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Brief article

Prolonged focal attention without binding: Tracking a ball for half a minute without remembering its color

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ABSTRACT

Conventional theories of cognition focus on attention as the primary determinant of working memory contents. However, here we show that about one third of observers could not report the color of a ball that they had just been specifically attending for 5–59 s. This counterintuitive result was obtained when observers repeatedly counted the passes of one of two different colored balls among actors in a video and were then unexpectedly asked to report the color of the ball that they had just tracked. Control trials demonstrated that observers' color report performance increased dramatically once they had an expectation to do so. Critically, most of the incorrect color responses were the distractor ball color, which suggested memory storage without binding. Therefore, these results, together with other recent findings argued against two opposing theories: object-based encoding and feature-based encoding. Instead, we propose a new hypothesis by suggesting that the failure to report color is because participants might only activate the color representation in long-term memory without binding it to object representation in working memory.

1. Introduction

As perceivers, people intuitively believe that they remember information as detailed as they had just experienced, which is exemplified by the adage "Seeing is believing". However, researchers have concluded that we remember what is attended, given evidence that attention plays crucial roles in working memory storage and maintenance (e.g., Awh, Vogel, & Oh, 2006; Chun, 2011; Gazzaley & Nobre, 2012; but see Fougnie, 2009), and without attention, people often failed to report clearly visible stimuli (e.g., a gorilla) or changes (e.g., person substitution) (e.g., Mack & Rock, 1998; Most, Scholl, Clifford, & Simons, 2005; Rensink, O'Regan, & Clark, 1997; Simons & Chabris, 1999; Simons & Levin, 1998).

Nonetheless, there is a debate concerning how an attended object is represented in memory. One hypothesis suggests that we obligatorily encode all features of an object into working memory irrespective of their task relevance (i.e., *object-based encoding hypothesis*; Gao, Gao, Li, Sun, & Shen, 2011; Luck & Vogel, 1997; Shen, Tang, Wu, Shui, & Gao, 2013; Vogel, Woodman, & Luck, 2001).

An alternative hypothesis is *feature-based encoding*, which argues that participants often encode only the task-relevant feature of a stimulus and filter out its task-irrelevant features (e.g., Awh et al., 2006; Olivers, Meijer, & Theeuwes, 2006; Woodman & Vogel, 2008), or encode distinct features of the same object independently (Fougnie & Alvarez, 2011).

One way to reconcile these hypotheses is to assume that object-based encoding occurs when the capacity limitation of cognitive processing is not met, while feature-based encoding constrains memory when capacity is exceeded and information must be prioritized. fMRI data (Xu, 2010) supported this hybrid hypothesis by showing object-based encoding in a low, but not a high working memory load condition.

However, this hybrid hypothesis was challenged by Chen and Wyble (2015a) which showed that observers often failed to report obvious attributes (e.g., color and identity) of an object in response to an unexpected question, even though they had just selectively paid attention to only that object, which should be well below the capacity of focal attention and working memory[1]. However, Chen and Wyble's paradigm may have yielded a momentary form of memory because the stimulus duration was at most 250 ms and

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[1] Note that Eitam, Yeshurun, and Hassan (2013) showed a similar failure to report one color of an attended stimulus, although participants may have treated the stimulus as two objects (Eitam, Shoval, & Yeshurun, 2015).

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participants only attended briefly. Such fleeting representations are assumed to be more susceptible to proactive interference or rapid forgetting (Nee & Jonides, 2013; Oberauer, 2002).

There are cases of change blindness for longer duration stimuli such as actor swaps (Levin & Simons, 1997; Levin, Simons, Angelone, & Chabris, 2002; Simons & Levin, 1998). However, the two actors' overall appearance in these studies were typically similar and attention to the actors might have been intermittent, which may have contributed to the failures to detect changes. In fact it was suggested that failures to detect changes might not occur for individuals with dramatically different appearance (e.g., Simons & Levin, 1998, p. 648). Furthermore, subjects might have failed to perform a memory comparison despite having formed memory representations (Levin et al., 2002).

Therefore, it remains an open question whether prolonged focal attention to a simple object for several seconds will necessarily produce a robust memory of that object's highly discriminable attributes that is sufficient for report immediately afterwards in response to an unexpected question. To investigate this question, we forced observers to track one of two colored balls in a video for multiple seconds repeatedly and then asked an unexpected question about the attended ball's color. Color was a salient and distinguishing feature of that ball, despite not being necessary for the tracking task.

2. Method

2.1. Participants

Sixty observers from the Pennsylvania State University psychology department subject pool participated in exchange for course credits. Four observers were replaced because their counting performance on pre-surprise trials was more than 2.5 SD below the mean.

