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Spatial Interference and Individual Differences in Looking at Nothing for Verbal Memory

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Abstract

People tend to look at uninformative, blank locations in space when retrieving information. This gaze behaviour, known as looking at nothing, is assumed to be driven by the use of spatial indices associated with external information. We investigated whether people form spatial indices and look at nothing when retrieving words from memory. Participants were simultaneously presented four words. During retrieval participants looked at the relevant, blank location, where the probe word had appeared previously, longer than the other blank locations. Additionally, word presentation was sometimes followed by a visual cue either co-located or not with the probe word. Valid cues functioned as visual reinforcement while invalid cues caused interference. Finally, participants with better visuospatial memory looked less at the relevant, blank location, suggesting a dynamic relationship between so-called "external" and "internal" memory. Overall findings suggest an automatic, instantaneous spatial indexing mechanism for words and a dynamic looking at nothing behaviour.

Keywords: looking at nothing; spatial indexing; mental representation; visuospatial memory; verbal memory; spatial interference; individual differences

Introduction

The human mind can anchor spatially-located information to external spatial locations. This mechanism has been expressed within a visual processing model, where the *location* of an object is separated from the *visual feature*s of it (Marr, 1982). This view, expanded into an exhaustive *spatial indexing model* (Pylyshyn, 2001), assumes that the visual system is able to individuate spatial relations before discerning a visual pattern and immediately index the locations of such patterns.

Additionally, within the model, spatial indices remain attached to a particular object independent of its movements and visual properties. Spatiotemporal continuity occurs even when the visual information disappears, as often manifested in mental imagery studies (i.e., Brandt & Stark, 1997). Accordingly, spatial indices tied to external visual and verbal information trigger eye movements when a mental representation is reactivated. Thus, when retrieving information from memory, people tend to exploit location-based indices and look at the seemingly uninformative, empty locations where the information originally occurred even if location is irrelevant to the task. This behaviour is known as *looking at nothing* (Ferreira, Apel, & Henderson, 2008).

In their pioneering study, Richardson & Spivey (2000) documented the use of spatial information and looking at nothing in verbal memory. Four faces randomly appeared on different quadrants of a two by two grid along with four corresponding spoken facts (e.g., "Shakespeare's first plays were historical dramas; his last was the Tempest"). On the next screen, a statement (e.g., "Shakespeare's first play was the Tempest") probed participants' memory for verbal information. During recall, there were significantly more looks at the blank quadrant where the face associated with the probed semantic information had been when compared to other quadrants. Thus, people did not just look at any *nothing* when answering the questions. Rather, they looked at an invisible spatial index, which was previously allocated to the information (Spivey & Geng, 2000).

Looking at nothing may be best thought of as an interface between internal and external worlds. Ferreira et al. (2008) proposed an *integrated memory architecture*, where external cues and internal representations work hand in hand to retrieve information as efficiently as possible (see also Richardson, Altmann, Spivey, & Hoover, 2009). More precisely, the integrated memory account combines visual/auditory and spatial information in the external world with visual, linguistic, spatial and conceptual counterparts in the mental world. When part of an integrated representation (linguistic information) is reactivated, the other parts (spatial information) are retrieved as well.

In the current study, we address the looking at nothing triangle, which is composed of (A) actual looking behaviour, (B) spatial indices and (C) mental representations. Unlike any other looking at nothing studies, we used single, visual words as retrieval material instead of visual objects (i.e., Johansson & Johansson, 2014; Martarelli & Mast, 2013; Spivey & Geng, 2000; Vankov, 2009; Wantz, Martarelli, & Mast, 2015) or auditorily presented statements which are explicitly associated with visual objects (i.e., Hoover & Richardson, 2008; Richardson & Kirkham, 2004; Richardson & Spivey, 2000; Scholz, Mehlhorn, & Krems, 2011, 2014). Our main motivation was to reveal automatic and instantaneous spatial indexing and clear-cut looking at nothing behaviour guided specifically by verbal memory in a visuospatial context. Additionally, we focus on two separate but interrelated questions with regard to different vertices of this triangle within the scope of dynamicity of looking at nothing.

