Three unpublished, publicly available visual search datasets with 151 participants

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Abstract

We provide three novel visual search datasets which have not been published before. Datasets 1 and 2 were collected in the lab with 1000Hz gaze data from an EyeLink 1000. Dataset 1 contains N=20 participants. Dataset 2 consists of two experiments with N=16 and N=15 participants, respectively. Dataset 3 was collected at a popular science festival, and contains mouse-movement data of N=100 participants.

1 Background

Visual search is one of the most common tasks that we perform throughout the day. Frequently, we search for groceries in an aisle, for a jigsaw puzzle piece, or for a screw while assembling furniture. In order to find an object (e.g., a specific screw), we must actively keep a search template in visual working memory (VWM), and then search for it amongst other items. In traditional search paradigms, templates have to be maintained in VWM throughout search, after transient and singular presentation (Bahle et al., 2018; Olivers et al., 2006; Olivers & Eimer, 2011;

Wolfe, 2021). After the offset of the templates, participants are presented with a search array and have to indicate whether a target was present.

However, in daily life, search templates often remain available for reinspection while we perform our tasks. For example, when assembling IKEA furniture, we can repeatedly sample information from the instruction manual which contains images of the required screws, boards, etc. Sampling from the manual can thus be used to memorize and search one item at a time (instead of all at once) and to boost existing memory representations. In Hoogerbrugge et al. (2023), we therefore introduced a novel paradigm in which templates could be reinspected throughout trials, and compared participants' behaviour to the classical approach in which templates could only be inspected once. When templates remained available for inspection, participants frequently resampled information from the template area – more so when search was difficult.

The findings in Hoogerbrugge et al. (2023) extended an existing line of research, namely that of a trade-off between storing internally in VWM versus using the outside world as an external store of information (O'Regan, 1992; Van der Stigchel, 2020). Humans prefer to offload 'effortful' processing and maintenance in memory as much as possible, and rather prefer to use the external world to store information. More specifically, external information is only memorized *if* and *when* it is needed for the task at hand, instead of being processed (and memorized) in advance (Droll & Hayhoe, 2007; Hayhoe et al., 2003). However, influencing the costs associated with sampling external information (e.g., saccade distance, time required, consequences of errors, etc.) can tip the scales of this trade-off towards decreased or increased reliance on memory (Ballard et al., 1995; Böing et al., 2023; Draschkow et al., 2021; Droll & Hayhoe, 2007; Gajewski & Henderson, 2005; Gray et al., 2006; Hayhoe et al., 2003; Hoogerbrugge et al., 2024; Inamdar & Pomplun, 2003; Koevoet et al., 2023; Melnik et al., 2018; Risko & Dunn, 2015; Risko & Gilbert, 2016; Sahakian et al., 2023, 2024; Somai et al., 2020; Triesch et al., 2003).

In the datasets presented here, we extended the paradigm from (Hoogerbrugge et al., 2023) and asked:

- **Dataset 1:** Does the preference for offloading memory change when external information is less reliable?
- **Dataset 2:** Do delay and distance manipulations replicate in our visual search paradigm?
- **Dataset 3:** Is there an optimal strategy for searching as fast as possible when templates can be resampled?

Our datasets did not warrant standalone publications, but we hope that they may be of use to the wider research community. For each dataset, we provide the experiment code along with raw data. Analysis code along with intermediate results and outcome files may also be provided.

2 Dataset 1: Scrambled template locations

Dataset 1 may be retrieved via the Open Science Framework https://osf.io/yuqxn/.

2.1 Goals

This dataset was collected to test whether external sampling behaviour changed when template locations were scrambled before each inspection, compared to when templates were stable. We found no difference in the number of inspections between conditions, although dwell times did differ. Likely, participants had to reorient after each crossing towards the templates, causing longer dwell times – but inspection frequency did not change.

2.2 Participants and procedure

20 participants (17 female, M_{age} = 21.2) with normal vision and no colourblindness performed the experiment. Prior to the experiment, participants read the

information letter, signed an informed consent form, and indicated their age and gender. Participants received €7 per hour or course credits. The experiment took approximately 75 minutes. The study was approved by the Faculty Ethics Review Board of Utrecht University (protocol number 21-0297).

2.3 Apparatus

Monocular gaze location was recorded with an EyeLink 1000+, at 1kHz. Stimuli were presented on a 27" 2560×1440 LCD monitor at 100Hz. Participants were seated and stabilized with a chin- and forehead rest at 67.5 cm from the monitor. The experiment was implemented with PyGaze (Dalmaijer et al., 2014).

