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I see you remembering: What eye movements can reveal about process characteristics of prospective memory

Josephine Hartwig[a*], Katharina M. Schnitzspahn[b], Matthias Kliegel[b], Boris M. Velichkovsky[c], Jens R. Helmert[a]

[a] Unit of Engineering Psychology and Applied Cognitive Research, Technische Universität Dresden, Zellescher Weg 17, 01062 Dresden, Germany

[b]Department of Psychology, University of Geneva, Boulevard du Pont d'Arve 40, CH- 1211 Genève 4, Switzerland

[c]Institute of Cognitive Studies, Kurchatov Research Center, 123182 Moscow, Russian Federation

[*]Corresponding author. Tel.: +49 351 463 34713, fax: +49 351 463 37741. *E-mail address*: hartwig@psychologie.tu-dresden.de

Abstract

Prospective memory performance describes the delayed execution of an intended action. As this requires a mixture of memory and attentional control functions, current research aims at delineating the specific processes associated with solving a prospective memory task. Therefore, the current study measured, analyzed and compared eye movements of participants who performed a prospective memory, a free viewing, and a visual search task. By keeping constant the prospective memory cue as well as the context of tasks, we aimed at putting the processes of solving prospective memory tasks into context. The results show, that when a prospective memory task is missed, the continuous gaze behaviour is rather similar to the gaze behaviour during free viewing. When the prospective memory task is successfully solved, on the other hand, average gaze behaviour is between free viewing and visual search. Furthermore, individual differences in eye movements were found between low and high performers. Our data suggest that a prospective memory task can be solved in different ways, therefore different processes can be observed.

Keywords: Eye movements, Prospective memory, Voronoi method

Introduction

Event-based prospective memory (PM) is defined as remembering and performing an intended action at the appropriate occasion (Carlesimo and Costa, 2011; Kliegel et al., 2008). In laboratory settings, this occasion is usually signified by a prospective memory cue (PMC) which is embedded in an ongoing task. Upon perceiving the PMC and therefore noticing the appropriate occasion, the ongoing task has to be interrupted in order to perform the intended action (Kliegel et al., 2007). However, how this appropriate occasion is recognised is a widely discussed topic and object of investigation. So far, several at least partially contradictory theories and frameworks have been proposed. Here we will discuss three of them briefly and present some related evidence.

The automatic associative activation theory as well as other "activation" views propose that the PM representation, including the representation of the appropriate occasion and the associated intention, is held at a given level of activation. If this level is high enough, the PM representation automatically interacts with the PMC at its detection (Guynn et al., 2001). Thus, the automatic associative activation theory suggests that the intended action comes to mind spontaneously, when the PMC is perceived (McDaniel et al., 2004). This implies that no conscious and therefore no strategic processes are applied to find the appropriate occasion to initiate the PM response signified by the PMC, which again implies that no or very few cognitive resources are required. Guynn et al. (1998) controlled the content of reminders of the PM task given by the experimenter during completion of the ongoing tasks. The target-group was prompted to think of the PMC, whereas the target + action-group was asked to remember the PMC and the intended action. Thereby Guynn et al. (1998) manipulated the association of PMC and memory trace. According to the automatic associative activation theory, such manipulation should influence the probability of a correct reaction upon perceiving the PMC, increasing it when both, target and action were stressed. While the target-group did not increase their performance in the PM task compared to a control group (no reminders), the target + action-group indeed showed a significant performance increase. This result supports the automatic associative activation theory, as strategic processes like monitoring for the appropriate occasion should have been triggered through both types of reminders (McDaniel and Einstein, 2000).

Opposing this view the Preparatory Attentional and Memory Processes Theory (PAM) proposes a constant requirement of strategic processes and therefore of cognitive resources (Smith, 2003; Smith and Bayen, 2004). During the period of time in which the appropriate occasion to act might occur, these processes can include nonautomatic monitoring of the surroundings as well as rehearsal of the PMC and the intended action (Smith, 2003; Smith and Bayen, 2004). Further strategic processes are supposed to be triggered while the PMC is present, including the differentiation of the PMC from other stimuli and occasions and the recall of the intended action (Smith and Bayen, 2004). Smith (2003) embedded the PM task in a lexical decision task for one group and compared performance to a group where the PM task was presented only after the lexical decision task was finished. Reaction times increased for the former group in the ongoing task even while no PMC was present. Furthermore, between-subject differences were apparent as participants with better than average performance on the PM task were slower in the lexical decision task. These findings support the PAM as they show a trade-off between PM and ongoing task and therefore suggest a need of resources while performing the PM task. This might be explained by monitoring processes to recognise the appropriate occasion or rehearsal of the PMC and/or intention.

