement research and therapy, such as with respect to ambient lighting conditions, time of day, eccentricity (i.e., visual angle), prism adaptation, dopaminergic medication, and duration and timing of bilateral stimulation, can be found in Phaf (submitted).

4.5. Conclusion

New dependent variables for eye-movement research, particularly with respect to emotion, were explored in this study. Two global accounts, distraction (i.e., WM) and regulation (i.e., OR and TDAC) hypotheses, were contrasted with these measures. Evidence weighed in favor of the latter, so for the moment this account seems to have won the competition between hypotheses. Post-hoc adaptation and elaboration however, into the novel dopaminergic regulation hypothesis, were required to address the motivational and lateralization aspects of eye-movement effects. Whether the theoretical innovations based on these preliminary results prove fruitful, of course, has to be shown by further research. Previously, negative conclusions about eye-movement effects (e.g., Matzke et al., 2015; Roberts et al., 2020) seem to have been due to their counter-intuitive nature, and also to the adoption of the statistical illusion, which has much impeded psychological theorizing (Phaf, 2020). Our deficient knowledge of the best stimuli, task settings, and context conditions (cf. Fiedler, Kutzner, & Krueger, 2012), may lead us to prematurely reject substantive eye-movement theories and therapies. The societal costs of missing out on the potential benefits of EMDR are much higher than of pursuing laboratory research and theoretical advances that zoom in ever more sharply on eye-movement mechanisms.

Author statement

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