BRIEF REPORT

Eye Movements Reveal Planning in Humans: A Comparison With Scarf and Colombo's (2009) Monkeys

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On sequential response tasks, a long pause preceding the first response is thought to reflect participants taking time to plan a sequence of responses. By tracking the eye movements of two monkeys (*Macaca fascicularis*), Scarf and Colombo (2009, Eye Movements During List Execution Reveal No Planning in Monkeys [*Macaca fascicularis*], *Journal of Experimental Psychology: Animal Behavior Processes*, Vol. 35, pp. 587–592) demonstrated that, at least with respect to monkeys, the long pause preceding the first response is not necessarily the product of planning. In the present experiment, we tracked the eye movements of adult humans using the paradigm employed by Scarf and Colombo and found that, in contrast to monkeys, the pause preceding the first item is indicative of planning in humans. These findings highlight the fact that similar response time profiles, displayed by human and nonhuman animals, do not necessarily reflect similar underlying cognitive operations.

Keywords: planning, serial order, simultaneous chain

Darwin's (1871) hypothesis that the difference in mind between human and nonhuman animals is "one of degree and not kind" (p. 105) is a major tenant of comparative psychology. Over the past two decades, comparative psychologists have begun to test the limits of Darwin's hypothesis by tackling what are, perhaps, the pillars of the human mind, including episodic memory (Clayton & Dickinson, 1998), episodic foresight (Correia, Dickinson, & Clayton, 2007; Mulcahy & Call, 2006), metacognition (Hampton, 2001), cooperation (Horner, Carter, Suchak, & de Waal, 2011), syntax (Abe & Watanabe, 2011), and causal reasoning (Taylor, Miller, & Gray, 2012). Much of this work, however, has been met with skepticism and so-called *killjoy explanations*, in which an animal's behavior is explained by appealing to simpler mechanisms (e.g., Beckers, Bolhuis, Okanoya, & Berwick, 2012; Boogert, Arbilly, Muth, & Seed, 2013; Carruthers, 2008; Dymond,

Haselgrove, & McGregor, 2013; Heyes, 2012; Suddendorf & Corballis, 2007, 2008; Suddendorf, Corballis, & Collier-Baker, 2009). Although not necessarily definitive, killjoy explanations highlight an important canon of comparative psychology, that is, similar overt behaviors do not necessarily reflect similar underlying cognitive operations.

For example, Scarf and Colombo (2009) questioned the validity of assuming that a response time profile, found to reflect planning in humans, also reflected planning in monkeys. The profile, displayed on sequential response tasks, consists of a long pause preceding the response to the first item and uniformly shorter pauses for all of the remaining list items. In the case of human participants, it is thought that the long pause preceding the first response reflects participants planning the sequence of responses they are required to emit, and that the subsequent short pauses reflect the execution of this plan (Henry & Rogers, 1960; Sternberg, Monsell, Knoll, & Wright, 1978; Zingale & Kowler, 1987). Curiously, nonhuman primates display the same response profile on the simultaneous chaining paradigm, a paradigm commonly used to investigate sequential processing in nonhuman primates (Colombo & Frost, 2001; Guyla & Colombo, 2004; Kawai, 2001; Ohshiba, 1997; Swartz, Chen, & Terrace, 1991; Terrace, 1984).

On the standard simultaneous chaining paradigm, a set of items is displayed simultaneously on a touch-sensitive computer monitor, and reward is provided only after a participant responds to each item in a set order. Recent variations of the simultaneous chaining paradigm have used the same display

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format, but have had subjects respond using joysticks rather than touch screens (e.g., Beran, Pate, Washburn, & Rumbaugh, 2004). To ensure that participants do not learn the required sequence as a succession of fixed motor responses, the configuration of the list items is changed randomly from trial to trial. To assess whether the pause preceding the first response was the product of planning, Scarf and Colombo (2009) tracked the eye movements of two cynomolgus monkeys trained on the simultaneous chaining paradigm. Although the "planning" profile was observed in the response time profiles of both monkeys, neither monkey displayed any actual evidence of planning. That is, on no trial did either monkey scan all of the list items before responding to the first item. Furthermore, on the large majority of trials, the monkeys responded to the first item immediately after locating it rather than scanning for additional list items to plan responses to. Finally, the response time to an item was the same whether the monkeys had previously seen the item while searching for an earlier item or whether they had not seen it. If the monkeys planned responses to items they had seen, one would expect shorter response times to these previously seen items.