The multiprocess framework describes different conditions of PM tasks (e.g. importance of the task, cue salience, difficulty of the ongoing task, etc.) that determine if strategic processes are needed to successfully solve the task or if it is possible to rely on rather automatic processes alone. According to this theory, it is possible that a spontaneous process of recognising the PMC is followed by the strategic recollection of the intended action or vice versa. Nevertheless, under specific conditions the task can also be solved through spontaneous or strategic processes alone (McDaniel and Einstein, 2000). Accordingly, behaviour might change not only within one PM task (intra-individual) but might differ also between participants (inter-individual). A study by McDaniel et al. (2004) showed how much PM performance and presumably each individual's approach to solve the PM task relies on task context. While manipulating the association between PMC and required response, the influence of attentional demands required by the ongoing task and the pre-exposure of non-targets in addition to the PMC as compared to pre-exposure of PMC only, was analysed. During trials with highly associated cues and responses PM performance was neither sensitive to attentional demands nor to the pre-exposure of PMC only or non-targets plus PMC. In low association trials, however, performance was sensitive to both, showing decrements during high attention- and non-target plus PMC pre-exposure conditions. According to the authors this implicates that none of the aforementioned theories alone is able to predict the performance in all contexts: The results in the high association condition support the spontaneous view while the low association results support views that include strategic processing. It is assumed that during these differing task conditions different approaches to solve the tasks were chosen. These results support the notion that a multiprocess framework is necessary (McDaniel et al., 2004).

However, several PM researchers are addressing the question if cognitive resources are always necessary to detect a PMC, or if spontaneous processes are sufficient in specific cases. E.g. Smith (2010) pointed out that the performance measures obtained in the behavioural paradigms provide only an indirect indicator of monitoring processes. Therefore, it has been suggested to include continuous measures that allow witnessing mental processing efforts more directly (Harrison and Einstein, 2010).

In the current study, we propose measuring eye movements while solving a PM task as a rather novel approach to further explore the processes associated with PM. Eye tracking combines several advantages as it is a noninvasive, under natural conditions obtainable physiological measure (Inhoff and Radach, 1998), low in latency and able to provide insights into the ongoing dynamics of processing. According to Velichkovsky (2002a) "in memory research [...] high resolution eye tracking can be applied for a microanalysis of the on-going exploratory behaviour at encoding and retrieval" (p.408). Interestingly, so far only one study has used this technique in the context of PM. West et al. (2007) asked their participants to complete a visual search and a PM task on alphabetic strings while measuring eye movements. The results showed that subjects tended to fixate longer on the stimulus they subsequently responded to, irrespective of the actual correctness of this response. The current study took this paradigm a step further. Complex visual material was used, resulting in greater freedom of natural viewing behaviour, allowing for analyses of more aspects of eye movements. We used all the advantages of eye movement measurement to access processes of performing a PM task, especially during the period of time until the appropriate occasion to act upon was detected. Thus, processes like monitoring or PMC perception were examined through eye movement analyses. Furthermore, processes before and following reaction to the PMC could be compared. For this purpose, we concentrated on two parameters of eye movement shown to be sensitive to current information processing: Duration of fixations on the one hand; and choices of gaze direction, i.e. fixation position analyses on the other.

Fixation durations are of fundamental interest to eye movement research as a plausible candidate for classifying cognitive processing in visual tasks such as reading, visual search, or image inspection. Fixations in the time course of task solving cannot be seen as equal, as task demands change over time and so—most probably—do fixations. Pannasch et al. (2008) demonstrated that for a wide variety of visual tasks fixations show an increase of duration over inspection time. Therefore, more sophisticated analyses on distribution characteristics can be informative. As was shown by Velichkovsky (1999) the mean skewness of fixation duration distributions is a valuable measure to further examine differences resulting from the tasks at hand. Encoding stimuli on a rather shallow level (e.g. the stimulus material during a word counting task) resulted in smaller positive skewness of fixation duration distribution, while skewness increased as stimuli were encoded on a deeper level. This measure was used in the current study to examine if the stimuli were encoded differently during the various tasks as well as during PMC hits and misses.

Analysis of fixation positions can inform if failing to perceive the PMC is the main reason to forget the PM task as, for example, the automatic associative activation theory (Guynn et al., 2001) may suggest. The task sensitivity of gaze behaviour was already shown by Yarbus (1967). What is looked at in a visual scene heavily depends on goals and intentions of the observer. In other words, gaze direction determines what we see and what we understand (Nuthmann et al., 2010). Due to the physiological structure of the eyes, gaze positions can be assumed to be identical with orientation of visual attention within the context of natural image inspection (Henderson, 2007). One remaining problem with the evaluation of continuous gaze direction still is its statistical analyses. While on a descriptive level differences can be depicted in a plausible way, deriving quantitative measures came into focus of research just recently. A procedure directly comparing and testing viewing strategies was proposed by Over et al. (2006) employing Voronoi diagrams as a measure of uniformity of fixation densities. Thereby, every single fixation is defined as the core of a Voronoi cell, with the size of this cell determined by the distances to neighbouring fixations. A distribution of cell sizes showing a low skewness can be attributed to a rather uniform fixation density (as is seen in visual search), whereas higher skewness values result from inhomogeneous gaze behaviour (as can be observed in free viewing). This measure allows to compare continuous gaze behaviour between free viewing and visual search and to finally put PMC hits and misses into context.