All gaze metrics are reported in degrees of visual angle (°). Before the start of the experiment, and between each block, the eye tracker was calibrated and validated with a 9-dot grid, allowing a mean error of 0.5° and a maximum per-dot error of 1.0°. The quality of calibration was automatically evaluated throughout the experiment while each pre-trial fixation cross was presented. If the gaze prediction error exceeded 1.5° for more than two consecutive trials, the eye tracker was re-calibrated.

2.4 Stimuli

Stimuli were a subset of complex shapes (introduced by Arnoult, 1956), which are commonly used in VWM research (e.g., Hoogerbrugge et al., 2023; Sahakian et al., 2023; Somai et al., 2020). The stimuli could be shown in four configurations (90° rotations) and in 8 colours, equally spaced along a perceptually uniform colour map (HSLuv). One of the original 30 stimuli was removed due to its high rotational symmetry, resulting in 928 unique stimuli. Stimuli were circa 1.5° in size.

2.5 Task and design

Participants performed a visual search task, in which the screen was divided into two sections by a vertical line; a smaller template area on the left and a larger search area on the right (Figure 1). The template area occupied the leftmost quarter (12.7°) of the screen and contained either 2 or 4 equally spaced templates. Templates would only be shown when gaze was detected in the template area, such that participants could not peripherally attend templates and search items simultaneously.

The search area occupied the rightmost three-quarters (36.8°) of the screen and contained either one target (matching exactly one of the templates) and 15 distractors in target-present trials, or 16 distractors in target-absent trials. Distractors were randomly picked and could therefore be presented multiple times within the search array. 75% of trials were target-present trials. Before the start of each trial, a central fixation cross was shown, and the trial would only start if a fixation was detected at that location. Participants memorized the template(s) in the template area, and searched for them in the search area; indicating for each trial whether one of the stimuli in the search area matched a template (by pressing the 'z'-key) or not ('/'-key). After each trial they received feedback, with the screen showing either 'Correct' or 'Incorrect' in blue or red text, respectively.

Participants could reinspect templates as often as they wished throughout the trial, but we manipulated the stability of template positions. In the *stable* conditions, templates would remain in the same place throughout a trial. In the *scramble* conditions, the order of templates was randomly shuffled before each inspection of the template area. This means that the locations in which templates could appear remained the same, but what was previously the top-most template could now become the bottom-most template, and so on. Thus, there were four conditions: 2-Stable, 2-Scramble, 4-Stable, and 4-Scramble. Conditions consisted of 60 trials, which were blocked, and block order was counterbalanced according to a Latin square.