The Scarf and Colombo (2009) study was an important contribution to research on planning in monkeys because it provided a clear answer as to whether the pause preceding the first response was the product of subjects planning, as had previously been suggested (Kawai, 2001; Ohshiba, 1997). In addition, it also helped to explain earlier work that found some evidence of planning using the mask task (Beran et al., 2004). On the mask task, following a response to the first item, the remaining items are covered by opaque white squares. Beran et al. (2004) trained monkeys on this task and found that they responded above chance to the masked item that was one item beyond the current response. Beran et al. suggested that rather than planning in the true sense (i.e., remembering the on-screen location of the next item to respond to), the monkeys may have simply been looking at the next item to respond to while making their response to the previous item. Consistent with this view, Scarf and Colombo found that on a large number of trials their monkeys would look at one item, then look at the next item, and then while looking at the latter respond to the former. With few exceptions (e.g., Inoue & Matsuzawa, 2009), this explanation can account for much of the evidence of "planning" in not just monkeys but nonhuman primates in general.

With respect to the use of eye movements to investigate planning, an open question is whether the eye movements of humans on the simultaneous chaining paradigm would reveal evidence of planning. To answer this question, in the present experiment, we tracked the eye movements of adult humans on the simultaneous chaining paradigm. If eye movements are a valid tool with which to assess planning, then we may expect to find evidence that humans, unlike monkeys, are planning a sequence of responses before their first response. Evidence of this nature would add to recent studies promoting the use of eye movements to investigate planning (Kaller, Rahm, Bolkenius, & Unterrainer, 2009; Nitschke, Ruh, Kappler, Stahl, & Kaller, 2012). The finding would also highlight that even when focal measures of behavior are comparable, such as reaction time profiles, comparative psychologists must be cautious when inferring that human and nonhuman animals are using similar cognitive operations.

Method

Participants

Seven university students participated in the present experiment. All participants read and signed a consent form prior to starting the experiment.

Materials

List items were displayed on a 15-in. MicroTouch (3M, St. Paul, MN) touch-sensitive monitor. The monitor was controlled by a PC located in a room adjacent to the experimental room. List items were presented in one of 16 spatial locations. The 16 locations were arranged in a four-by-four matrix and centered on the computer screen. List items were digitized color photographs of man-made objects. Auditory feedback was provided by a speaker located above the touch-sensitive monitor.

Procedure

The four 8-item lists were trained as simultaneous chains (Terrace, 1984). For each list, all eight items were displayed simultaneously from the start of training and participants registered each response by touching the respective item. Participants were told they would have to determine the correct order of the eight items through the process of trial and error. Participants were also told that if they made an incorrect response, the stimuli would disappear and a new trial would start after a brief timeout. The spatial configuration of the eight items was changed on each trial to prevent participants from learning lists as rote motor response sequences. On each trial, the configuration was drawn randomly from a set containing over 461 million possible configurations.