In the current study we analyzed skewness of Voronoi cell size distributions to quantify viewing strategies (Over et al., 2006) as well as skewness of fixation duration distributions in order to learn more about cognitive processes underlying a PM task. We were explicitly interested in a direct comparison of processes associated with a PM to processes during other visual tasks, namely free viewing and visual search, as these tasks include processes that might be applied during a PM task. Furthermore, the PM task outcomes (PMC hit and miss) were measured in order to learn more about underlying determinants of successfully solving a PM task. Based on the three described theories of PM, somewhat differing predictions concerning eye movement data during these tasks may be derived.

The automatic associative activation theory implies no active cue search processes and thus no change in behaviour during PM tasks as compared to free viewing. Therefore, eye movement analyses of median fixation duration and saccadic amplitude, as well as skewness of distributions of fixation durations and of Voronoi cell sizes should be equal in both conditions. Furthermore, there should be no differences between hits and misses as well as between the time period before and following the hit regarding fixation duration measures and overall fixation density, as again in all cases no strategic processes are applied. There should, however, be a difference in fixating the PMC between hits and misses, as looking at this cue would spontaneously trigger the associated intention while failures would result from visually missing the PMC.

The PAM on the other hand seems to imply a stronger impact on eye movement behaviour during a PM task, differing from free viewing in all measures. If monitoring is employed, eye movement data during the PM task should be more similar to visual search. Assuming the PM task is not entirely forgotten, there should again be no differences between hits and misses regarding gaze direction as in both cases strategic processes should be triggered initially. There should be differences, however, between the time period before and following the hit, as after finishing the task participants will be able to resume free viewing. Therefore fixation density following a hit should equal that of free viewing. Assuming participants did forget the PM task intermittently, there should be differences between PMC hits and misses as strategic processes should be applied during hits while free viewing is conducted during misses.

The multiprocess framework implies a mixture of approaches and therefore in data, as parts of the task can be solved through strategic and others through spontaneous processes. Furthermore there might be individual differences in solving the PM task.

Methods

Participants

18 female and 4 male students of the Technische Universität Dresden participated in the study. All were between 19 and 29 years of age (*M* = 23.2, *SD* = 3.2) and had normal or corrected to normal vision. Subjects were naïve to the purpose of the study. Written, informed

consent was obtained prior to the study. Participants received either €7.50 or course credit. The study was conducted in line with the declaration of Helsinki.

Apparatus

Participants were seated individually in a dimly lit room, with their head positioned on a chin rest. Images were displayed on a 19-inch CRT monitor which was viewed from a distance of 60 cm, resulting in a viewing angle of approximately 25° vertically and 33° horizontally. Its screen resolution was 1024 by 768 pixels, the refresh rate 100 Hz. Eye movements were recorded monocularly at 1000 Hz using an SR Research Ltd. EyeLink1000 eyetracker (SR Research, Osgoode, Ontario, Canada). Before testing, a 9-point calibration was completed and repeated if the error in any fixation point exceeded 1° or if the average error for all points was more than 0.5°. A second 9-point array was used to validate the calibration. Participants' reactions were registered with the Cedrus RB-830 Response Pad (Cedrus Corporation, 2011). The response keys were marked with different colours and participants were instructed according to these colours.

Stimuli

94 digitized copies of colour paintings dating from the 15th to the 20th century were displayed centrally. They either had a resolution of 1024 by 768 pixels or were stretched to one of the measures while keeping their proportions filling the surrounding space with greyscale resembling the paintings' mean brightness value. For the ongoing task each painting was paired with a snippet which was 100 by 100 pixels in size. Half of them were cut from the same painting the other half was taken from paintings that were similar in style, colour and semantic content.

Procedure

Our study comprised three tasks. In a free viewing task ten paintings were shown consecutively, 20 seconds each. Each painting was followed by a centrally presented snippet, which had to be attributed to being a cut-out of the previously seen painting or not. This was done by pressing one of two buttons. Viewing of the snippet was terminated by the button press. Participants were instructed to react as fast as possible while retaining high accuracy. Free viewing was followed by the PM task, where the allocation of the snippets was used as the ongoing task (OT). Embedded in this OT, the PM task was to press one of two prespecified buttons on the response pad as soon as the participant saw a book or statue in the paintings. Participants were told to continue their task of viewing the painting after the reaction. 60 paintings were shown during this task. These included 12 paintings with a PMC (i.e., six books and six statues). Paintings were shown for 20 seconds each. Thirdly, a visual search task was conducted. Former PMCs (i.e., books and statues) were used as targets. In addition to the 12 previously seen paintings with book or statue, the visual search task contained 12 new pictures displaying a visual search target (again book or statue), that had not been shown before, and 12 new pictures displaying neither book nor statue. Participants had to indicate whether a book, a statue or none were present in the painting by pressing one of three buttons. There was no time limit, but participants were instructed to react as fast as possible while retaining high accuracy. The paintings were shown until 1.5s after the reaction. We used a different number of paintings within each task to balance between the time necessary to conduct the experiment and gaining sufficient data. Between the PM task instruction and its conduction the German version of the need for cognition scale (Bless et al., 1991, original version by Cacioppo & Petty, 1982) was given as a filler task. The results are not reported here. Following the PM task, participants' retrospective memory for PM task instruction was verified. Eye movements were recorded throughout the experiment. Each task was preceded by a calibration and validation and each trial was preceded by a drift correction to maintain accuracy. For each subject, an experimental session lasted approximately 1,5h.