2.2. Apparatus

Stimuli were presented on a 17-in. CRT monitor (1024 × 768, 75 Hz) with MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Observers sat 50 cm from the screen, and responded via keyboard.

2.3. Stimuli and procedure

Trials started with a black central fixation cross (1.03°) for 200 ms, which was replaced by a 500 ms black word "Ready" followed by a recorded video of size 22 × 13° (640 × 360 pixels, 25 fps) wherein two different colored balls (e.g., red and blue) were passed among six actors[2] who walked continuously (Fig. 1). The balls were selected from a set of four colored balls (i.e., red, green, blue, and purple, 0.65° to 1.94° diameter according to position). The ball that was passed *first* at the beginning of each video was designated as the target, while the other ball was designated as the distractor. Observers were instructed to count the passes of the target ball from one actor to another while ignoring the distractor ball. The number of passes differed between the target and distractor balls in 87.5% of videos (average 2.3 passes difference). After the video a 200 ms fixation screen preceded a two alternative forced-choice numbers (e.g. 19 or 20 passes) and observers responded by pressing either the 1 or 2 key in an unspeeded response.

There were 12 types of videos based on the color combinations of the four balls with each combination having 3 durations (short duration: average 8 s, 3 or 4 passes; medium duration: average 26 s, 10 or 11 passes; and long duration: average 44 s, 19 or 20 passes). Each observer saw one video of each color combination at each of the three durations, for one of the two pass numbers, chosen randomly, totaling 36 trials (12 video types × 3 duration conditions) in a randomized order. On the first 31 pre-surprise trials, observers reported the number of target-ball passes with feedback.

On the 32nd trial (i.e., surprise trial), immediately after the 200-ms fixation following the video, observers were unexpectedly presented with a forced-choice recognition test array consisting of four words (RED, GREEN, BLUE, and PURPLE) in black along with this question "*This is a surprise memory test! Here we test the "Color" of the target ball*, *Press a corresponding number to indicate the "Color" of the target ball*". The four color words were presented in a random order alongside the numbers 1–4. Observers were then asked to report the number of passes. The surprise trial was followed by four control trials that were identical to the surprise trial. The Surprise trial videos were evenly distributed among the three video durations across participants, but video duration had no effect on accuracy.

3. Results

Pre-surprise trials had an average of 10% pass-counting errors indicating that observers could track the target ball. However, on the surprise question, 37% (22/60) of these observers failed to select the ball's correct color (Fig. 2). Interestingly, for these 22 *incorrect observers*, 73% (16/22) of them selected the distractor ball color, which is significantly more than chance, (73% vs. 33%, χ^2 (1, N = 44) = 7.379, p = .007, φ = .41).

Critically, on the trial immediately after the surprise trial (i.e., control trial 1), when observers now expected that they might have to report the ball's color, color-report errors dropped to 17% (10/60), which was significant (17% vs. 37%, χ^2 (1, N = 120) = 6.136, p = .013, φ = .23). Color report error in the following three control trials remained consistently low (13%, 13%, and 12% errors). On erroneous control trials participants reported the distractor color 88% of the time, indicating that tracking the wrong ball was the source of most errors on control and presurprise trials.

For pass-counting, performance on the control trials (8%, 15%, 13%, and 17% errors) was similar to the pre-surprise trials (10% error), suggesting that observers could remember the ball's color without much cost. Performance in the surprise trial (28% error) was worse than other trials, which is likely because the pass-counting question occurred after the surprise question, which might have caused forgetting of the pass count. Pass counting performance remained stable during the pre-surprise trials, averaging 12% error in the 6 trials prior to the surprise.

To ensure that this effect is robust, we replicated the experiment with two minor modifications to reduce the probability of tracking the wrong ball. We removed 11 videos which consistently produced poor pass-counting (more than 15% errors) and we paused the first frame of the video for one second prior to the video start.

We replicated the results. 19 of 60 (32% error) participants were incorrect in color report on the surprise trial, and 15 of these 19 (79%) incorrect participants reported the distractor ball color instead, which is significantly more than guessing (79% vs. 33%, χ^2 (1, N = 38) = 7.836, p = .005, φ = .45). The color report error dropped to 7% in the first control trial which was significant (7% vs. 32%, χ^2 (1, N = 120) = 12.102, p < .001, φ = .32) and remained low (Fig. 3). Pass counting errors were also low (4% pre-surprise, 8.8% control), except for the surprise trial (30%) which mirrored the previous experiment.

[2] The actors were assigned to two groups, one for each ball. This grouping of the actors changed at random per trial.