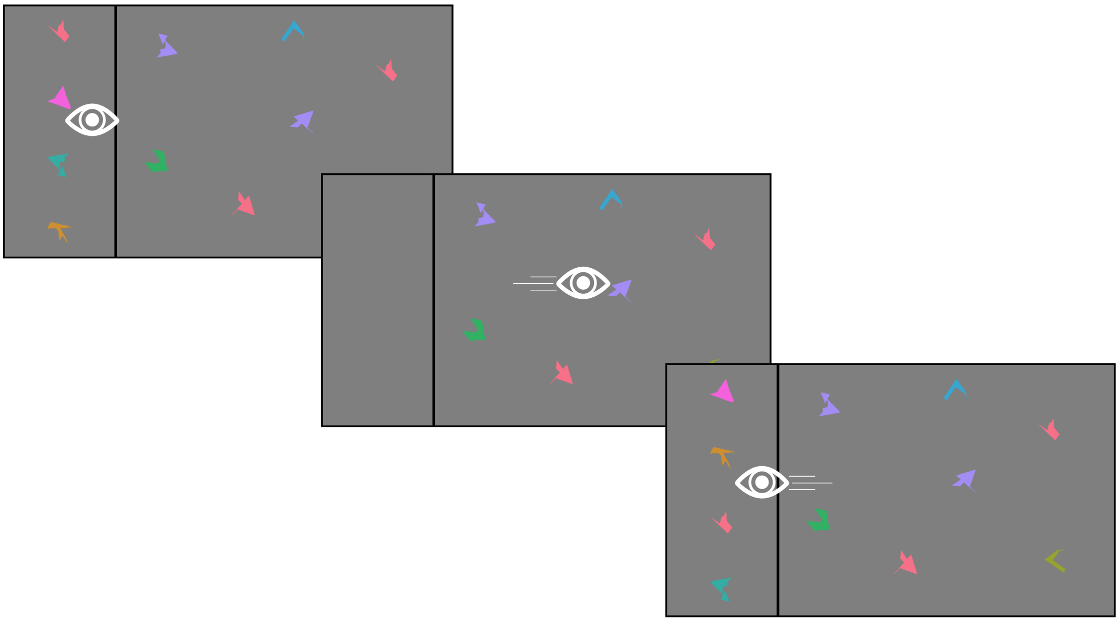

Figure 1: Experimental design of Dataset 1. Participants had to inspect templates on the left and find one matching target on the right. Templates were only visible while gaze was in the template area. After each inspection of the template area, the templates remained the same, but their positions within the template area were randomly scrambled. Stimuli are not to scale.

3 Dataset 2: Delay and distance manipulations

Dataset 2 may be retrieved via the Open Science Framework https://osf.io/nf8qc/.

3.1 Goals

The goal of Experiment 1 was to attempt a replication of e.g., Böing et al., 2023; Gray et al., 2006; Melnik et al., 2018; Sahakian et al., 2023; Somai et al., 2020. Those studies showed that participants increased working memory usage, and sampled external information less often, when access to external information was delayed. This replication was successful, showing increased memory usage with longer delay periods.

The goal of Experiment 2 was to attempt a replication of e.g., Ballard et al., 1995; Draschkow et al., 2021; Inamdar and Pomplun, 2003. They showed that participants increased working memory usage, and sampled external information less often, when external information was placed further away from the area where memory contents needed to be used. This replication was unsuccessful, but we think that the distances employed were not large enough to cause a pronounced shift in behaviour.

3.2 Participants and procedure

16 participants (10 female, ages 18-41) with normal vision and no colourblindness performed both experiments. Both experiments were run consecutively. Prior to each experiment, participants read the information letter, signed an informed consent form, and indicated their age and gender. Participants received €7 per hour or course credits, with each experiment taking approximately 60 minutes. In between experiments, participants took a break of 10-15 minutes. The study was approved by the Faculty Ethics Review Board of Utrecht University (protocol number 21-0297).

3.3 Apparatus

Monocular gaze location was recorded with an EyeLink 1000+, at 1kHz. Stimuli were presented on a 27" 2560×1440 LCD monitor at 100Hz. Participants were seated and stabilized with a chin- and forehead rest at 67.5 cm from the monitor. The experiment was implemented with PyGaze (Dalmaijer et al., 2014).

All gaze metrics are reported in degrees of visual angle (°). Before the start of the experiment, and between each block, the eye tracker was calibrated and validated with a 9-dot grid, allowing a mean error of 0.5° and a maximum per-dot error of 1.0°. The quality of calibration was automatically evaluated throughout the experiment while each pre-trial fixation cross was presented. If the gaze prediction error exceeded 1.5° for more than two consecutive trials, the eye tracker was re-calibrated.

3.4 Stimuli

Stimuli were a subset of complex shapes (introduced by Arnoult, 1956), which are commonly used in VWM research (e.g., Hoogerbrugge et al., 2023; Sahakian et al., 2023; Somai et al., 2020). The stimuli were black and could be shown in four configurations (90° rotations). Stimuli were circa 1.5° in size.

3.5 Task and design

Participants performed a visual search task, in which the screen was divided into two sections by a vertical line; a smaller template area (left) and a larger search area (right). The template area occupied the leftmost quarter (12.7°) of the screen and contained 4 equally spaced templates. Templates would only be shown when gaze was detected in the template area, such that participants could not peripherally attend templates and search items simultaneously.

The search area occupied the rightmost three-quarters (36.8°) of the screen and contained either one target (matching exactly one of the templates) and 10 distractors in target-present trials, or 11 distractors in target-absent trials. Distractors were randomly picked and could therefore be presented multiple times within the search array. 75% of trials were target-present trials. Before the start of each trial, a central fixation cross was shown, and the trial would only start if a fixation was detected at that location. Participants memorized the template(s) in the template area, and searched for them in the search area; indicating for each trial whether one of the stimuli in the search area matched a template (by pressing the 'z'-key) or not ('m'-key). After each trial they received feedback, with the screen showing either 'Correct' or 'Incorrect'.