To help participants acquire each list, following each correct response, a tone was sounded and the item was flashed once. When the entire list was completed correctly, a series of tones was sounded and the screen was cleared for a variable intertrial interval of 2 to 4 s, after which the next trial automatically appeared. An incorrect response caused the background screen to change from white to black and initiated a 3-s timeout, which was followed by a new trial. The criterion for advancing to a new list was completing eight of the last 10 trials correctly. For example, if a participant correctly completed a list on Trial 15 but then made errors on Trials 16 and 17, the participant would need to respond correctly on the next seven consecutive trials (Trials 18–24) to achieve criterion. If a participant was unable to achieve criterion within 99 trials, he/she was moved to the next list. The lists were trained in four different orders that were selected according to a Latin square design (List Order 1: List I → List II → List III → List IV; List Order 2: List III → List I → List IV → List II; List Order 3: List II → List IV → List I → List III; and List Order 4: List IV → List III → List II → List 1), with each participant completing one of these four orders.

Eye movements were monitored with a SensoMotoric Instruments (Boston, MA) EyeLink head mounted eye-tracker. Head restraint was not used but participants were encouraged to keep

head movement to a minimum. At the start of a session, the standard SensoMotoric Instruments 9-point calibration procedure was used. Nine dots were presented at uniform distances on the screen. Calibration was completed when the average error at all nine positions was no more than 2.0°. During testing, eye movements were sampled at 250 Hz, and the X and Y coordinates were stored in a computer and subsequently analyzed offline.

Results

All seven participants reached criterion on the four lists. Because of a computer failure, Participant 1's data from the fourth list was lost. This missing value was replaced using random imputation (Gelman & Hill, 2007). This is a potentially risky strategy with so few observations, but the patterns of significance remained the same when this subject was removed from the analyses. On average, participants required 36.0, 29.3, 28.1, and 30.2 trials, respectively, to acquire their first, second, third, and fourth list. A one-way analysis of variance (ANOVA) with list (4: first vs. second vs. third vs. fourth) as a repeated measure was significant, $F(3, 18) = 3.41$, $p = .04$, $\eta_p^2 = .36$, 95% CI [0.0, 0.49]. Based on the average number of trials, it is clear that there was a substantial reduction in trials to criterion after List 1, and then little change. Tukey's HSD tests were used to confirm this: List 3 was reliably different from List 1, List 2 was nearly so, and there were no other reliable differences.

For the eye movement analysis, the eight criterial trials (i.e., eight trials on which participants responded to all eight items correctly) were used, organized by item (A–H) and decomposed into two components. *Scan time* is the time spent fixating items other than the one to which a response is required; *look time* is the time spent fixating the next target item. For example, when the next response should be to Item C, looks to C would be counted as look time, and looks to any other item would be counted as scan
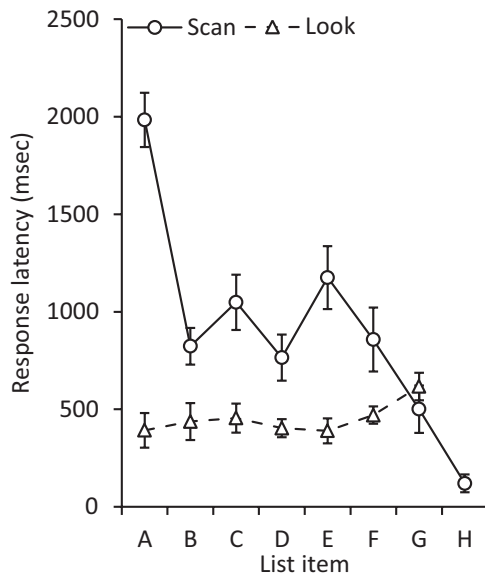

Figure 1. Scan (time fixating items other than the next target) and look (time fixating the next target) fixation time as a function of Item. Error bars represent ±1 standard error.

time. Fixation time as a function of item and component is shown in Figure 1. In Figure 1, it is clear that there are two transitions in the ratio of scan to look behavior, due primarily in changes to the amount of scan time, as one would expect if participants were planning. Before the response to Item A, subjects engaged in substantial scanning (looking ahead). For Items B–F, scan time and look time were roughly constant, but at Items G and H, scan time dropped and look time increased.

