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# “Looking-at-nothing” during sequential sensorimotor actions: Long-term memory-based eye scanning of remembered target locations

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ABSTRACT

Before acting humans saccade to a target object to extract relevant visual information. Even when acting on remembered objects, locations previously occupied by relevant objects are fixated during imagery and memory tasks – a phenomenon called “looking-at-nothing”. While looking-at-nothing was robustly found in tasks encouraging declarative memory built-up, results are mixed in the case of procedural sensorimotor tasks. Eye-guidance to manual targets in complete darkness was observed in a task practiced for days beforehand, while investigations using only a single session did not find fixations to remembered action targets. Here, it is asked whether looking-at-nothing can be found in a single sensorimotor session and thus independent from sleep consolidation, and how it progresses when visual information is repeatedly unavailable. Eye movements were investigated in a computerized version of the trail making test. Participants clicked on numbered circles in ascending sequence. Fifty trials were performed with the same spatial arrangement of 9 visual targets to enable long-term memory consolidation. During 50 consecutive trials, participants had to click the remembered target sequence on an empty screen. Participants scanned the visual targets and also the empty target locations sequentially with their eyes, however, the latter less precise than the former. Over the course of the memory trials, manual and oculomotor sequential target scanning became more similar to the visual trials. Results argue for robust looking-at-nothing during procedural sensorimotor tasks provided that long-term memory information is sufficient.

## 1. Introduction

When interacting with our environment, we use our eyes to extract task-relevant sensory visual information of target objects. However, the eyes are sometimes shifted to remembered targets, although visual information is not available – a phenomenon called looking-at-nothing (Ferreira, Apel, & Henderson, 2008; Johansson, Holsanova, Dewhurst, & Holmqvist, 2011; Richardson, Altmann, Spivey, & Hoover, 2009; Richardson & Spivey, 2000). Looking-at-nothing refers to the behavior of saccading to empty locations, e.g., on a screen or behind an occluder where task-related material had been available or is expected to be. This behavior is robustly observed during visual imagery and memory-recall tasks (Brandt & Stark, 1997; Johansson, Holsanova, & Holmqvist, 2005; Johansson, Holsanova, & Holmqvist, 2006; Johansson & Johansson, 2013; Johansson et al., 2011; Laeng & Teodorescu, 2002; Mast & Kosslyn, 2002; Noton & Stark, 1971a, 1971b; Spivey & Geng, 2001). It has been hypothesized that saccading to locations that have previously been occupied by to-be-remembered material might facilitate memory encoding and recall (Johansson & Johansson, 2013; Johansson et al., 2011; Laeng & Teodorescu, 2002). As a covert shift of attention obligatorily precedes every gaze shift (Deubel & Schneider, 1996), the facilitated recall might be grounded on attention allocation to the location previously occupied by the to-be-recalled object. In any case, the phenomenon of looking-at-nothing proves that humans can use memory information to direct their gaze to task-relevant locations in space.

Imagery and memory-recall tasks encourage explicit or declarative memory encoding, because memory retrieval is explicitly required to solve the task. Therefore, the question arises whether the phenomenon of looking-at-nothing can also be found in tasks that are dominated by implicit procedural memory such as sensorimotor tasks. Fixations to action-target locations in the absence of visual information were indeed found in a well-practiced cup-stacking task (Foerster, Carbone, Koesling, & Schneider, 2012). Participants performed the 14-days trained cup-stacking sequence (speed stacking or sport stacking, see also Foerster, Carbone, Koesling, & Schneider, 2011) first with normal

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lighting and afterwards in complete darkness, while gaze was recorded. Even without any visual information, participants saccaded to upcoming hand-target locations slightly before the hands reached the locations. The eye-hand dynamics as well as the sequence of fixated locations, the scanpath, were highly similar between light and dark condition. The results argue that procedural long-term memory (LTM) can indeed be used to direct attention and gaze to target locations when visual information is not available.

Contrastingly, Flanagan, Terao, and Johansson (2008) found only a loose relationship between eye and hand movements across visual conditions in two sensorimotor tasks. In one experiment, participants pointed to visual versus remembered targets. In another experiment, participants manipulated visual objects or manipulated objects behind a shutter in complete darkness. Both tasks were not practiced beforehand. Pointing target locations were randomly chosen prior to each trial and participants reacted to a specific configuration only once before they had to point from memory, both times in a self-regulated sequence. Similarly, each object-manipulation sequence was repeated only four times with visual information before participants had to act from memory. Thus, procedural memory might have been too fragile to trigger looking-at-nothing in these single-session investigations in which the required motor actions were not practiced much. As it is known that especially procedural learning strongly benefits from sleep consolidation (Stickgold, 2005; Walker, Brakefield, Morgan, Hobson, & Stickgold, 2002), it is also possible that looking-at-nothing during sensorimotor procedures occurs robustly only after sleep consolidation. Not only manual but also the corresponding oculomotor trajectory might have been sufficiently consolidated for looking-at-nothing behavior to occur only in multiple day investigations.

