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Abstract

Remembering the past and imagining the future both rely on complex mental imagery. We considered the possibility that constructing a future scene might tap a component of mental imagery that is not as critical for remembering past scenes. Whereas visual imagery plays an important role in remembering the past, we predicted that spatial imagery plays a crucial role in imagining the future. For the purpose of teasing apart the different components underpinning scene construction in the two experiences of recalling episodic memories and shaping novel future events, we used a paradigm that might selectively affect one of these components (i.e., the spatial). Participants performed concurrent eye movements while remembering the past and imagining the future. These concurrent eye movements selectively interfere with spatial imagery, while sparing visual imagery. Eye movements prevented participants from imagining complex and detailed future scenes, but had no comparable effect on the recollection of past scenes. It has been known that impressive similarities between remembering the past and imagining the future are accompanied by relevant differences. The present findings uncover another fundamental discrepancy between the two processes.

Keywords: Episodic future thinking - Prospection - Eye movements - Visual imagery - Spatial mental imagery.

Introduction

"There is not only one time:

There are many ribbons that slide parallel

often in the opposite sense"

Eugenio Montale

People can withdraw from the current moment and mentally project themselves to an alternative time and place, as they remember their past or imagine their future (Szpunar, 2011). Importantly, the cognitive and neural processes involved in remembering the past seem to be the same as the cognitive and neural processes involved in imagining the future (*episodic future thinking*, Atance & O'Neill, 2001; Buckner & Carroll, 2007; de Vito & Della Sala, 2011). In this article, we show that even though both remembering the past and imagining the future depend on mental imagery, they involve a different mix of *spatial* and *visual* mental imagery.

The neural activity underpinning the remembrance of the past is strikingly similar to the neural activity underpinning episodic future thinking (Buckner & Carroll, 2007; Irish & Piguet, 2013; Schacter, Addis, Hassabis, Martin, Spreng, & Szpunar, 2012). The set of cognitive processes sustaining these two functions is thought to overlap considerably (Addis, Wong & Schacter, 2007; D'Argembeau & Van der Linden, 2004; Levine, Svoboda, Hay, Winocur, & Moscovitch, 2002; Manning, Denkova, & Unterberger, 2013). Nonetheless, relevant neuroimaging (Addis, Wong, & Schacter, 2007; Okuda et al., 2003), behavioral (Addis, Musicaro, Pan, & Schacter, 2010; D'Argembeau & Van der Linden, 2004; Gamboz, Brandimonte, & de Vito, 2010a), and neuropsychological studies (Berryhill, Picasso, Arnold, Drowos, & Olson, 2010; de Vito et al., 2012) have reported marked differences or dissociations (Irish, Addis, Hodges, & Piguet, 2012) between the ability of remembering the past and that of imagining the future.

Both functions reflect the construction of mental scenes that involve complex mental imagery (Hassabis & Maguire, 2007; Schacter & Addis, 2007). However, mental imagery is a multifarious cognitive tool, which relies on at least two components, a *spatial* component, and a *depictive* (Kosslyn & Thompson, 2000), also labeled *visual,* component (Reisberg & Heuer, 2002). We need to carefully consider the possibility that these various components might be differentially involved in remembering the past and in imagining the future.

While it seems reasonably clear that remembering the past crucially requires visual imagery (Rubin, Schrauf, & Greenberg, 2003), much remains to be elucidated about the mix of visual and spatial imagery required to imagine the future (de Vito, 2012).

One possible means to address this issue is to explore the disruptive effect of voluntary eye movements on episodic future thinking. Voluntary eye movements are known to disrupt mental imagery (Postle, Idzikowski, Della Sala, Logie, & Baddeley, 2006).

Early studies (e.g., Perky, 1910) indicated a tight link between eye movements and mental images. Neisser (1967) then argued that eye movements are necessary to the construction of a visual image, and Baddeley (1986) posited that voluntary eye movements interfere with visuo-spatial mental imagery. This hypothesis is supported by experimental data (Hale, Myerson, Rhee, Weiss, & Abrams, 1996; Laeng & Teodorescu, 2002; Lawrence, Myerson, Oonk, & Abrams, 2001; Pearson & Sahraie, 2003; Postle et al., 2006). Further studies showed that eye movements (specifically, endogenously generated smooth pursuit) reduce the vividness and emotional impact of personal recollections (Andrade, Kavanagh, & Baddeley, 1997). This effect extends to upsetting visual images of feared future events (Engelhard, van den Hout, Janssen, & van der Beek, 2010).