A two-way ANOVA with item (8: A–H) and component (2: scan or look) as repeated measures was used to assess significance. There was a significant effect of item, $F(7, 42) = 27.72$, $p < .001$, $\eta_p^2 = .82$, 95% CI [0.64, 0.84], and component, $F(1, 6) = 19.10$, $p < .001$, $\eta_p^2 = .76$, 95% CI [0.09, 0.80], and a significant Item × Component interaction, $F(7, 42) = 39.06$, $p < .001$, $\eta_p^2 = .87$, 95% CI [0.73, 0.88]. To begin unpacking the interaction, we assessed the simple effect of item at each level of component. For scan and look, the effect of item was significant: scan, $F(7, 42) = 39.83$, $p < .001$, $\eta_p^2 = .87$, 95% CI [0.73, 0.88]; look, $F(7, 42) = 5.08$, $p < .001$, $\eta_p^2 = .46$, 95% CI [0.13, 0.52]). We then applied Tukey's (HSD) post hoc analysis (with a threshold of $p < .05$) to each simple effect. For scan time, fixation time was significantly longer at Item A than any other item and significantly shorter at Item H than any other item; fixation time at Item G was also significantly shorter than at Item C or Item E (confirming that the sharp drop after Item A and the smaller drop at late positions were significant). For look time, fixation time was significantly greater at Item G than all other positions except Item H, and fixation time was significantly greater at Item H than at Item A or Item E (confirming that look time increased significantly at late items).

To determine whether participants were planning their responses, we conducted the same three tests employed by Scarf and Colombo (2009). First, we assessed whether participants scanned all of the list items before responding to Item A. To do this, we looked at the eight criterial trials each participant completed on each list, providing a total pool of 216 trials. On only two trials (.93%), each of which were by a different participant, did a participant scan all the list items before responding to Item A. This finding is comparable to the data from Scarf and Colombo's monkeys, as neither monkey scanned all of the list items on any trial.

Of course, scanning all of the list items is a rather stringent criterion for planning; therefore, in the second test, we assessed whether participants continued to scan one or more additional items after locating Item A. To do this, on each trial, we coded whether a participant responded to Item A immediately after locating it or whether he/she proceeded to scan one or more additional items after locating Item A. Participants continued to scan additional items on significantly more trials than trials on which they immediately responded to Item A, $t(6) = 3.92$, $p = .008$, Cohen's $d = 1.48$, 95% CI [0.93, 6.77] (see Figure 2). When this same analysis was performed on the data from Scarf and Colombo's (2009) monkeys, they displayed the exact opposite trend, responding to Item A immediately on significantly more trials than trials on which they scanned additional items after locating Item A, $t(1) = 14.12$, $p = .045$, $d = -9.98$, 95% CI [−31.73, −0.09] (see Figure 2). In addition, when directly compared using Welch's t test for unequal sample sizes, participants scanned additional items on a significantly greater percentage of
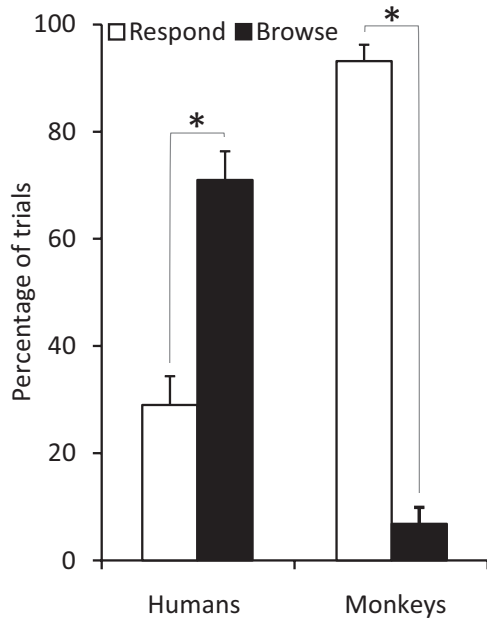
Figure 2. Percentage of trials on which humans and Scarf and Colombo's (2009) monkeys responded to Item A immediately after locating it (Respond) or continued to scan additional items after locating Item A (Browse). Error bars represent ±1 standard error.

trials (71%) than Scarf and Colombo's monkeys (7%), $t(6.46) = 10.40$, $p < .001$, $d = 8.33$, 95% CI [4.52, 16.24].

