Behavioural Processes 91 (2012) 313–317

Contents lists available at SciVerse ScienceDirect

Behavioural Processes

journal homepage: www.elsevier.com/locate/behavproc

Short report

The breakfast effect: Dogs (*Canis familiaris*) search more accurately when they are less hungry

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ARTICLE INFO

Article history:
Received 14 May 2012
Received in revised form
20 September 2012
Accepted 22 September 2012

Keywords:
Breakfast
Glucose
Executive control
Memory
Dogs
Motivation

ABSTRACT

We investigated whether the consumption of a morning meal (breakfast) by dogs (*Canis familiaris*) would affect search accuracy on a working memory task following the exertion of self-control. Dogs were tested either 30 or 90 min after consuming half of their daily resting energy requirements (RER). During testing dogs were initially required to sit still for 10 min before searching for hidden food in a visible displacement task. We found that 30 min following the consumption of breakfast, and 10 min after the behavioral inhibition task, dogs searched more accurately than they did in a fasted state. Similar differences were not observed when dogs were tested 90 min after meal consumption. This pattern of behavior suggests that breakfast enhanced search accuracy following a behavioral inhibition task by providing energy for cognitive processes, and that search accuracy decreased as a function of energy depletion.

For humans it has been suggested that breakfast is the most important meal of the day. It is said to help regulate blood sugar and balance insulin output, improve metabolism, and reduce hunger (Pereira et al., 2011; Rosén et al., 2011). Research has found that breakfast consumption is also associated with better cognitive performance (Wesnes et al., 2003; Benton and Sargent, 1992). Children who have consumed breakfast are more attentive, have better spatial memory, and show greater recall for information presented to them verbally than those who have not (Mahoney et al., 2005). A recent review has reported that children and adolescents who consume breakfast generally demonstrate better memory and test grades (Rampersaud et al., 2005).

The size of the breakfast meal is known to be an important factor for cognitive enhancement. A breakfast meal that provides over 20% of the recommended energy intake (REI) improves physical endurance, creativity, problem solving skills, and working memory in children, more than a breakfast meal providing less than 10% of REI (Wyon et al., 1997). Research also suggests that a breakfast meal that causes a slower but longer rise of blood glucose levels (low on the Glycemic Index, GI) results in greater attention, cognition, and better memory later in the morning, relative to a meal that results in a faster but shorter rise of blood glucose levels (Mahoney et al., 2005; Benton and Owens, 1993; Benton et al., 2003).

Blood glucose levels are a relevant factor for cognitive performance because circulating blood glucose is the primary energy resource of the brain (Benton et al., 1996; Donahue and Benton, 1999). Though the brain represents only 2% of a person's body mass, it disproportionately consumes approximately 25% of the body's glucose (Gailliot, 2008). Research suggests that cognitive processes that require executive control (e.g., selective attention, working memory and self-regulation) are especially sensitive to glucose levels, and that performance on tasks that require executive control improve when glucose levels are increased (Scholey et al., 2001). Breakfasts differing in carbohydrate quantity and quality increase glucose levels to different degrees for varying durations, and these differences may explain why certain types of breakfast are better able to sustain cognitive performance throughout the morning (Ingwersen et al., 2007).

Further evidence that executive control is reliant on glucose is that the invocation of these processes is associated with the depletion of blood glucose levels (Gailliot et al., 2007; Fairclough and Houston, 2004). For example, in an executive control task, participants who control their attention and override a strong habitual response to read aloud the name of a word in order to say the color in which the word is printed for 15 min (Stroop task) deplete their blood glucose levels to a greater degree than participants who do not need to regulate their behavior because the meaning and the color of the word are congruent (Fairclough and Houston, 2004). This inhibitory induced depletion results in poorer performance

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0376-6357/$ – see front matter
http://dx.doi.org/10.1016/j.beproc.2012.09.012

on subsequent tasks (e.g., tasks requiring effortful persistence) that also require executive control (Gailliot et al., 2007). Similar deficits in performance are observed when hungry participants initially control their impulse to eat cookies (but not radishes) for 10 min and are subsequently asked to persist on unsolvable puzzles. Their performance is poorer relative to participants that do not inhibit their behavior to the same degree because they were told to avoid eating radishes (but not cookies) (Baumeister et al., 1998).

