PSYCHOLOGY

A gaze bias in the mind's eye

Can the eye movements we make when there is nothing to look at shed light on our cognitive processes? A new study shows that tiny gaze shifts reveal people's attended locations in memorized—rather than visual—space. The discovery indicates that the oculomotor system is engaged in the focusing of attention within the internal space of memory.

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The human ability for visualization extends far beyond the physical items that surround us. We are able to dismiss the constant influx of photons hitting our retinas and instead picture the layout of our kindergarten classroom, envision the gently swaying palm trees of our dream vacation, or foresee the face of a yet-to-be-born child. As we inspect imaginary objects and people with our mind's eye, our corporeal eyeballs latch onto the fantasy. Research has found that our eyes can move as if seeing, even when there is nothing to look at[1]. Gaze explorations of remembered and imagined visions have been reported in many contexts, including in long-term memory retrieval tasks[2] and, perhaps, even as we chart the dreamscapes of rapid eye-movement (REM) sleep[3]. A new study in *Nature Human Behaviour* by van Ede and colleagues[4] adds a novel important dimension to this prior work by showing that gaze shifts during certain memory-based tasks need not involve revisiting previous gaze locations, but can have much smaller magnitudes, in line with the microsaccade direction biases that occur during covert spatial attention tasks. These findings of van Ede and colleagues indicate that the oculomotor system is engaged in focusing attention within the internal space of memory. This involvement not only predicts observers' performance during memory retrieval, but also leaves traces all the way to their eyes.

Microsaccades—the small, jerk-like eye movements we involuntarily produce during gaze-fixation attempts—have been linked to covert attention, i.e., attention that is localized away from the centre of gaze[5]. Specifically, a growing body of evidence indicates that microsaccade directions tend to be biased towards covertly attended locations, presumably due to the extensive overlap between the saccadic and attentional control neural systems[6]. A central innovation introduced by van Ede and colleagues is that they probed the oculomotor system's contribution to the focusing of attention, not in the spatial

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layout of an actual scene, but within the observers' memorized space.

The team conducted four complementary experiments that characterized the gaze behaviour of human participants during memory retrieval. Each experiment required observers to hold multiple coloured and oriented bars in working memory, and report either the bars' orientation or their colour after a short delay.

In Experiment 1, participants memorized two bars of different colours and orientations, briefly presented to the left and right of a central fixation cross. After a 2- to 2.5-s delay, the central cross changed colour, prompting participants to report the orientation of the colour-matching bar. Of note, this task did not explicitly require participants to remember the locations of the probed items. Yet, a systematic bias emerged, shifting participants' gazes towards the probed items' previously held positions. That is, when a probed item had appeared on the left side of the screen, there was a subsequent leftward gaze bias. Conversely, probed items presented on the right side of the display were followed by rightward gaze biases. These biases were too small in magnitude to signify gaze revisits to the probed items' prior locations, but were consistent with the microsaccade direction shifts that take place when observers attend to covert locations (see ref. [5] for a review). The timing of gaze biases in the present study is in keeping with that of the voluntary deployment of attention[7], suggesting that the oculomotor system is involved in attentional focusing within memorized spatial maps.

Experiment 2 extended these findings by probing a four-item array of coloured and oriented bars, and adding informative or neutral retrocues about the items to be probed. In neutral retrocue trials, gaze biases were comparable to those observed in Experiment 1 (now in both the horizontal and vertical planes). In informative retrocue trials, gaze biases occurred largely after the retrocue, rather than after the presentation of the probe. Larger gaze biases after the retrocue were linked to faster response times and smaller biases to slower responses, implying a functional link between the strength of the bias and its effectiveness to focus attention. The lack of bias after the probe (which now provided only redundant information) indicated that the retrocue had already successfully focused attention on the relevant item, and thus there was no need for subsequent refocusing. In other words, the gaze bias signalled the process of focusing attention, not that of sustaining an established attentional focus, within memory space.

Whereas attentional selection from working memory produced involuntary shifts in gaze, the opposite was not true. In Experiment 3, involuntary gaze-shift manipulations were not sufficient to trigger the facilitation of attention in visual working memory. Finally, Experiment 4 showed that the gaze bias observed while focusing attention in memorized locations (in Experiments 1 and 2) was not restricted to orientation reports, but was also present when participants were tasked with reporting the colour of an oriented bar.

van Ede and colleagues' combined results suggest that microsaccade directions point to covertly attended locations, not only in in visual space but also within the internal space of memory. They also provide new evidence that microsaccadic features can serve as indicators of cognitive engagement, even in the absence of visual stimulation[8].

Some questions remain to be explored in future research. For instance, what are the potential contribution of intersaccadic drifts to the gaze biases found in the current study? Do such gaze biases hold in other kinds of memorized spaces, such as the spatial relationships between objects within locations stored in long-term memory (such as the position of the blackboard with respect to the teacher's desk in our kindergarten classroom)? The use of gaze biases as a diagnostic indicator of memory loss and other cognitive impairments is also an intriguing possibility, particularly in light of recent explorations of altered microsaccade characteristics in neurological disease[9,10].

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References

1. Ferreira, F., Apel, J. & Henderson, J. M. *Trends Cogn. Sci.* **12**, 405–410 (2008).
2. Johansson, R. & Johansson, M. *Psychol. Sci.* **25**, 236–242 (2014).
3. Arnulf, I. *Arch. Ital. Biol.* **149**, 367–382 (2011).
4. Van Ede, F., Chekroud, S.R. & Nobre, A.C. *Nat. Hum. Behav.* https://doi.org/10.1038/s41562-019-0549-y (2019).
5. Martinez-Conde, S., Otero-Millan, J. & Macknik, S. L. *Nat. Rev. Neurosci.* **14**, 83–96 (2013).
6. Corbetta, M. et al. *Neuron* **21**, 761–773 (1998).
7. Müller, M. M., Teder-Sälejärvi, W. & Hillyard, S. A. *Nat. Neurosci.* **1**, 631–634 (1998).
8. Siegenthaler, E. et al. *Eur. J. Neurosci.* **39**, 287–294 (2014).
9. Alexander, R.G., Macknik, S.L. & Martinez-Conde, S. *Front. Neurol.* https://doi.org/10.3389/fneur.2018.00144 (2018).
10. Kapoula, Z. et al. *Age (Dordr.)* **36**, 535–543 (2014).

Competing interests

The authors declare no competing interests.