In the final analysis, we examined whether response times to a list item were shorter if participants had viewed the item before a response was required to it (i.e., while they were searching for an earlier item in the list). If participants were planning, or at the very least able to remember the location of items they were yet to respond to, we would expect to see a clear response time advantage for items participants had viewed compared with items they had not viewed. To investigate this, we simply calculated the average response time to items if they were viewed while searching for earlier items and compared it with the average response time to items that were not viewed while searching for earlier items. Participants' response times were significantly longer to items they had not viewed when compared with items they had viewed, $t(6) = 3.11$, $p = .02$, $d = 1.66$, 95% CI [0.44, 5.65] (see Figure 3). When this same analysis was performed on the data from Scarf and Colombo's (2009) monkeys, they displayed no such response time advantage, $t(1) = 1.06$, $p = .48$ (see Figure 3).

Discussion

In the present experiment, participants displayed a long response time to Item A followed by relatively short response times to the remaining list items. This pattern of response times is widely considered to be indicative of participants planning a sequence of responses (Kawai, 2001; Ohshiba, 1997; Sternberg et al., 1978; Swartz et al., 1991; Zingale & Kowler, 1987). Consistent with this notion, a trial-by-trial analysis revealed that, whereas participants rarely scanned all the list items prior to responding to Item A, on the majority of trials, participants did continue to scan additional

items after locating Item A, suggesting that they were not simply scanning for the first item to respond to. In addition, an analysis of participants' response times revealed that participants were quicker to respond to an item they had previously seen (i.e., that they had scanned while searching for a previous item) compared with an item they had not previously seen. Together, these findings provide evidence that, on the simultaneous chaining paradigm, human participants plan a sequence of responses at the outset of a trial. This finding is consistent with studies of speech, typewriting, and saccadic eye movements that have suggested that the long first-item response time reflects planning (Inhoff, 1986; Inhoff, Rosenbaum, Gordon, & Campbell, 1984; Lajoie & Franks, 1997; Rand & Stelmach, 2000; Sternberg et al., 1978; Wu & Remington, 2004; Zingale & Kowler, 1987).

With respect to the eye movement data, the results of the present study are best compared with studies that have tracked eye movements during typing and reading. These studies use a paradigm in which the size of a visual "window" is manipulated such that anywhere from zero to several later items (e.g., letters or words) are displayed. The smallest number of items that can be displayed, without a decrement in performance, is used to determine how far ahead in the sequence a participant is looking. These studies have demonstrated that participants look anywhere from one to seven items beyond the current response (Furneaux & Land, 1999; Inhoff & Wang, 1992; Salthouse, 1985, 1986; Truitt, Clifton, Pollatsek, & Rayner, 1997). In the present experiment, before responding to Item A, participants could potentially look ahead between one (i.e., just Item B) and seven (i.e., B, C, D, E, F, G, and H) items. As noted above, on only two trials, each completed by a different participant, did a participant browse all seven items before responding to Item A. To compare our data with those collected during typing and reading, we decomposed the browse component
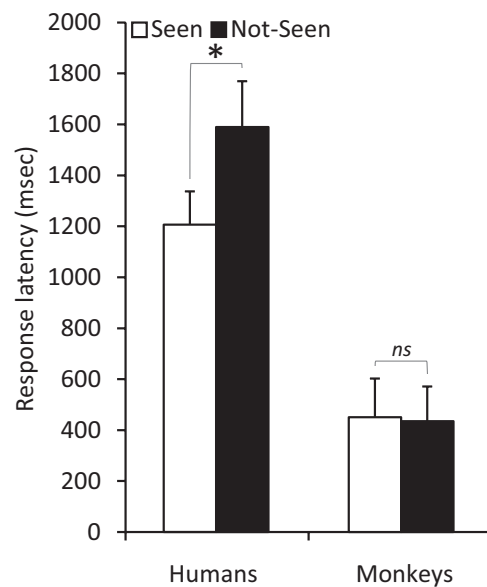