Memory and persistence in nonhuman animals also appears sensitive to glucose (Messier, 2004; Miller et al., 2010). When rats perform tasks believed to require working memory, decreases in hippocampal extra-cellular glucose levels are observed (McNay et al., 2000). Glucose injections replenish this depletion and facilitate working memory in rats when given before training (McNay et al., 2000). Glucose also facilitates the acquisition of appetitive and aversive tasks by rats (Hughes, 2003; Flint and Riccio, 1997; Messier, 1997).

Similarly, glucose has been found to affect persistence on an unsolvable puzzle task by dogs. When hungry dogs are initially required to inhibit their behavior and control their body movements while alone in a room (i.e., exert self-control), they persist for less time on a subsequent unsolvable puzzle task than those that are not required to initially inhibit their behavior (Miller et al., 2010). If such dogs consume a glucose (but not a calorie free placebo) drink following the exertion of self-control, these deficits are not observed (Miller et al., 2010)

Initial behavioral inhibition by dogs has also been shown to negatively affect search accuracy in an invisible displacement search task. Following a 10 min sit stay, dogs search less accurately when an object is hidden in one of two identical containers mounted on the ends of a rotating wooden beam, and rotated 90°, than after being placed in a cage for a similar duration (Miller, 2010). This observation corresponds with another from research with humans, where working memory is poorer following an initial act of self-control. When participants are asked to focus their attention on a woman being interviewed in a film and to ignore words displayed at the bottom of the screen for 10 min, they subsequently recall fewer words on a working memory task than participants who watched the same video without controlling their attention (Schmeichel, 2007). The consumption of a glucose drink improves performance on working memory tasks (Sünram-Lea et al., 2001). Taken together, these results suggest that an initial act of behavioral inhibition by dogs depletes glucose levels, a cognitive energy resource, and that this depletion is responsible for reduced search accuracy.

To date, however, there has been no clear demonstration that breakfast (relative to the absence thereof) improves cognitive performance by nonhuman animals. There is some evidence that allowing fasted rats unlimited access to food for 90 min before testing negatively affects their performance on a delayed matching-to-position task (Kirkby et al., 1995). However, these negative effects probably represent a lack of motivation for the food rewards associated with accurate responding. If animals consumed a limited amount of food (analogs to a typical human breakfast) positive effects on performance may be observed. The observation of these effects would provide convergent evidence that breakfast improves cognitive performance during the morning, moreover, it would question the standing hypothesis that accuracy by animals is optimized by extreme hunger induced motivation.

The purpose of the current research was to explore the aforementioned hypotheses by assessing whether search accuracy by dogs would be affected by the consumption of breakfast and, if so, whether these effects would be moderated by the delay between breakfast consumption and cognitive testing. The latter was of interest because glucose levels rise and fall following breakfast consumption (Jenkins et al., 1981; Hill et al., 2009), and human cognitive performance has been observed to fluctuate in accordance (Hoyland et al., 2008; Wesnes et al., 2003). In order to test these hypotheses, we adopted a two-task paradigm known to affect search accuracy by dogs, which appears sensitive to energy manipulations. The tasks were administered in succession; the first required 10 min of behavioral inhibition (sit–stay) and was administered because it was known to reduce persistence and search accuracy in food restricted dogs (Miller et al., 2010). Moreover, given that exogenously administered glucose can replenish these deficits, it was hypothesized that breakfast contingent differences in blood glucose levels would attenuate the expected performance decrements. The secondary task was a visible displacement search task believed to require working memory. The dogs were tested at two different times in the morning while in either a fasted state or following the consumption of a breakfast. It was hypothesized that dogs would search more accurately after consuming breakfast than when fasted, furthermore, it was hypothesized that these performance differences would be greater shortly after breakfast (30 min) in comparison to when tested later in the morning (90 min).

1. Method

1.1. Subjects

Fourteen dogs (*Canis familiaris*), 9 females and 5 males, ranging from 12 to 120 months in age ($M = 47.3$ months), privately owned, were recruited. All dog owners confirmed that their dogs were in good health, that their dogs were motivated by food rewards, and that they were willing to fast their dogs overnight (12 h prior to participating). The weight of the dogs in kg was recorded. Of the dogs that participated in the experiment, 3 came from breeds classified by the American Kennel Club as herding dogs (2 Belgian tervuren and a Belgian sheepdog), 3 were sporting dogs (golden retrievers), one was a hound dog (beagle), one a working dog (boxer) and 6 were of mixed breeding.