Data analyses

Eye movement data were analyzed with SPSS 19.0. Skewness of Voronoi cell size distribution was calculated with MATLAB R2011b. Blinks (as identified by the SR Research Ltd. EyeLink1000 tracker's on-line parser, i.e. loss of pupil image due to eyelid occlusion), fixations shorter than 50 ms, fixations and saccades outside the screen and the first and last fixation in each trial were excluded from analyses. Areas of Interest (AoI) were drawn around books and statues, respectively, adding a margin of 0.5° in order to account for eye tracker's accuracy, resulting in an average AoI size of 26006 pixel (*SD* = 45106). Eye movement data within paintings with book or statue were assigned according to participants' reaction to PMC hits and PMC misses.

As previous studies reported right skewed distributions of both fixation durations and saccadic amplitudes (e.g. Pannasch et al., 2008; Van Loon et al., 2002; Yang and McConkie, 2001), medians will be reported in the current study. Additionally, medians as compared to means provide a more robust measure of central tendency with less vulnerability to extreme values (Aron and Aron, 2003). To estimate effect sizes, we report *partial* η^2, the variance explained by a variable when other variables are excluded from the analyses.

Our analyses focused on the processes within the time window between the start of image inspection until the correct reaction to the PMC (PMC hit). In PM trials where the appropriate occasion was not noticed or not reacted to (PMC miss), we determined the respective time window and thereby the cut-off point individually for every subject based on their mean reaction times in successful trials. The same values were applied to the free viewing task data (free viewing). For visual search, again the time window between start of presentation and reaction was examined (visual search).

Results

The PM task was solved correctly in 66.8% (*SD*=31.4) of the trials. There was no significant correlation between size of the PMC and number of correct reactions, $r_s=.522$, $p>.05$. Across all trials the ongoing task was solved correctly in 76.4% (*SD*=7.4) of cases. These results show that ceiling effects could be avoided in both task types. The visual search task was solved correctly in 82.7% (*SD*=7.1) of cases. There was a significant difference in performance between paintings that had been seen before (*M*=79.7%, *SD*=7.8) and those new to the participants (*M*=85.7%, *SD*=11.0), $F(1,22)=5.26$, $p<.05$, *partial* $\eta^2=.19$.

In a first step, we compared the median fixation duration and median saccadic amplitude between the four conditions. Data until described cut-off were included. Both calculated repeated measures ANOVAs with task (free viewing, PMC miss, PMC hit and visual search) as within-subject factor were significant, $F(3, 57)=8.79$, $p<.001$, *partial* $\eta^2=.32$, and $F(3, 57)=7.35$, $p<.001$, *partial* $\eta^2=.28$, respectively. Bonferroni adjusted post hoc pairwise comparisons certified both measures to be sensitive to differences between free viewing and visual search, all *p*s<.01. Median fixation duration was smaller but median saccadic amplitude was higher in visual search . Moreover, visual search showed significant differences to PMC hits and misses in saccadic amplitude, $p<.05$, again with higher values in visual search. PMC hits could be distinguished from free viewing through fixation duration, $p<.01$, with a lower median in PMC hits. There were however no significant differences between PMC hits and misses (see Table 1 for all values).

Table 1: Insert about here.

In a second step, we focused on possible differences between PMC hits and misses by analysing the AoIs. The PMC was fixated in 88.5% (*SD*=12.4) of the hits and 56.4% (*SD*=25.9) of the misses, $F(1, 19)=24.83$, $p<.001$, *partial* $\eta^2=.57$. Additionally, differences in dwell time on the AoIs between hits and misses were significant, $F(1, 19)=23.14$, $p<.001$, *partial* η^2=.55. While the average dwell time was 552ms (*SD*=305) on the PMC before a hit, it was only 177ms (*SD*=283) in a miss trial within the same time span. Additional ANOVAs on median fixation duration, *F*<1, and number of fixations made within these AoIs, *F*(1, 19)=23.99, *p*<.001, *partial* η^2=.56, suggest that longer dwell times are related to the latter measure. On average, 1.92 fixations (*SD*=.95) were made on the PMC before a hit and only 0.63 (*SD*=.91) in a miss.

To see whether the stimuli within the tasks of this study were encoded differently, we calculated two one-way repeated-measures ANOVAs with the skewness of fixation duration as dependent variable. The first comprised task (free viewing, PMC miss, PMC hit, and visual search) as within-subject factor and relied on data until cut-off, as described earlier, resulting in significant differences, *F*(3, 57)=19.23, *p*<.001, *partial* η^2=.50. Bonferroni adjusted post hoc pairwise comparisons showed significant differences between visual search and all other tasks, all *p*s<.01, other comparisons were not significant, *p*>.05 (Figure 1). The second ANOVA comprised the time window following cut-off and therefore included three tasks (free viewing, PMC miss and PMC hit). There were no differences in skewness of fixation duration, *F*<1.

Figure 1: Insert about here.

While the skewness of fixation duration informs about the depth of processing the skewness of Voronoi cell sizes is a spatial measure of viewing behaviour, indicating strategy use while viewing the stimulus. Differences in skewness of Voronoi cells in the PM task should indicate whether participants searched for the PMC (skewness should equal that of visual search) or relied on spontaneous processes (skewness should equal that of free viewing).