Figure 3. Response latencies to an item as a function of whether an item had not been previously seen or had been previously seen for both humans and Scarf and Colombo's (2009) monkeys. Error bars represent ±1 standard error.

from Figure 2. Participants, on average, looked one item ahead on the majority (57%) of browse trials; two items ahead on 21% of trials; and three, four, five, six, and seven items on 9%, 6%, 3%, 2%, and 1% of trials, respectively. One potential explanation for why our participants did not consistently browse more than one or two items ahead is due to their limited experience with the task. Indeed, participants who are proficient at a task, such as expert typists, look farther ahead than less proficient participants (Salthouse, 1986). One avenue for future research may be to vary participants' experience with the task, and perhaps with specific lists, and investigate whether increased experience results in a greater degree of planning.

The main aim of the present experiment was to compare the performance of our human participants with the performance of Scarf and Colombo's (2009) monkeys. Despite the fact that both humans and monkeys displayed the "planning" response profile, direct comparisons revealed that humans appear to plan ahead on the simultaneous chaining paradigm and monkeys do not. This finding highlights the importance of using multiple measures when investigating cognitive abilities and when drawing comparisons between species. Importantly, the dearth of evidence for planning in monkeys is not restricted to Scarf and Colombo's monkeys. Our group (Scarf, Danly, Morgan, Colombo, & Terrace, 2011; Scarf, Terrace, & Colombo, 2011) and others (Beran & Parrish, 2012; Beran et al., 2004; Koba, Takemoto, Miwa, & Nakamura, 2012) have collected data from a large cohort of monkeys and found that, even when the simultaneous chaining paradigm is set up such that planning is required to respond correctly, very few monkeys display a convincing ability to plan beyond the very next response.

The absence of strong evidence for planning in monkeys is also apparent in research that focuses on planning over longer time scales (Bourjade, Thierry, Call, & Dufour, 2012; Paxton & Hampton, 2009; Suddendorf & Corballis, 2007). Naqshbandi and Roberts (2006) conducted a study in which monkeys were presented with a choice between either one or four pieces of date. Naturally, during the baseline phase of the experiment, the monkeys almost exclusively chose the four pieces. In the experimental phase, the monkeys' water bottles were removed from their cages and their choice determined how long the water bottles were removed. If the monkeys chose the single piece of date, the water bottles were removed for 30 min. However, if the monkeys chose the four pieces of date, the water bottles were removed for 3 hr. Naqshbandi and Roberts predicted that, because both quantities of dates induced thirst in the monkeys, if the monkeys could plan for the future (i.e., anticipate that they will need to drink after eating dates), they should reverse their baseline preference for the large quantity and start to choose the small quantity. That is exactly what was found.

There is reason, however, to view the Naqshbandi and Roberts (2006) results with caution. Indeed, one potential problem with the Naqshbandi and Roberts study is that the monkeys made a gradual rather than immediate shift from choosing the large quantity to choosing the small quantity. The gradual change is not what we would predict if the monkeys were planning (Suddendorf & Corballis, 2007), and it makes it difficult to rule out the possibility that the change was simply based on associative learning (Shettleworth, 2007). In addition, a recent attempt to replicate Naqshbandi and Roberts findings with rhesus monkeys failed (Paxton & Hampton, 2009). In any case, as Suddendorf and Corballis (2007)

note, "If the monkey did think ahead . . . why did they not continue to select four date pieces and simply eat one or two and keep the others until enough water was available?" (p. 343).