1.2. Materials

Dogs were caged in heavy-duty plastic dog kennels (91 cm long × 64 cm wide × 69 cm high) in a room adjacent to the experimental room. Evo® turkey and chicken formula dog food served as the breakfast meal. The meal size for each dog was half of the total amount of energy it would need to maintain its resting energy requirements (RER). The formula used to calculate this amount was 0.5(30[body weight in kilograms]) + 70) (Earle, 1993). Dogs were given ad libitum access to water. Within the experimental room (3.9 m long × 3.8 m wide) a carpet (1.2 m long × 0.8 m wide) was placed on the floor against the wall for the subject dog to sit on and six identical opaque plastic containers (15 cm diameter × 10 cm deep) with lids were arranged in a semi-circle around it. Each container was 1.2 m from the dog, and the containers were separated by 50 cm (see Fig. 1). In each container a second smaller plastic container (6 cm long × 6 cm wide × 3.5 cm deep) was placed. The smaller containers had perforated lids that allowed odors to escape while preventing dogs from accessing the approximately 20 g of heated chopped wieners (Oscar Mayor®) that were placed inside. These containers reduced the probability that dogs could use odor cues to locate the visibly displaced target food during testing. Individual pieces of wiener (1 g) were used to bait the containers during testing. A mirror was placed strategically on the wall so that the experimenter could watch the dogs from outside the room through a small opening in the door.

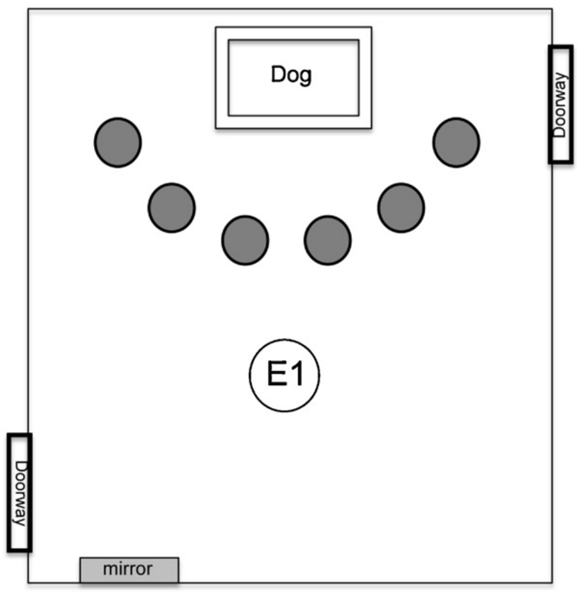

Fig. 1. The experimental room as it was setup for the working memory search task.

2. Procedure

2.1. Pre-training

All of the dogs stayed at the laboratory during the day (Monday–Thursday; between the hours of 9–17:00) for two weeks prior to testing for acclimatization and training purposes. Dogs were trained to maintain a sitting position while alone for 10 min using positive reinforcement, and were reinforced for searching for hidden objects. These dogs had previously participated in experiments on object permanence.

2.2. Breakfast manipulation

Dogs were randomly assigned to one of two groups (30 min or 90 min) before testing. Dogs in each group were tested twice, once in a fasted state and once following the consumption of a breakfast meal. Testing order was counterbalanced across dogs and testing sessions were separated by one week.

Following a 12-h overnight fast, dogs arrived at the laboratory between 8 and 9 am and were kenneled. Once inside the kennels, dogs in the 30 min group were given their prescribed breakfast meal (which they consumed in less than 5 min) or not before waiting 30 min to be tested. Dogs in the 90 min group were treated similarly except that they were tested 90 min after breakfast consumption. Immediately before testing each dog was walked on leash outside the laboratory (5 min) for elimination purposes.

2.3. Test phase 1: self-control exertion

Two experimenters who were naïve to both the meal condition (breakfast vs. deprived), and the effect that delay may have on performance, were responsible for administering testing. Upon entering the experimental testing room one of these experimenters cued the subject dog to "Sit" and "Stay". Following this cue, the experimenter (E1) exited the room and joined the second experimenter (E2) in the adjoining room, while the dog maintained a sitting position with the door slightly ajar. E1 watched the dog (without being seen by the dog) via a carefully placed mirror. If the dog moved from its position, E1 returned and gave the sit–stay cue again. E2 recorded the number of cues and the time at which each cue was given. The dog remained alone in the room for a total of 10 min. When the dog was released, it was given a small piece of wiener (1 g) and praised by E1 for 30 s inside the testing room. Then E2 entered the testing room and the second phase of testing began.