Two one-way repeated-measures ANOVAs with skewness of Voronoi cell sizes as dependent measure were calculated. Again the first comprised all tasks (free viewing, PMC miss, PMC hit and visual search) and relied on data until the previously described cut-off point, resulting in significant differences, *F*(3, 57)=41.75, *p*<.001, *partial* η^2=.69. Bonferroni adjusted post hoc pairwise comparisons showed significant differences between all trial types, all *p*s<.001, except for free viewing and PMC miss trials, *p*>.05 (Figure 2). The second ANOVA comprised the data following the cut-off point and included three tasks (free viewing, PMC miss, PMC hit). There was a reliable difference, *F*(2, 38)=3.55, *p*<.05, *partial* η^2=.16. However, Bonferroni adjusted post hoc pairwise comparisons showed no significant differences, all *p*s>.05.

Figure 2: Insert about here.

To analyze if individual differences were responsible for the Voronoi data, participants were grouped regarding their performance level in the PM task. Low performers (six participants) had six or less PMC hits (50% or less), high performers (14 participants) showed seven or more. Only data until average reaction time was used. A two-way mixed ANOVA with task (free viewing, PMC hit and PMC miss) as within-subject factor, performance group as between-subjects factor and skewness of Voronoi cell sizes as dependent variable was calculated (see Figure 3). The analysis showed a significant effect in task, $F(2, 36)=4.56$, $p<.05$, *partial* $\eta^2=.20$. Yet, Bonferroni adjusted post hoc pairwise comparisons showed no significant differences, all *p*s>.05. However, a difference between high and low performers was obtained, $F(1, 18)=4.94$, $p<.05$, *partial* $\eta^2=.22$. There was no significant interaction between task and performance group, $F(2, 36)=2.90$, $p>.05$.

Figure 3: Insert about here.

Discussion

The current study aimed at providing insights into the processes of performing a PM task through eye movement analyses. Our main results include the fixation of the PMC even during misses but differing dwell times on it compared to hits. Furthermore, our results show an equal skewness of Voronoi cell size distribution of PMC miss and free viewing trials as well as differences in this measure between PMC hit and all other tasks before average reaction time, while following it no differences are apparent. Last but not least we could show differences in viewing behaviour between low and high performers. These results will be discussed specifically in the following.

As shown by Yarbus (1967) different tasks are accompanied by different eye movements. Our data confirm this by showing differences between free viewing and visual search in several eye-tracking parameters: The longer saccades and shorter fixations show the processes during searching. Participants move their eyes in long saccades across the whole painting and fixate only briefly to check whether the fixated item is the target; a behaviour that is not found during free viewing in that extent. The smaller skewness of fixation duration during visual search, signifying a lesser number of long fixations, confirms this pattern.

To differentiate between PMC hits and misses more complex statistical measures are necessary. It is not sufficient to analyse fixation positions only, as during more than half of the PMC misses the PMC had been fixated at least once, which replicates the data of West et al. (2007). Of course, this means that in more than 40% of the PMC misses no focal attention was given to the PMC, which seems to dovetail with the automatic associative activation theory as one of the here suggested main causes of failing the task (Guynn et al., 2001). However, contrary to such a clear conclusion, during those PMC miss trials when the PMC was fixated either no automatic interaction took place between the stimulus and its representation in memory to notice the appropriate occasion, or the intended action was not triggered spontaneously. As no participant failed all PMCs, it is unlikely that the intention was completely forgotten. Furthermore, all participants correctly retrospectively recalled and reported the PM instructions after task completion. However, participants might not have attended to the stimulus or, possibly, the PMC was not processed deeply enough to signify the occasion. Processing, however, measured by median fixation duration or skewness of fixation duration as shown by Velichkovsky (2002b; 1997) did not differ between PMC hits and misses. Hence it might be suggested that during these fixations the same computations took place (Pannasch and Velichkovsky, 2009).

There were, however, differences in dwell time, as before a hit PMCs were fixated more often. Apparently more time is needed to understand the significance of the seen stimulus and process the gained information. This might be explained by first noticing the appropriate occasion and in a second step, marked by a second fixation, the intention is triggered and executed. This conclusion is supported by data from Kliegel et al. (2007), who recorded the skin conductance responses during a PM task. They presented words as PMCs and semantically and phonologically similar non-cues. While skin conductance response was highest for PMCs, it was higher for non-cues than correct rejects. Further research has to be done combining several physiological measures to investigate the generality of this view and whether both of the described stages are strategic or spontaneous processes.