More recent studies of future planning in monkeys have examined their performance on Tulving's (2005) spoon test, considered by many as the litmus test for future planning (Scarf, Gross, Colombo, & Hayne, 2013; Suddendorf & Corballis, 2010; Suddendorf, Nielsen, & von Gehlen, 2011). The spoon test is based on an Estonian children's story, in which a little girl dreams about attending a friend's birthday party. Guests at the party are served the girl's favorite dessert; unbeknownst to the little girl, however, guests were required to bring their own spoon. Because she does not have a spoon, the little girl must stand by and watch as others enjoy the dessert. The next night, the girl tucks a spoon underneath her pillow, just in case she returns to the party in her dreams. According to Tulving, the little girl's behavior demonstrates future planning in that she anticipated her return to the party and planned accordingly (i.e., ensuring she would have a spoon with her). The monkey studies required monkeys to save, and subsequently transport, either a tool they could use to access food (Dekleva, van den Berg, Spruijt, & Sterck, 2012) or tokens they could exchange for food (Bourjade et al., 2012). Despite the monkeys in both studies undergoing extensive training across multiple experiments, not a single monkey displayed convincing evidence of planning (Bourjade et al., 2012; Dekleva et al., 2012). By way of comparison, 3-year-old children pass Tulving's spoon test on the very first trial and without any prior training (Scarf et al., 2013; Suddendorf et al., 2011).

Outside of the behavioral work with monkeys, recent studies with rats have purportedly demonstrated neural evidence of planning and mental time travel (e.g., Buzsáki & Silva, 2012; Gupta, van der Meer, Touretzky, & Redish, 2010; Pastalkova, Itskov, Amarasingham, & Buzsáki, 2008; Pfeiffer & Foster, 2013). In the most recent of these studies, Pfeiffer and Foster (2013) recorded from hippocampal place cells while rats performed a spatial memory task. They found that, prior to movement, hippocampal place cells fired in sequences that depicted the trajectory to a remembered goal location, even in cases in which the combination of the start and goal location was novel. To rule out the possibility that these future trajectories simply reflected the path in front of the rat (i.e., a path that the animal was currently viewing), Pfeiffer and Foster controlled for the direction of the head, and found that the trajectories were not influenced by the direction the rat was facing. Based on their findings, Pfeiffer and Foster concluded that rats engage in "mental time travel" and that the hippocampus serves as a "substrate for the recall of imaginary events" (p. 78).

Although studies of this nature are likely to reignite the debate on the continuity of mental time travel (Balter, 2013; Corballis, 2012, 2013; Suddendorf, 2013), a recent study that tracked the eye movements of rats (Wallace et al., 2013) casts doubt on Pfeiffer and Foster's (2013) conclusions. Using ocular videography and a novel method of analysis, Wallace et al. (2013) demonstrated that the eye movements of rats differ fundamentally from those of other mammals, such as primates, in that the direction in which the two eyes are looking frequently differs substantially. This independent movement, when combined with the lateral position of the eyes and their substantial viewing angle ~200°, suggests that the head direction of rats may be a poor indicator of the direction the animal is currently viewing. Consequently, even though Pfeiffer and Fos-

ter controlled for head direction, it is still possible that their rats had an eye on their future trajectory.

In summary, a large body of work supports our conclusion that the ability to plan in monkeys is extremely weak when compared with humans. Critically, this view is based on data from multiple methodologies that assess planning over both short and long time scales. Glover (2004) has suggested that difference between the planning abilities of monkeys and humans can be attributed to the parietal lobes. The parietal lobes are a brain structure critical for advanced planning and an area that has undergone extensive expansion in humans since they diverged from monkeys some 30 million years ago (Simon, Mangin, Cohen, Le Bihan, & Dehaene, 2002; Van Essen & Dierker, 2007; Vanduffel et al., 2002). If this hypothesis is correct, then the planning abilities of monkeys, and perhaps other nonprimate species, may be neurobiologically constrained.

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