3.5.1 Experiment 1: delay

Participants could reinspect templates as often as they wished throughout the trial, but in two conditions we added a delay before templates reappeared (Figure 2). In the baseline condition there was no delay. In the delay conditions, each time participants moved their gaze toward the template area an hourglass symbol would appear for 1500 or 3000 milliseconds (blocked conditions). After the delay had been served in full, the templates would appear. If participants moved their gaze back to the search area before completing the delay period, the timer would reset.

The 0ms, 1500ms and 3000ms conditions consisted of 30 trials each, which were blocked. Block order was counterbalanced according to a Latin square.

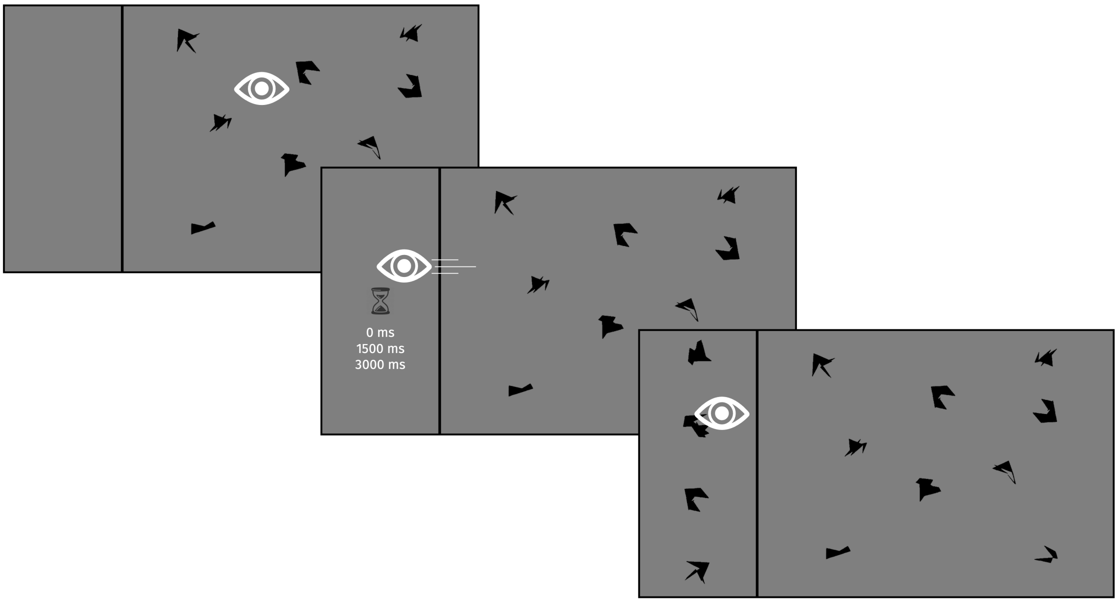

Figure 2: Experimental design of Dataset 2 - Experiment 1. Participants had to inspect templates on the left and find one matching target on the right. Templates were only visible while gaze was in the template area. Depending on the experimental condition, templates could appear immediately after gaze was shifted to the template area, or template appearance could be delayed by 1500ms/3000ms. During this delay an hourglass would indicate that participants had to wait. Stimuli are not to scale.

3.5.2 Experiment 2: distance

Again, participants could reinspect templates as often as they wished throughout the trial, but we manipulated the distance between the templates and the search array. The items in the search array could be placed in one of three sectors of the search area (near, medium, far). Each sector occupied 12.3° of the search area (Figure 3).

The near, medium and far conditions consisted of 30 trials each, which were blocked. Block order was counterbalanced according to a Latin square.

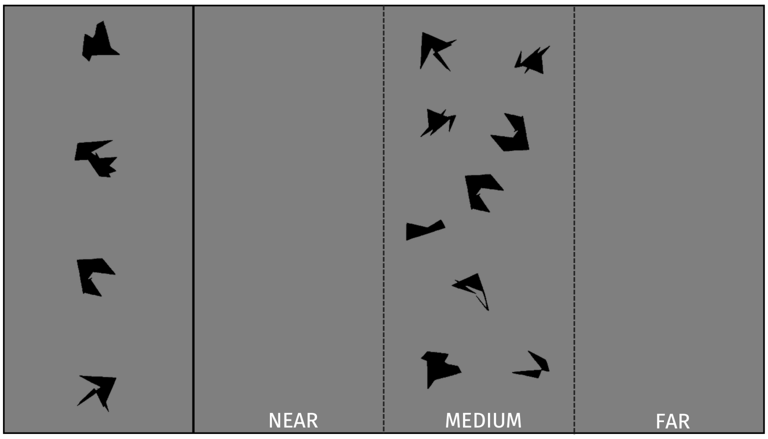

Figure 3: Experimental design of Dataset 2 - Experiment 2. Participants had to inspect templates on the left and find one matching target on the right. Templates were only visible while gaze was in the template area. Depending on the experimental condition, the stimuli in the search area could be grouped near, medium, or far from the template area. Stimuli are not to scale.