A close examination of the literature, however, suggests that only spatial mental imagery has been shown to be disrupted by concurrent eye movements. The visual component of mental imagery has rarely been investigated under simultaneous eye movements (see e.g., Exp 4 in Postle et al., 2006). Pearson and Sahraie (2003) demonstrated that concurrent voluntary eye movements reduce spatial memory task significantly more than equivalent covert attention shifts or limb movements. Indeed, all experiments showing impairment of mental imagery due to concurrent eye movements employed spatially loaded tasks (Lawrence et al., 2001; Pearson and Sahraie 2003; Postle et al., 2006). Even more tellingly, Postle and colleagues (2006, Study 4), as well as de Vito and colleagues (in press), presented participants with tasks tapping either the visual or spatial component of mental imagery, and showed that voluntary eye movements impaired performance on the latter, but not on the former. Postle and colleagues (2006) asked participants for the delayed recognition of the shape of previously provided targets, and for the delayed recognition of the location of previous targets. After the presentation of the target, participants underwent a "distraction period" in which they were asked either to continuously move their eyes or to read some words appearing on the screen. The results indicated that saccadic distraction affects spatial working memory performance, but not performance on a non-spatial task that is equally difficult. On the contrary, word reading disrupts working memory for shape, but not for locations. de Vito and colleagues (in press) observed that an additional task of concurrent eye movements perturbed performance for the iconic version of a spatial imagery test (Brooks matrices) but not for the iconic versions of visual imagery tests (Animal tails task and Curvy Letter task).

Accordingly, the question of whether remembering the past and imagining the future depend on the same mix of mental imagery can be explored by investigating the disruptive effects of voluntary eye movements.

To this end, we instructed participants to perform cue-dependent memory tasks as well as future thinking tasks, concurrently with two different secondary tasks: eye movement and hand tapping. This latter condition was added because previous studies suggested that it could interfere with mental imagery tasks (e.g., Farmer, Berman, & Fletcher, 1986; Logie & Marchetti, 1991; Moscovitch, 1994; Salway & Logie, 1995; Smyth, Pearson, & Pendleton, 1988). Its inclusion thus ensured that our results would not simply reflect the unspecific effect of any attention-demanding concurrent task.

We hypothesized that spatial imagery serves the ability of future thinking to a greater extent, if compared to the ability of remembering past events. Indeed, relative to autobiographical memory, future thinking requires a more extensive constructive process (Schacter, Addis, Hassabis, Martin, Spreng, Szpunar, 2012). Thus, concurrent voluntary eye movements are likely to disrupt future thinking, while sparing episodic memory.

Method

Participants

Fourteen young adults (9 men) entered this experiment. Participants were right-handed students recruited at the University of Edinburgh. Their average age was 31.14 years (SD = 2.24). None was under psychoactive pharmacological treatment or had a history of neurological or psychiatric disorder. Participants did not receive any compensation. Before starting the testing session, participants signed an informed consent form. The study procedures were approved by the local ethical committee and were carried out in accordance with the Declaration of Helsinki.

Materials

Participants were initially briefed that they would be required to mentally re-experience and pre-experience twelve autobiographical episodes (six occurred within the past; six occurring in the future and never occurred in the past), in response to randomly presented cue words. This technique of open-ended cueing paradigms has been largely used in most of the previous future thinking studies on healthy participants and has been proved to be sensitive to future imagining deficits in patients (Squire, van der Horst, McDuff, Frascino, Hopkins, & Mauldin, 2011). Participants were given an explicit temporal frame with each future/past cue (i.e., next few years/last few years). Aiming at eliciting past and future events, two sets of eight words, matched for familiarity, frequency, imageability, and concreteness, were selected (Burani, Barca, & Arduino, 2001). Within each list, the words were randomly assigned to the two temporal directions and rotated in the past/future conditions. Then, each participant was given one of these two sets. The experimenter further explained that the events had to be remembered or imagined in as much detail as possible. Participants also were encouraged to produce temporally and contextually specific events and to vividly imagine novel and plausible future episodes, given their current plans. When constructing future episodes, participants were explicitly instructed not to describe a memory or any part of it, or something they planned to do, but rather to imagine something completely new. This procedure follows those of D'Argembeau & van der Linden (2004) and of Addis, Wong, & Schacter (2007). The order of presentation of temporal connotation (i.e., past and future) was counterbalanced.