Spatial Interference and Spatial Indexing

First, we probe (1) how (in)congruency of interfering spatial cues affects spatial indexing and looking at nothing. A plethora of studies show that the human mind is susceptible to spatial manipulation in tasks even when the location is irrelevant to successful performance. People react faster and perform better when there is spatial compatibility between cue and probe (the Simon effect; Simon & Rudell, 1967). Although there is evidence for a Simon-like effect in spatial indexing (Vankov, 2009), relatively little is known about the role of spatial interference and congruency in looking at nothing.

Understanding spatial interference and congruency is important for defining a spatial encoding mechanism. Looking at nothing has been observed even when the locations associated with the to-be-retrieved information moved and thus updated the spatial indices. Both adults and 6-month-olds were able to track moving events and looked at the updated locations, indicating a flexible and dynamic spatial indexing structure (Richardson & Kirkham, 2004). In light of such evidence, we might argue that if looking at nothing is sensitive to systematic cue manipulation (i.e., Wühr & Ansorge, 2007), that is, to (in)congruencies with the original indices, then the link between a spatial indexing mechanism and looking at nothing might be stronger than previously thought. More precisely, such a directional link might suggest that not only the existence but also the magnitude of looking at nothing is determined by the strength and stability of spatial encoding.

Interfering cues are also important in understanding the interplay between (B) spatial indices and (C) mental representations. If looking at nothing depends on internal operations working with external spatial cues, then spatial codes which are updated with interference should lead to less looking at nothing. This is predicted based on the assumption that, in such as a case, space becomes unreliable: i.e., there is competition between the mental representations corresponding to the spatial indices for words and for cues, respectively. In contrast, a valid spatial code should strengthen the association between mental representations corresponding to the word and to its location, which, in turn, should be reflected in looking behaviour. While stability of spatial indexing across time has been shown (Martarelli & Mast, 2013; Wantz et al., 2015), spatial stability and the role of interference in looking at nothing still remain largely unknown.

Integrated Memory and Individual Differences

Additionally, we investigate the relationship between (A) looking at nothing and (C) mental representations by asking (2) whether there are individual differences in looking at nothing behaviour based on "internal" visuospatial memory. We hypothesize that the cognitive system uses both internal and external cues to access memory traces. Therefore, external cues may be used to relieve internal operations, and people with relatively worse visuospatial memory should rely more on looking at nothing behaviour (and vice versa). Determining the existence or absence of a correlation between individual visuospatial memory differences and memory-driven eye movements is essential to understanding the intrinsic nature of looking at nothing and its relation with mental representations. If a correlation is found, it will provide further evidence for the integrated memory account (Ferreira, et al., 2008). There is already growing evidence that looking at nothing changes according to internal demands. For example, people tend to exhibit less looking at nothing as they are asked to study and recall the same sentences over and over again, suggesting less reliance on external cues as the task becomes easier through repetition (Scholz et al., 2011). However, not much is known about how differences in internal memory map onto differences in looking at nothing behaviour within the scope of integrated memory operations.

Our experimental paradigm diverges from the previous looking at nothing studies in the following ways: (1) Single words were used instead of visual objects as information to be retrieved. Looking at nothing is fundamentally a visuospatial phenomenon. However, what makes the words recognizable visually is both controllable and not usually related to vision (Harm & Seidenberg, 2004). Thus, we aimed to disentangle the retrieval items from the visual environment to be able to observe more refined behaviour. We also aimed to systematically manipulate and control the stimuli and rule out any item-related effect on the memory load and thus, looking at nothing. Accordingly, words were controlled for a number of memory-related variables. (2) Participants were exposed to retrospective memory interference which was irrelevant to the main task. We expected to push out old information (i.e., encoded words) from the episodic buffer (Baddeley, 2000) and encourage participants to depend on spatial indices for the retrieval of words. (3) Words to be retrieved were presented simultaneously and were not explicitly associated with any kind of visual object. Rather, participants processed the words together and were expected to form immediate indices based on the word location. This is how verbal information is processed in real-world cognitive tasks such as reading (see Fischer, 1999), thus making the task more naturalistic. We aimed to unearth more ecologically valid, systematic and robust looking at nothing behaviour.