Here, it is investigated whether looking-at-nothing can robustly be found in a sensorimotor task within a single session, i.e., without intermittent sleep consolidation of the sensorimotor procedure. Crucially, participants started with a longer series of trials with visual information available, allowing to building up procedural memory of a sufficient strength. Afterwards, gaze behavior was investigated over an equally long series of trials without visual information available. Thereby, it can be revealed how robustly participants scan remembered action-target locations with their eyes from LTM when short-term memory has already faded. In this case, looking-at-nothing might be abandoned, modified or intensified provided that action-completion feedback is still available.

Eye movements were recorded while participants performed a computerized version of the number connection test or trail making test A (Army Individual Test Battery., 1944; Foerster & Schneider, 2015; Reitan, 1958). In this sequential sensorimotor task, participants had to click as fast as possible on numbered circles in ascending order (here 1–9). Visual and procedural LTM encoding was enabled by a 50-trials visual action phase with the same spatial arrangement of nine visual targets. In a consecutive 50-trials memory-based action phase, participants were asked to click at the remembered locations on a blank screen in the same sequence as during the visual phase. Auditory feedback signaled clicking success throughout the experiment. Scanpath analyses were performed to reveal how precisely participants scanned the visual and remembered target locations in sequence over the course of the visual and memory-based action phases.

## 2. Methods

### 2.1. Participants

Eleven right-handed students (4 male and 7 female) from Bielefeld University, Germany, participated in the experiment. Participants' mean age was 25 years. All participants had either normal or corrected-to-normal visual acuity. All were naïve with respect to the purpose of the study, gave informed consent, and were paid for their participation. The study was conducted in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

### 2.2. Apparatus and stimuli

The experiment was controlled by the Experiment Builder software (SR Research, Ontario, Canada) on a Dell Optiplex 755 computer. The stimuli were displayed on a 19-in. CRT monitor (ViewSonic Graphics Series G90fB) with a refresh rate of 100 Hz and a resolution of 1024 × 768 pixels controlled by an ATI Radeon HD 2400 Pro graphics card. The computer mouse and keyboard as well as an extra-large mouse pad (88 × 32 cm) were used. Each participant's right gaze position was recorded by an EyeLink 1000 tower system (SR Research). The eye tracker's sampling rate was 1000 Hz, and participants' viewing distance was fixed at 71 cm with a chin and forehead rest throughout the experiment. The cursor position was recorded with the monitor's sampling rate of 100 Hz. Color and luminance were measured at the screen center in CIE Lxy coordinates using an X-Rite i1 Pro spectrophotometer.

All stimuli were black ($L = 0.3\ cd/m^2$, $x = 0.32$, $y = 0.33$) and displayed on a gray background ($L = 78.9\ cd/m^2$, $x = 0.29$, $y = 0.30$). The mouse cursor was an upwards pointing arrow of approximately 0.68 degrees of visual angle (°v.a.) width and 1.69°v.a. height. The target stimuli consisted of 9 numbers (Arial, font style bold, font size 35), each surrounded by an unfilled circle (2.04°v.a. diameter, line width 6). The first circle was located in the center of the screen. The spatial distribution of the other 8 circles was randomly generated with the prerequisite that each outer field of an imagined 3 by 3 grid contained one circle and circles had a minimal distance of 2.04°v.a. to each other (from border to border) as well as to the screen border. The minimal distance between the nearest two circles 5 and 7 happened to be 5.93°v.a. in the generated display (from center to center). The same spatial configuration was used throughout the entire experiment (Fig. 1).

### 2.3. Procedure

The experiment was divided into a first visual action phase with numbered circles on the screen and a consecutive memory-based action phase with a blank screen. Each phase started with a written instruction on the screen followed by a 9-point calibration and validation procedure. Only calibrations with averaged validation accuracy below 1.0°v.a. were accepted. In the visual phase, participants had to click as fast as possible in ascending order on the 9 numbered circles presented on the screen (Fig. 1, top). Participants were informed that the configuration of target stimuli stayed the same throughout the whole experiment. An example trial preceded the visual phase. In the subsequent memory phase, only the mouse cursor was displayed on the grey background (Fig. 1, bottom), and participants were instructed to click as fast as possible on the locations that were previously occupied by the numbered circles in the same sequence as before. A click was counted as correct, if the mouse cursor was within a diameter of 3.06°v.a. around the current target's center. A correct click was followed by a high-pitched tone. An incorrect click was followed by a low-pitched tone. After all 9 circles were clicked on in the right order trial completion time was displayed on the screen. Each trial was preceded by a central fixation on a black ring (.45°v.a. outer size and .11°v.a. inner size). The visual phase as well as the consecutive memory phase consisted of 5 blocks à 10 trials, adding up to 100 trials in total. A block information display separated each block. Participants could start each block and trial by pressing the space bar. Participants were allowed to take self-paced breaks in-between blocks and trials. All participants completed the experiment within 40 min. The participant with the fastest time in each phase earned 6 € extra.