The cues were read, one at a time, by the experimenter with the instructions about the temporal direction (remember or imagine in the future). Once an episode had been recalled or imagined, it was recounted by the participant. There was no time limit. Participants were allowed to keep on verbally illustrating the event until they thought that nothing else could be added. We maintained constant the prompting procedure for the participants in all the experimental conditions. When participants stopped talking, the experimenter asked only once whether there was any further detail that they would have liked to add.

Recollections and simulations were digitally recorded to enable later transcriptions and subsequent scoring of participants' responses.

After the transcription, a trained rater, who was blind to the hypothesis of the study, used the standardized scoring procedure developed by Levine, Svoboda, Hay, Winocur, & Moscovitch (2002) to systematically parse the details generated in the past and future events. This allowed the rater first to segment the main event (i.e., the most talked about, with a brief timeframe) into details and then to distinguish between (a) internal details (i.e., episodic information pertaining to the main event, specific to time and place) and (b) external details (general knowledge related to the event). A second rater, trained for this purpose, then scored the protocols of 10 participants. The inter-rater reliability (r) between the original rater and the new rater was $r = .96$, $p < .001$ for the number of internal details, and $r = .98$, $p < .001$ for the number of external details.

Internal details were further categorized into: (a) event (happenings, individuals present, physical/emotional actions and reactions, weather), (b) place (information about the environment where the event occurred), (c) time (date, season, month, day of the week, time of day), (d) perceptual (sensory information, body position) and (e) emotion (emotional state, thoughts). External details were categorized into: (a) external event (specific details from other incidents, from all of the above categories, external to the main event), (b) semantic (general knowledge or facts, ongoing events, extended states of being), (c) repetition (unsolicited repetition of details), and (d) other (metacognitive statements, editorializing).

Procedure

Testing was carried out in one single session. All participants were tested individually and sat facing the same experimenter in a quiet testing environment. They performed the task in three experimental conditions. Participants were required to mentally re-experience and pre-experience four autobiographical episodes (two past and two future) in each condition. The "control" condition was a free viewing condition not involving a concurrent task. In the "hand tapping" condition participants performed the main task while concurrently tapping a square on a board with their right hand. The tapping task was paced by a metronome, which was set on "Largo", at 40 bpm, to equate the speed of the dot moving on the screen in the "eye movement" condition. The participants' hands were covered so that movements were performed without visual processing.

Finally, in the critical "eye movement" condition, the task was performed concurrently with lateral, continuous, and voluntary eye movements. Red fixation and green target stimuli on a white background were presented on a 17 inch CTR monitor (1024 x 768 pixels) at 100 Hz. Participants were seated with their head in a chin rest and their eyes horizontally and vertically aligned with the center of the screen at a distance of 80 cm. Eye movements were recorded with the EyeLink 1000 system (detection algorithm: pupil and corneal reflex, 1000 Hz sampling). A five point horizontal-vertical calibration was run at the start of the experiment. Each trial began with a drift correction and a tone accompanying the onset of a 0.5° red dot presented on the left side of the screen at an eccentricity of 8.5° of visual angle. The experimenter started each trial by pressing the spacebar. As soon as the experimenter started the trial, the dot became green and moved continuously from left to right at a frequency of 0.6 Hz, spanning a total distance of 17° of visual angle. Participants were required to fixate the dot until it was red and then to follow it with their gaze as soon as became green and started moving. The experimenter stopped the trial when a single episode was recounted. Participants were also asked to perform a baseline condition in which they were instructed solely to follow the dot for 60 seconds.

The tapping task was voluntary and exogenously driven to match the fundamental characteristics of the eye movement task, and was introduced to tease apart the disruptive effect of a motor task and the disruptive effect that might be specific for eye movements. Thus, the tapping task was used to ensure that future thinking was not simply disrupted by any additional motor task.

The order of presentation of the three concurrent tasks was fully counterbalanced across the participants.

Results

The performance in the future thinking task, in each condition, is shown in Figure 1. A 3 (Concurrent task: Eye movements vs. Tapping vs. Control) x 2 (Direction of time travel: Past vs. Future) analysis of variance (ANOVA), with all variables as within-subjects factors, was carried out on the mean number of internal details.

The results revealed main effects of both Concurrent task, $F(1, 13) = 13.96$, $MSE = 445.36$, $p < .001$, and Direction of time travel, $F(1, 13) = 14.2$, $MSE = 966.96$, $p < .005$. These indicated that participants generated a greater number of internal details during the control ($M = 27.64$, SD = 13.72) and the hand tapping ($M = 26.76$, SD = 13.99) conditions than in the eye movements condition ($M = 20.33$, SD = 12.72); and that, overall, more internal details were uttered for the past events ($M = 28.3$, SD = 13.94) than for future events ($M = 21.52$, SD = 10).