Method

Participants

The experiment was carried out with forty-eight students at the University of Birmingham (six males; $M_{\text{age}} = 19.92$, $SD = 1.96$, range: 18 – 27, four left-handed). All participants were monolingual native speakers of British English as determined with the Language History Questionnaire (version 2.0; Li, Zhang, Tsai, & Puls, 2013). Participants reported normal or corrected-to-normal vision, no speech or hearing difficulties and no history of any neurological disorder. They received either £6 ($n = 12$) or course credit ($n = 36$) for participation. All participants were fully informed about the details of the experimental procedure and gave written consent. Post-experiment debriefing revealed that all participants were naïve to the purpose of the experiment.

Materials

There were 192 trials involving 864 unique nouns in total. Trials were evenly divided into two groups (n = 96) as experimental (positive probe) trials and fillers. Probe words in the experimental trials were among the four study words in the encoding phase, whereas a different, not seen, word was probed in fillers. Words in the experimental trials (n = 384) were drawn from the extensions of Paivio, Yuille and Madigan norms for 925 nouns (Clark & Paivio, 2004). The word pool was filtered to exclude words shorter than 3 letters and longer than 6 letters. Imageability, frequency (logarithmic values of occurrences per million in Kučera & Francis, 1967; and the CELEX database, Baayen, Piepenbrock, & Gulikers, 1995), age of acquisition, concreteness, availability (Keenan & Benjafield, 1994), length in letters and number of syllables were identified as major predictors of verbal memory (Rubin & Friendly, 1986) and used to control the experimental stimuli.

The subset was then grouped into quadruples and trial sets were identified. Words within quadruples were matched on age of acquisition, availability, concreteness, imageability, length in letters, log frequency and number of syllables (all *SD*s < 2.00 and all *SE*s < 1.00). Words were further controlled so that no word started with the same letter, rhymed or related semantically with any other in the quadruple. Monosyllabic, disyllabic and trisyllabic words were evenly distributed [e.g., (3, 3, 3, 3), (1, 2, 1, 2) or (3, 2, 3, 2) etc.]. The word in each trial set with the median imageability value was selected as the probe among four words leaving the others as distractors (see Rubin & Friendly). Welch's t-tests revealed no significant difference between the probe and distractor words in any of the variables (all ps > .05). Thus, any word among the four words in each trial set was as likely to be remembered as any other word. Words in filler trials were drawn from the Toronto Word Pool (Friendly, Franklin, Hoffman, & Rubin, 1982). They were also controlled to develop a consistent stimuli set. Words were grouped into quintuples and matched on log frequency in CELEX database (all *SD*s < 0.60 and all *SE*s < 0.30). Welch's t-tests revealed that there was no significant difference between the probe and the study words in frequency, length in letters or number of syllables (all ps > .05).

We formed 192 unique mathematical equations (e.g., (5X2) – (1+8) = 1) to present as memory interference between encoding and retrieval phases (see Conway & Engle, 1996 for a similar design). Half of the equations were correct. Incorrect equations were further divided into two equal groups: The results were either plus or minus one of the correct result.

Apparatus

Stimuli were presented on a TFT LCD 22-inch widescreen monitor operating at 60 Hz with a resolution of 1680 x 1050 pixels (501.7 mm x 337.4 mm). The monitor was placed 640 mm in front of the participant. A chin and forehead rest was used to reduce head movements. Participants' eye movements were monitored using SR EyeLink® 1000 (sampling rate: 1000 Hz, spatial resolution < 0.5°, http://sr-research.com/eyelink1000.html). Viewing was binocular but only the left eye was monitored. Auditory material was produced by a native female speaker of British English in a sound attenuated room and recorded using Audacity (version 2.1.10, http://web.audacityteam.org). Participants responded (yes/no they had seen the word) by pressing one of two keys on a standard keyboard. Eye movement data were analysed using the SR EyeLink® Data Viewer (version 2.4.0.198, http://www.sr-research.com/accessories_EL1000_dv.html). No drift or blink correction procedure was applied. Data were analysed and visualised with R (version 3.2.3) (R Core Team, 2015).