4 Dataset 3: Speeded visual search

Dataset 3 may be retrieved via the Open Science Framework https://osf.io/brmtd/.

4.1 Goals

In Hoogerbrugge et al. (2023, 2024), we argued that being able to resample external information benefits speed and accuracy, and allows minimization of effort. Although we usually ask participants to be as fast and accurate as possible, these studies have been collected in dark and quiet labs, separated from the pressures and distractions of the outside world.

For Dataset 3, we attempted to investigate the storage/sampling trade-off in a busy setting and under high time pressure. We theorized that loading up VWM with multiple items worsens speed and accuracy when under high pressure. Furthermore, we wanted to investigate whether there is an optimal template inspection duration. For instance, inspecting too briefly may lead to imprecise memory representations which worsens performance – and inspecting too long may cost time unnecessarily. To this end, we collected data at Betweter Festival, a popular science festival in Utrecht, The Netherlands. We let visitors duel each other by simultaneously providing them with the same search task on two separate computers. The visitor who completed the task faster than their opponent won the duel. Moreover, there was a leaderboard with the fastest times of the evening.

We found that participants who inspected templates relatively long were also relatively faster at the task. However, we did not find any other specific strategies which led to the best completion times without being able to exclude individual differences in e.g., memory capacity. As such, this dataset did not warrant a standalone publication, but may be useful to other researchers.

4.2 Participants and procedure

100 visitors performed the experiment (56 women, 41 men, 3 non-binary; M_{age} = 33.3, range = 21-67) . Two visitors did not provide their age. 86 visitors indicated that they had no history of neurological or psychiatric disorders, 12 indicated that they did. Two visitors provided no answer. Visitors were asked to rate their own competitiveness on a slider scale (0-100), how many hours per week they played video games, and how many alcoholic drinks they had consumed on that day. Outcomes of these questions can be found in the data repository.

The study was approved by the Faculty Ethics Review Board of Utrecht University (protocol number 21-0297). All visitors gave consent to publish their data.

4.3 Apparatus

The experiment was implemented with PyGame and Tkinter. The experiment was run on two laptops, each connected to their respective 55" 1920×1080 monitor at 60Hz. Visitors stood at a table at 60-80cm from the monitor, such that the whole screen occupied a visual angle of approximately 75-90° horizontally by 47-60°

vertically. Mouse cursor location was recorded at 50-60Hz.

4.4 Stimuli

Stimuli were a subset of complex shapes (introduced by Arnoult, 1956), which are commonly used in VWM research (e.g., Hoogerbrugge et al., 2023; Sahakian et al., 2023; Somai et al., 2020). The stimuli were black and could be shown in four configurations (90° rotations). Due to the varying viewing distance, stimuli were approximately 3°-4° in size.

4.5 Task and design

In order to track approximately where visitors looked without limiting their peripheral vision too much, the screen was black by default, and we used a spotlight around the cursor location (similar to MouseView; Anwyl-Irvine et al., 2022). This spotlight revealed an area approximately 40% of the screen in diameter (35-45°, depending on viewing distance). The outer rim of the spotlight gradually darkened, making the fully revealed area 25-35° (Figure 4A).

Prior to the task, visitors were verbally instructed about the task and performed one practice trial. To start each trial, visitors were instructed to hover their cursor over a circle on the left-hand side of the screen. This circle gradually became green, and after hovering for one second the trial started.

Visitors had to inspect search templates on the left-hand side of the screen and find exactly one matching target on the right-hand side. Targets were the same shape and rotation as one of the templates. Distractors could be the same shape but in a different rotation. The search area contained 70 possible locations where stimuli could appear, outlined by gray rectangles. There were always 4 templates, 20 distractors, and 1 target.