Of high interest also is the difference in skewness of Voronoi cell sizes between PMC hits and misses and how these values compare to free viewing and visual search. As Over et al. (2006) showed, different tasks can be differentiated by differing skewnesses of Voronoi cell sizes. In reverse, tasks that evoke the same behaviour should evoke the same skewness. Before average reaction time there were no differences between PMC misses and free viewing. This shows that participants viewed the paintings during a PMC miss in the same way as they did without having a task: they view smaller parts of the paintings in more detail and disregard others, resulting in some bigger Voronoi cells and lots of smaller ones. This seems to be in line with assumptions of the automatic associative activation theory as well as the multiprocess framework. However, only if we assume that the PM task is entirely forgotten during these trials, the data are predicted by PAM theory. The skewness of Voronoi cell sizes in PMC hit trials on the other hand was between free viewing and visual search. There are three ways to interpret this result. Either all participants used a certain strategy to recognise the appropriate occasion to act. This supposed strategy is characterised by a behaviour that is neither a detailed viewing of the painting nor a far stretched search but is in-between. This interpretation follows the PAM (Smith and Bayen, 2004), supporting the view that all participants use strategic processes, as long as the task itself is not forgotten (i.e. within subject variation of strategy use). A different interpretation is that the average skewness of Voronoi cell sizes of PMC hits is made of values of the two different extremes. Meaning some participants used a strategy like monitoring to recognise the appropriate occasion, therefore having small Voronoi skewnesses. Others, however, relied on spontaneous processes and meanwhile were viewing the painting as if they had no task. This interpretation follows the multiprocess framework, supporting the claim, that inter-individual differences are responsible for different behaviour and therefore different approaches to solve a PM task (i.e. between subject variation of strategy use). This will be discussed in the paragraph following next. A third interpretation is that the data reflect between as well as within participants variation, e.g. some participants rely on spontaneous processes more than others, while the individual approach to task solving differs during its completion. This follows the multiprocess framework as well.

Another interesting detail is the increase of skewness of Voronoi cell sizes within the PMC hit trials after the PM task is done. This confirms the assumption of strategy use of at least some participants, thereby supporting the PAM and multiprocess framework. The data presented here allow for the conclusion that after successfully solving the PM task, subjects return to a viewing behaviour highly comparable to free viewing. This supports the notion that the intention is deactivated after solving the PM task.

To clarify if a consistent strategy to solve the PM task was used by all participants or if idiosyncratic differences are responsible for the average skewness values, we grouped participants regarding their performance level. Our data reflect the idiosyncratic behaviour to influence the spatial distribution of fixations. This shows that different participants use different approaches to solve the PM task as was proposed by the multiprocess framework (McDaniel and Einstein, 2000) and recent studies arguing for considerable inter-individual differences in the employment of controlled processes such as monitoring (e.g., Albiński et al., 2012). Furthermore, as can be seen in Figure 3, participants seem to keep their approach up across all trial types. Low performers show similarly higher skewnesses in free viewing, PMC hits and PMC misses. It means they look at few areas of the painting in more detail disregarding others, which implies their reliance on spontaneous processes. This, however, fails if the PMC is not focally fixated by chance or the association between the intention and representation of the appropriate occasion is too weak. High performers on the other hand show decidedly lower values across all trial types. These low values remind of the visual search and might resemble the process of monitoring: an equidistant exploration of the whole painting at all times to find the appropriate occasion to act. As was pointed out by Smith (2003), good PM performance is accompanied by increased monitoring even in non-PM-trials. Likewise even high performers use this strategy with success to a greater or lesser extent. If the strategy of monitoring is not implemented as thorough, the appropriate occasion to act is missed.

These differences in viewing behaviour between high and low performers can reflect their idiosyncratic strategies in solving PM tasks. Indirectly, this explanation is supported by data from a number of studies. Individual differences have for example been suggested by Guynn et al. (1998), who found that certain reminders might be used differently by some participants, or by Loft and Yeo (2007), who suggested individually different perceptions of task difficulty as reason for variability in PM task processing. The multiprocess framework (McDaniel and Einstein, 2000) explicitly mentions individual differences as a source of variability in the approach to solve PM tasks. Confirming this, Einstein et al. (2005) demonstrated that about half of their participants showed costs in the ongoing task while the other half did not. This was interpreted as some participants using monitoring strategies while others relied on spontaneous processes. Even in conditions in which monitoring is not encouraged and spontaneous retrieval is supported, some participants seemed to keep their monitoring strategy up (Einstein et al., 2005). Although the multiprocess framework does suggest idiosyncratic differences in strategy use, it is not a widely discussed topic in PM literature (but see recently Albiński et al., 2012). The particular approach used by an individual might be dependent on physical or cognitive conditions. For instance, differences might result from age and working memory capacity as investigated by Kliegel and Jaeger (2006), or Cherry and LeCompte (1999). Furthermore, it might depend on states or traits of the participant. For example, Goschke and Kuhl (1993) suggested the personality dispositions "state orientation" and "action orientation" as influencing factors on retaining intended actions in memory. Cuttler and Graf (2007) analyzed different traits like the Big Five or perfectionism. They found that individuals with high scores in conscientiousness had a better performance in PM tasks, while socially prescribed perfectionism did impair the performance. They did not, however, investigate the used strategy.