Procedure

A pre-experiment questionnaire involving Language History Questionnaire and Edinburgh Handedness Inventory (Oldfield, 1971) was administered.

Eye tracking started with a standard nine-point calibration and validation, which confirmed high data quality (average calibration error < 1° and maximum calibration error < 1.50°). The experiment was composed of five consecutive phases. **Fixation**: A fixation cross appeared at the centre of the screen for 500 ms. **Encoding**: Participants were presented four words on a 2 x 2 grid for 1600 ms. Words (Times New Roman, font size = 40) were centrally placed in rectangular boxes (285 x 85 in pixels, 7.6° x 2.4° of visual angle). **Cueing**: A flashing black dot appeared in cue trials for 1000 ms either in the same (valid cue) or in the diagonal quadrant (invalid cue) as the original location of the probe word in the encoding phase. There was also a third condition where no cue was presented between encoding and interference. The cue manipulation was a between-subjects variable. An equal number of random participants (n = 16) saw the probe word with valid cue, invalid cue or without any cue. **Interference**: Participants were presented a mathematical equation and asked to identify whether the equation was correct or not within 10,000 ms. **Retrieval**: The probe word was auditorily presented as participants looked at the blank grid with empty boxes. Participants were asked to make an unspeeded yes/no judgement to determine whether they had seen the probe word among the four words shown in the encoding phase within 10,000 ms (or they timed-out).

The order of trials and equations were fully randomised. The location of all words in all conditions was counterbalanced with Latin Square design to control gaze biases so that each word appeared an equal number of times in each location of the grid. The experiment was divided into four equal blocks and there was a short pause between blocks. A typical session lasted approximately 60 minutes. Overall accuracy in interference equations was 81.19% and 86.07% in the verbal recognition test, suggesting that participants were attending to the task.

Following the experiment, a computerized version of the Corsi block-tapping task (Milner, 1969) operated on PEBL (Psychology Experiment Building Language, version 0.13, test battery version 0.7, http://pebl.org) (Mueller & Piper, 2014) was used to measure visuospatial short-term memory.

Results

Dwell time percentage (i.e., percentage of total time - in milliseconds - spent on a specific interest area) was used as the main gaze measure and dependent variable because it is immune to differences in task duration. Accordingly, four rectangular interest areas corresponding to the quadrants were identified. All interest areas were of the same size (502 x 368 in pixels, 13.4° x 10.6° of visual angle). They framed the rectangular boxes and were not contiguous. A circular interest area with a diameter of 40 pixels (1.1° of visual angle) was also defined at the centre of the grid. Dwell time percentages accrued on the interest areas during the retrieval phase (from the presentation of the probe word until the participant's response) were calculated. Fixations were a minimum duration of 40 ms. Fixations outside the interest areas (6.54%) were omitted.

Looking at Nothing with Spatial Interference

We began by investigating whether there was a difference between spontaneous looking times across quadrants and cue conditions during the retrieval phase. Dwell time percentages allocated to three irrelevant quadrants were averaged into one irrelevant quadrant and analysed against the relevant quadrant across the three different cue conditions. A mixed analysis of variance showed a main effect of quadrant $F1(1, 141) = 14.40, p < .001; \eta_p^2 = .09$; $F2(1, 573) = 15.85, p < .001, \eta_p^2 = .03$ and an interaction effect of cue condition $F1(2, 141) = 3.60, p = .03, \eta_p^2 = .05$; $F2(2, 573) = 2.89, p = .06, \eta_p^2 = .01$. Paired t-tests revealed that participants looked significantly longer at the relevant quadrant than the average of three irrelevant quadrants when retrieving the probe word in all conditions together and in the valid cue condition (see Table 1).