A significant interaction between Concurrent task and Direction of time travel, $F(1, 13) = 4.78$, $MSE = 195.77$, $p < 0.05$ indicated that a lower number of internal details was produced in future episodes in the eye movements condition ($M = 13.92$, SD = 5.35) than during the hand tapping condition ($M = 25.28$, SD = 12.56), $t(13) = 4.96$, $MSE = 2.28$, $p < .001$, and the control condition ($M = 25.35$, SD = 13.75), $t(13)= 4.24$, $MSE = 2.69$, $p < .005$. No significant differences in the number of internal details were observed between the hand tapping condition and the control condition.

A separate 3 (Concurrent task: Eye movements vs. Tapping vs. Control) x 2 (Direction of time travel: Past vs. Future) ANOVA was conducted on the mean number of external details, and showed a main effect of the Concurrent task, $F(1,13) = 4.12$, $MSE = 25.64$, $p < .05$, and Direction of time travel, $F(1,13) = 6.16$, $MSE = 21.5$, $p < .05$. These indicate that a greater number of external snippets was uttered during the eye movements condition ($M = 3.58$, SD = 4.19), if compared to the tapping ($M = 2.53$, SD =3.25), and the control conditions ($M = 1.67$, SD = 1.61); and that more external details were generated in future ($M = 3.1$, SD = 3.83) than in past episodes ($M = 2.09$, SD = 2.5).

The interaction between Concurrent task and Direction of time travel was also significant, $F(1,13) = 17.53$, $MSE = 44.86$, $p < .001$, indicating that the number of external details generated in future episodes was greater in the eye movement condition ($M = 5.53$, SD = 4.96) than in the control condition ($M = 1.67$, SD = 1.89), $t(13)= 3.2$, $MSE = 1.2$, $p < .01$, and the hand tapping condition ($M = 2.1$, SD = 2.92), $t(13)= 4.13$, $MSE = 3.1$, $p < .005$.

Finally, the subcomponents of internal details (i.e., events, place, time, perceptual details and emotions) were separately analysed. We compared, both in past and future episodes, the number of details for each subcomponent in the three conditions (Eye movements vs. Tapping vs. Control), by means of t-tests. The Bonferroni adjustment was applied, $\alpha = .016$, to correct for multiple comparisons. No differences were found in any of the subcomponents in past episodes. On the contrary, for what concerns future episodes, the following significant differences were found in the components of the events, place, and emotions:

Events: the number of details was significantly lower in the eye movement conditions ($M = 4.03$, SD = 1.64), when compared to the tapping condition ($M = 9.35$, SD = 4.88), $t = 4.29$, $MSE = 1.23$, $p < .005$, and the control condition ($M = 9.25$, SD = 4.68), $t = 4.33$, $MSE = 1.2$, $p < .005$.

Place: the number of details was significantly lower in the eye movement conditions (M = 2.00, SD = 1.00), when compared to the tapping condition (M = 3.21, SD = 1.08), t = 6.04, MSE = 0.2, p < .001, and the control condition (M = 3.6, SD = 1.94), t = 3.82, MSE = 0.41, p < .005.

Emotions: the number of details was significantly lower in the eye movement conditions (M = 1.39, SD = 1.86), when compared to the control condition (M = 2.85, SD = 2.44), t = 4.09, MSE = 0.35, p < .005.

Eye-tracking data can also be useful to interpret our results. In the eye movement condition, we recorded the mean "error" distance (in mm), between the position of a participant's gaze and the position of the dot on the screen. The higher the conflict between eye movements and the main task, the greater this error distance should be. We decided to remove the unique outlier who scored 3 standard deviations above the mean of the group for these analyses. The error distance during future thinking (M_{mm} = 22.87, SD = 14.74) was significantly greater than that observed in the baseline condition (M_{mm} = 10.30, SD = 4.67), $t(12)$= 2.82, MSE = 4.44, p < .05. Similarly, the error distance during episodic memory (M_{mm} = 19.55, SD = 10.6) was significantly greater than that observed in the baseline condition, $t(12)$= 2.95, MSE = 3.12, p < .05. No significant differences were observed between the error distance during episodic memory and future thinking conditions.