Our eye movement analyses not only confirm task related differences in visual strategy (i.e. between free viewing and visual search) but seem to support the view, that neither strategic nor spontaneous processes alone are able to describe how PM tasks are solved, as neither monitoring is always necessary nor spontaneous processes always sufficient to solve PM tasks. Therefore our data seem to support the multiprocess framework as it proposes differing processes depending not only on task but also on the individual (McDaniel and Einstein, 2000). Through the analyses of eye movements, as has been done by West et al. (2007), we were able to examine the processes of solving a PM task. Because of the material used, our study was not as highly controlled as was the study by West et al. (2007) in regard to PMC size and position. However, due to the usage of visually complex material we were enabled to survey complex fixation position statistics, therefore gaining deeper insights. Particularly the skewness of Voronoi cell sizes illustrates—as it increases to free viewing level after finishing the PM task—that not all participants rely on spontaneous processes. Furthermore, individual differences in solving the PM task are apparent and kept up by the participants beyond PM trials. Further research on individual differences will have to shed more light on this question. Moreover, simple and advanced physiological measures can be successfully combined with eye-tracking to deepen the insights into processes involved in solving PM tasks.

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Corresponding author's address: J. Hartwig, Institute of Psychology III, Chair of Engineering Psychology and Cognitive Ergonomics, Technische Universität Dresden, 01069 Dresden, Germany; email: hartwig@psychologie.tu-dresden.de.

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Figure Captions

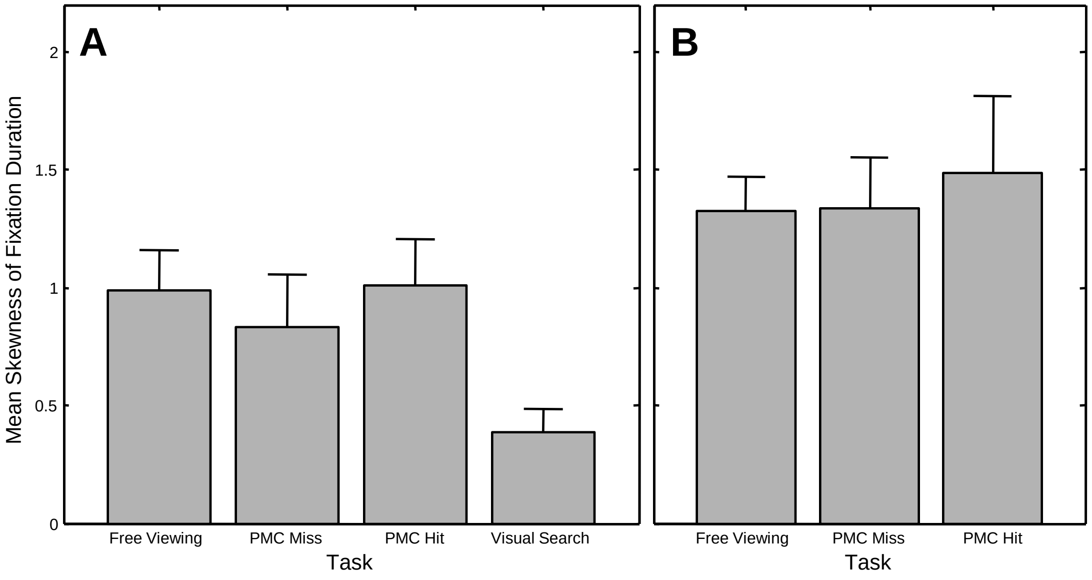
Figure 1: Skewness of fixation duration distribution within the different tasks. A: Data before cut-off point. B: Data following the cut-off point. Error bars represent the 95% confidence interval.

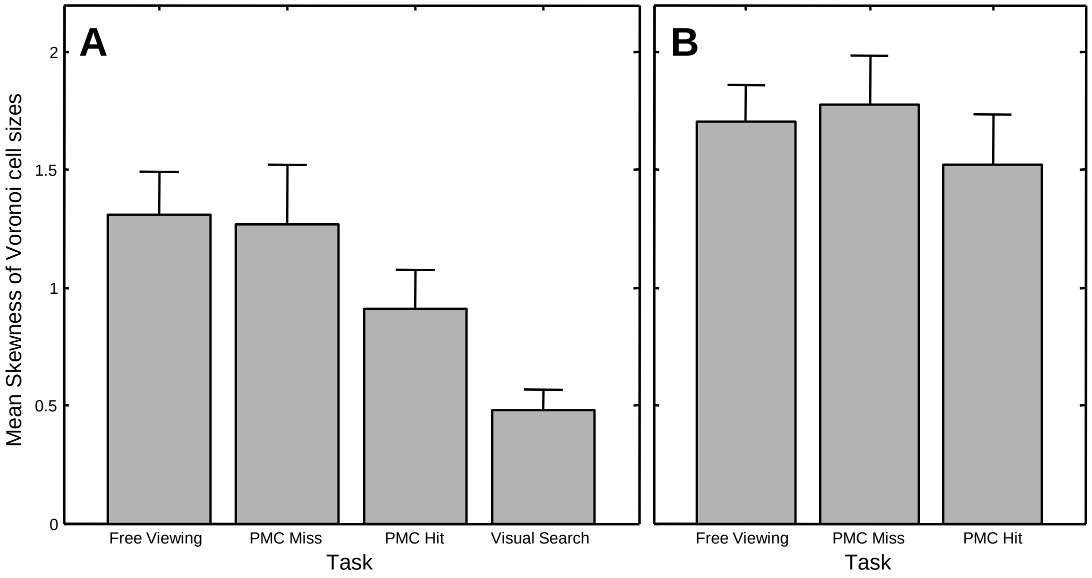
Figure 2: Skewness of Voronoi cell size distribution within the different tasks. A: Data before cut-off point. B: Data following the cut-off point. Error bars represent the 95% confidence interval.