Table 1: Differences between dwell time percentages of relevant and irrelevant quadrants under different cue conditions (*df* = 47).

Condition	Relevant	Irrelevant	*t*	*p*	*d*
Valid	0.22	0.17	3.66	.00	0.6
Invalid	0.19	0.19	0.64	.53	0.1
No Cue	0.19	0.17	1.93	.06	0.3

Participants did not look at the relevant quadrant significantly longer in the invalid cue condition. Therefore, dwell time percentages in the invalid cue condition were further analysed to understand the impact of the invalid cue. A repeated measures analysis of variance showed that there was not a significant difference between dwell time percentages across cue quadrant (i.e., where the cue was presented in the cueing phase) ($M = 0.20$, $SD = 0.08$), relevant quadrant ($M = 0.19$, $SD = 0.08$) and irrelevant quadrant ($M = 0.18$, $SD = 0.06$) $F1(2, 94) = 1.33, p = .27$; $F2(2, 382) = 1.95, p = .15$.

Dwell time percentage spent on the relevant, blank quadrant decreased significantly across blocks $F(3, 141) = 4.33, p = .006, \eta_p^2 = .08$.

Individual Differences in Looking at Nothing

We investigated whether looking at nothing behaviour changes according to the visuospatial memory differences of participants. Overall, there was a significant, positive correlation between dwell time percentage spent on the central interest area and visuospatial memory measured with Corsi block-tapping test r_s (46) = .34, $p = .02$ such that participants with better visuospatial memory tended to look more at the centre of the screen and did not look at "nothing" (i.e., relevant, blank quadrant) by definition. An additional variable, *looking at nothing strength*, was formulated by simply subtracting dwell time percentage spent on the central interest area from dwell time percentage spent on the relevant quadrant. As expected, there was also a significant, negative correlation between looking at nothing strength and visuospatial memory r_s (46) = - .29, $p = .04$ (see Figure 1).

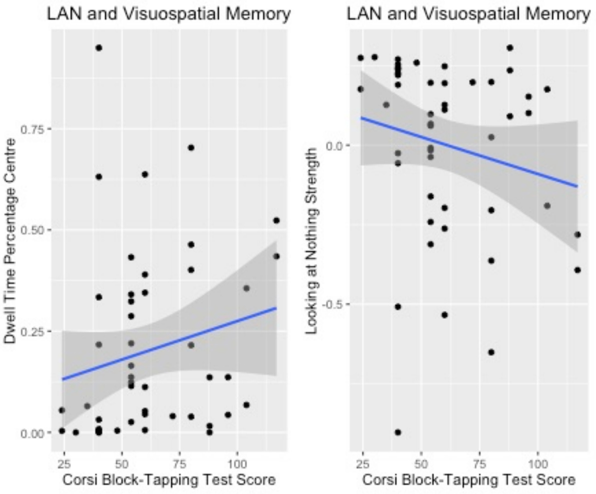

Figure 1: Scatterplots showing the correlations between looking at nothing and visuospatial memory.

To analyse the effect of the interfering cue on the correlation between looking at nothing and visuospatial memory, participants were divided into two equal groups: (1) good (memory score, $M = 79.08$ $SD = 19.54$) and (2) poor (memory score, $M = 43.04$ $SD = 9.43$) visuospatial memory. Welch's t-tests showed that participants with better visuospatial memory looked significantly less at the relevant, blank quadrant when retrieving the probe word during the invalid cue condition compared to participants with poor visuospatial memory (Good $M = 0.17$, $SD = 0.07$, Poor $M = 0.22$, $SD = 0.07$) $t(45.95) = 2.49, p = .02, d = 0.7$ but not in valid or no cue condition (*p*s > .05). The effect of invalid cue was confirmed with Spearman correlations. As found in all conditions together, there was a significant, positive correlation between dwell time percentage spent on the central interest area and visuospatial memory r_s (46) = .33, $p = .02$ and also a significant, negative correlation between looking at nothing strength and visuospatial memory r_s (46) = - .35, $p = .01$ in invalid cue condition.