When visitors found the target, they had to click on it. Subsequently, the next trial started, including the hover-to-start screen (*"Correct! Place your mouse there to start the next trial"*). If visitors clicked on a distractor instead of a target, the hover screen reappeared (*"Incorrect... Place your mouse there to retry this trial"*), after which they could continue the trial. As such, giving erroneous responses increased trial duration by slightly more than one second. Given that there were 20 distractors, there was a high incentive to be both fast and accurate.

All visitors performed 6 trials. Critically, visitors always participated in pairs and dueled against each other on two different screens. To this end, we randomly generated 20 trial layouts before data collection, and each visitor was assigned a subset of 6 trials. Due to difficulty with synchronization between laptops, pairs of visitors did not receive the exact same set of layouts. After both visitors had completed the practice trial and indicated that they were ready to start, one of the experimenters pushed a button which initiated the experiment on both computers.

After the task, visitors were shown a distribution of other visitors' completion times compared to their own (Figure 4B). Completion times were computed as the total duration between the start of the first trial until the target was clicked in the last trial.

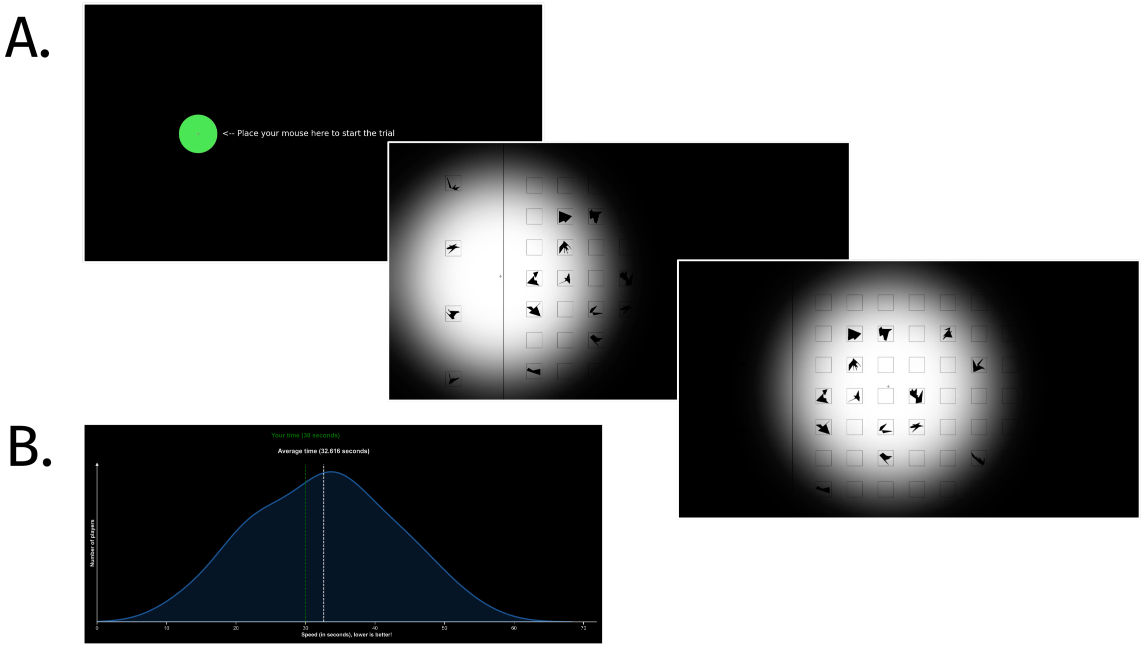

Figure 4: Experimental design of Dataset 4. **A.** An example overview of a trial. Participants had to hover their cursor over the circle, which gradually became green. When the trial started, a spotlight would illuminate part of the screen while the rest was occluded. Participants could move their cursor to inspect parts of the screen and click the target when they found it. **B.** A synthetic example of the end-screen. Participants were shown a distribution of other visitors' completion times compared to their own.

Acknowledgments

RB collected Dataset 1. **GK** collected Dataset 2. **AJH** and **AS** conceptualized and collected Dataset 3. **AJH** drafted the manuscript. **AJH** curated the data and code. **AJH, CS, TCWN, SVdS** were involved in supervision, conceptualization, and revising the manuscript. The authors thank participants at Betweter Festival for donating their time and data. Additional thanks to volunteers who helped collect data at the festival. This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement n° 863732), awarded to SVdS.

Competing interests The authors declare no competing interests.

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