Discussion

Event construction plays a pivotal role in remembering the past (Bartlett, 1932; Tulving, 2002). Moreover, the two most influential hypotheses on the cognitive underpinning of episodic future thinking contend that scene construction plays a crucial role also in foresight, although they interpret this role in different ways (Hassabis & Maguire, 2007; Schacter &

Addis, 2007). The "constructive simulation hypothesis" (Schacter & Addis, 2007) contends that foresight relies on episodic memory. To contemplate the infinite array of elaborated simulations of possible upcoming episodes, people need to mentally manipulate, and rearrange the items that unfolded in the past. Thus, according to this theory, the ability to make mental excursions in the future was a driving force in the evolution of the scene construction at the bases of episodic memory (Tulving, 2002). On the other hand, the "scene construction hypothesis" (Hassabis & Maguire, 2007) maintains that the mental scene construction underpins the creation of settings where both past and future events can unfold, and suggests that "real memories are reconstructed along very similar lines to the way imagined events are constructed" (Hassabis, Kumaran, Maguire, 2007, p. 14371).

Our findings stand partly in contrast with the scene construction hypothesis which states that episodic memory and future thinking rely on the same mechanism of scene construction. We suggest that the construction of new future imaginary experiences requires spatial imagery, while the (re)construction of personal past episodes does not, at least not to the same extent.

Despite strong evidence that the two abilities of forecasting and remembering personal past share a number of similarities (Schacter & Addis, 2007; for a review see Irish & Piguet, 2013), it is feasible that constructing a future scene might require crucial components, which are not fundamental in (re)constructing a personal memory. When reconstructing a personal past event we need to look for a unique combination of details. On the contrary, future thinking is more "open-ended and generative" (Suddendorf & Corballis, 2007, p. 302) so that the number of future scenarios that might be envisaged is potentially infinite.

Therefore, future thinking might rely on some components of mental imagery more than on others. For the purpose of teasing apart the different components underpinning scene construction in the two experiences of recalling episodic memories and shaping novel future events, we used a paradigm that disrupted one of these components (spatial) relatively sparing the other one (visual). Our results showed that voluntary eye movements disrupt future thinking, while having no effect on the recollection of past episodic memories. In particular, this effect is selective for the subcomponents of the internal details strictly pertaining to the event, the place, and the emotions; whereas the perceptual and the temporal subcomponents are relatively spared. We were not surprised to observe that the effect of concurrent eye movements was not selectively apparent for the spatial component of future event representations. In fact, events that lack a spatial context have been also found to be less rich (Hassabis, Kumaran, & Maguire, 2007). As to the emotions, we expected a reduced emotional impact of future events imagined during concurrent eye movements (Engelhard et al., 2010).

In parallel with the failure to produce internal details, we observed an inflation of external details, when participants generated future episodes during the eye movement condition. This interesting data mirrors findings reported on heterogeneous populations of patients (Addis, Sacchetti, Allyc, Budson, & Schacter, 2009; de Vito et al., 2012; Gamboz et al., 2010b; Irish et al., 2012). It has been shown that, when a cognitive function that is crucial for future thinking is impaired, people are prone to rely on alternative strategies that help them to enrich their narratives (Addis et al., 2009). Thus, it is probable that, since the generation of future internal details was hindered, participants tended to fill the gap in their recollections, by providing a greater amount of tangential, off-target snippets.

The performance in visually tracking a dot proved similar in future thinking and autobiographical memory task, thus excluding that our findings could be simply due to a trade-off effect. Furthermore, although our sample size is relatively small, the findings clearly reveal a strong effect of eye movements on future thinking.