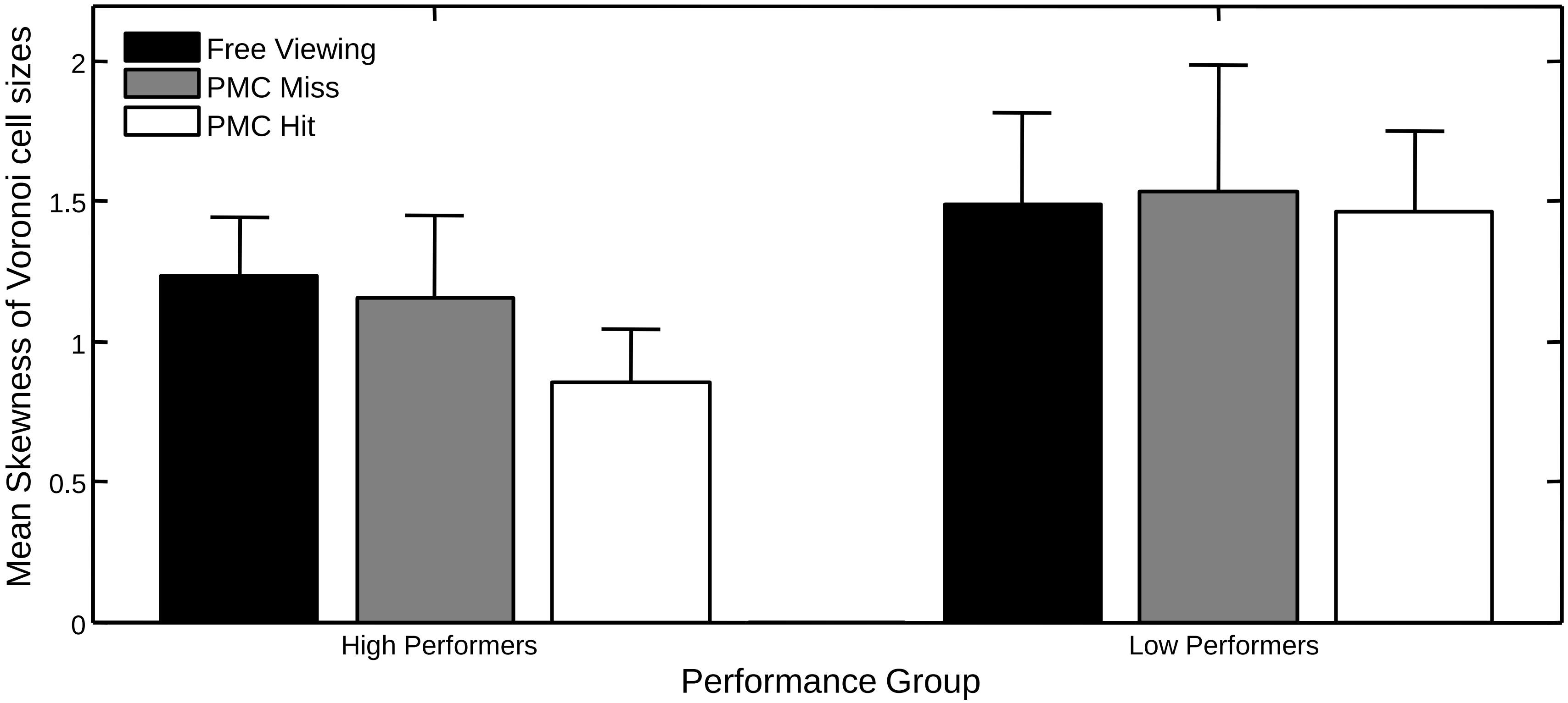
Figure 3: Skewness of Voronoi cell size distribution for the two performance groups. Error bars represent the 95% confidence interval.

Table 1: Median fixation duration and median saccadic amplitude with standard deviations (in ms) of all tasks until cut-off.

Task	Fixation Duration		Saccadic Amplitude	
free viewing	237.95	(34.78)	3.70	(.90)
PMC miss	229.00	(37.46)	4.09	(1.65)
PMC hit	219.20	(25.65)	4.07	(.90)
visual search	211.30	(24.38)	4.92	(1.07)


A
B
Mean Skewness of Fixation Duration
0
0.5
1
1.5
2
Free Viewing
PMC Miss
PMC Hit
Visual Search
Task
Free Viewing
PMC Miss
PMC Hit
Task


A
B
Mean Skewness of Voronoi cell sizes
0
0.5
1
1.5
2
Free Viewing
PMC Miss
PMC Hit
Visual Search
Task
Free Viewing
PMC Miss
PMC Hit
Task


Free Viewing
PMC Miss
PMC Hit
Mean Skewness of Voronoi cell sizes
0
0.5
1
1.5
2
High Performers
Low Performers
Performance Group