Discussion

In the present study, we investigated the spatial indexing and looking at nothing processes with (in)congruent spatial cues for simultaneously presented single words in a recognition memory test, and whether visuospatial memory differences between participants correlate with looking at nothing behaviour. Participants instantly formed spatial indices corresponding to simultaneously presented words even though the locational information was unnecessary for the successful completion of the task. They also looked at relevant, blank locations significantly longer than the other, irrelevant blank locations when they were asked to retrieve the probe word.

We replicated a looking at nothing effect with marginal significance in a "pure" looking at nothing condition where no cue was presented. Given that the presented words were not explicitly associated with visual cues in our experiment, results might be interpreted as further evidence for the automaticity and availability of spatial indices (Vankov, 2009), which, guide eye movements to empty locations. Along with that, the novelty of the present research lies in the use of words instead of visual objects. The fact that participants used the visuospatial channel to access verbal memory traces suggests that looking at nothing is a distinctive, memory-oriented behaviour and might be even more robust than previously documented. One might argue that the looking at nothing effect in this study can be accounted for by an attentional mechanism initiated by the interfering cues. However, participants also looked at the relevant, blank quadrant without any cue in the pure looking at nothing condition with a marginally significant difference and a small effect size. Further, they did not look at the previous location of the cue longer than the other quadrants in the invalid cue condition. Therefore, we conclude that spatial indices formed for single words can reliably orient eye movements to blank locations in a recognition memory task.

Results from the cue manipulation confirmed our hypothesis in general and resulted in a Simon-like effect (Wühr & Ansorge, 2007). As expected, participants formed spatial indices for cues. When the spatial index corresponding to the probe word and the index corresponding to the cue matched (as in the valid cue condition), the looking at nothing effect was amplified. However, when these indices were in competition (as in the invalid cue condition), the initial index was updated and eye movements to the relevant, blank location were disrupted. Taken together, cue manipulation results demonstrate that the link between spatial indexing and looking at nothing is indeed dynamic and systematic. Similarly, we observed a decrease in looking at nothing towards the end of the experiment, which was in favour of the previous findings (Scholz et al., 2011) with the exception that participants in our study studied different items throughout the experiment. One explanation could be that as the participants gradually became accustomed to the task, mental load decreased and so did the necessity to draw information from space.

The relation between mental load and reliance on space was also reflected in individual differences results. To our knowledge, this is the first evidence showing individual differences when looking at nothing. Participants with better visuospatial memory, thus richer internal sources, relied less on the spatial indices and consequently looking at nothing. The tendency of looking at the centre was revealed among these participants probably because they were faster in general and did not have the necessity to refer to any blank quadrants including the relevant one. Although the correlations were either weak or moderate, this alone might be regarded as clear evidence for the integrated memory model, where external (space) and internal (mental representations) elements of memory work together (see Jackendoff, 1996). More importantly, differences were mostly pronounced in the invalid cue condition. Thus, in the event of spatial interference and confusion, participants with better visuospatial memory seemed to disengage from the space by ignoring any deictic code either attached to words or cues, and turned to internal sources. This is particularly important considering that, looking at the centre was not a general trend among all participants in invalid cue condition. The correlation might also suggest that looking at nothing is not a by-product but a functional (Johansson & Johansson, 2014; Scholz et al., 2014) and even a strategic behaviour which systematically changes not only with the processing demands of the task but also from individual to individual. In a nutshell, our results suggest that there is a balanced trade-off between internal and external sources driven by task conditions in order to make the most of environmental opportunities and cognitive capacity.

Looking at nothing is a unique case in that it demonstrates how the cognitive system can maximize efficiency by spreading the cognitive problem across three domains with the act of looking, the environment with the spatial indices and mental representations in the brain. Further, looking at nothing in this study can be regarded as an example of very efficient multimodal coordination given that participants studied verbal information and made use of the visuospatial canvas when auditorily probed. In this regard, the study is expected to have broader implications towards a new and unorthodox understanding of cognition.

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