A number of studies suggested that eye movements during imagery allows to correctly position each part of a scene (e.g., de Vito et al., in press; Postle et al., 2006), while having no effect on the *visual* component of mental imagery. The exact nature of the spatial process that distinguishes the disruption exerted by eye movement seems to rely in the fact that "commands to the eyes for each fixation are stored along with the visual representation and are used as spatial index in a motor-based coordinate system for the proper arrangement of parts of an image (Laeng & Teodorescu, 2002, p. 207). Laeng, Bloem, D'Ascenzio and Tommasi (2014) observed that, when asked to retrieve the image, participants were likely to fixate the same regions of space as those fixated during the perceptual scrutiny of the shape. Johansson and Johansson (2014) also showed that constraining eye movements to a central fixation cross or to an incongruent location (i.e., incongruent with the original location of the to-be-remembered object) more readily affected memory for the spatial arrangement between two objects, than memory concerning the visual orientation of an object. Consequently, concurrent eye movements might selectively interfere with spatial imagery, while sparing visual imagery. These two types of imagery are said to play a different role in autobiographical memory. Visual imagery plays a key role (see for instance Johnson & Raye, 1981). In particular, one component of visual imagery, i.e. long-term visual memory, is fundamental for autobiographical memory (Greenberg & Rubin, 2003). The prevalence of visual imagery in autobiographical memories has long been acknowledged (Brewer, 1988; Galton, 1883). More recently, visual images have been identified as the "main representational format of episodic memories" (Conway, 2009, p. 2308). Indeed, a loss of the ability to generate visual images may determine a retrograde amnesia (e.g., Conway, 2005). On the contrary, spatial deficits do not produce profound global autobiographical amnesia (Barr, Goldberg, Wasserstein, Novelly, 1990). According to Conway (2009), the information contained in the visual images is "configural", i.e., the objects represented in the visual images are already in relation to each other. This preexisting configuration may be sufficient when retrieving an episodic memory, but may not be enough when distinct details are to be collected from distinct memories and recombined together, as in the case of future thinking. In this case, the objects that are contained in a visual image need to be differently configured. We may suggest that, when foreseeing, it is crucial to break down the preexisting relations between the objects present in the autobiographical memories in order to alternatively arrange each parts. Spatial imagery may be very important in serving this dynamic process. Indeed, our results confirm that voluntary eye movements do not hamper the recollection of autobiographical memories. Eye movements might blur the image (Andrade, Kavanagh, Baddeley, 1997), though leaving it still accessible. On the contrary, crucially, we demonstrated that eye movements prevent participants from imagining complex and detailed future scenes. In sum, it has been widely acknowledged that episodic memory is particularly important for the ability of future thinking. It has been also suggested that the images derived from experience serve to provide specific content to more abstract scripts to be projected in the future (Conway, 2009). However, our findings suggest that such specific evidence may not be projected into the future as it is, but rather that it needs to be further processed. To the purpose of imagining novel future events, people need to spatially reorganize the preexistent configuration of mental images of the past. Therefore, whereas episodic memory is dominated by visual imagery, episodic future thinking is likely to be dominated by spatial imagery. This implies that past and future are not constructed in the same manner. Future direction of the present work may unfold into neuropsychological studies aiming at further investigating whether or not patients with an impaired ability of spatial imagery may be still capable to project themselves into novel future scenarios.

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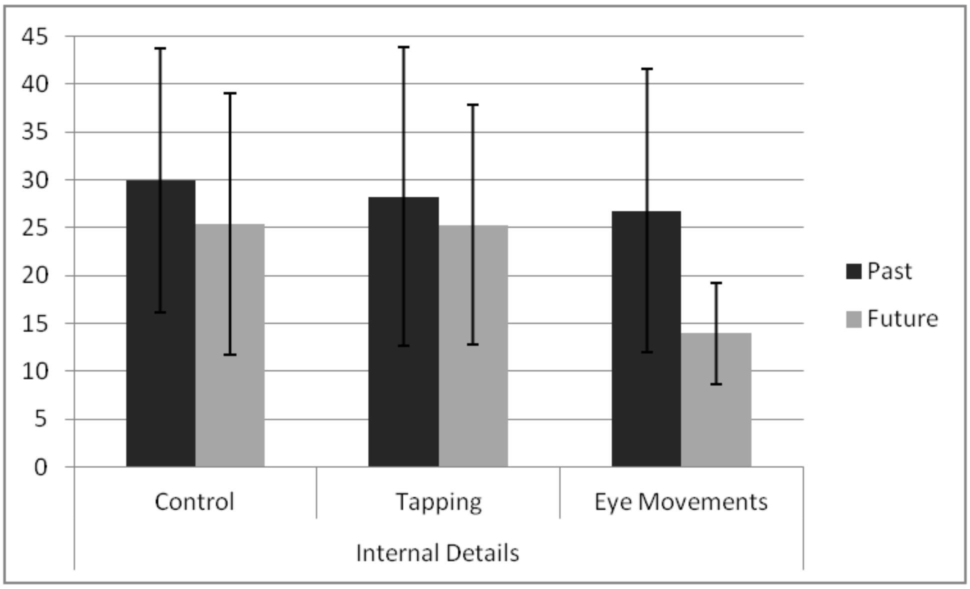
Eye movements disrupt episodic future thinking


45
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Control
Tapping
Eye Movements
Internal Details
Past
Future

Figure 1. Performance (expressed in mean number of internal details produced) on past and future tasks in all the conditions. Error bars show standard error of the mean.