2.4. Test phase 2: search task

Working memory was assessed using a visible displacement search task. At the start of each visible displacement trial, E1 cued the dog to sit and stay on a mat before returning to a predetermined point 2 m in front of the dog (see Fig. 1). E1 then attracted the dog's attention by holding a treat and saying "Cookie!" or "Treats!" Once the dog was visually attending, E1 walked to one of the containers (each container was baited equally often and was randomly assigned). Once E1 reached the assigned container, he lifted the lid, placed the treat inside and on top of the smaller perforated container, and replaced the lid. He then slowly backed away from the container, assumed a neutral position at the predetermined point, and looked straight ahead at the opposite wall. E1 then cued the release of the dog with the word "okay!" and the dog was allowed to approach the containers. The delay between baiting and releasing the dog was approximately 10 s. Physical contact with a container within 90 s of release was considered a choice. Additional verbal praise was given for a correct choice as E1 removed the lid to allow the dog access to the treat. If the dog did not choose correctly, E1 said "Too bad!" before removing the treat from the correct container. If the dog stood up or moved forward before being released, E1 stopped the trial by saying "Too bad!" and replaced the dog on the mat before reinitiating the trial. If the dog failed to indicate a container within 90 s, E1 similarly stopped and reinitiated the trial. Such delays were infrequent, and testing was discontinued if E1 had to reinitiate the same trial 4 times in succession. One dog was dropped from the experiment because he refused to make physical contact with the containers after several incorrect trials. E2, who was seated near the door, was responsible for announcing trial number and for recording search accuracy. E2 discreetly observed the trials by facing the wall to the left of the dog, directing his face towards his clipboard, and remaining motionless during the search trials. Each testing session consisted of 36 trials. The duration of the memory test was approximately 50 min. After testing, E1 and E2 reviewed the number of recorded errors to ensure that accuracy was correctly reported.

3. Results

Most dogs completed all 36 trials of the memory test. However, some dogs stalled and refused to search. Three of the dogs in the 30 min condition stalled, two after breakfast but not when tested in a fasted state (both dogs completed 18 trials after breakfast before stalling), and one dog was stalled after breakfast and when fasted (this dog completed 19 trials in each session before stalling). One of the dogs in the 90 min condition stalled after breakfast (28 trials completed). Thus, the average number of trials completed differed between breakfast conditions, however, this difference was not statistically significant, $t(12) = 1.48$, $p > .16$.

In order to compare search accuracy, dogs' scores were converted into percentage of first choices of the correct container. All dogs searched above chance levels in each condition, however, on average, dogs that were tested 30 min after the consumption of a breakfast meal exhibited the greatest degree of search accuracy (73.3% correct). When these dogs were tested in a fasted state they searched less accurately (64.2% correct). Dogs tested after 90 min performed similarly following both meal consumption (65.2% correct) and when fasted (64.8% correct) (see Fig. 2).

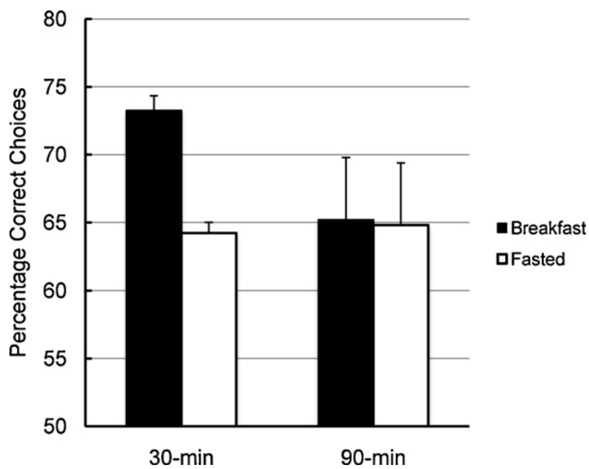

Fig. 2. Mean search accuracy for dogs tested 30 or 90 min after the consumption of breakfast or when fasted. Error bars represent ±SEM.

A two-tailed correlated *t*-test revealed that search accuracy significantly differed by breakfast condition for the 30 min group, $t(6) = 5.79$, $p < .01$, $d = .65$. These dogs searched more accurately when they had consumed a breakfast before testing. This difference was not observed in a two-tailed correlated *t*-test for the 90 min group $t(5) = .09$, $p = .29$, $d = .02$. Given the large individual differences in canine working memory (Miller et al., 2009) between group differences were not statistically analyzed.

4. Discussion

Previous research has shown that when dogs are initially required to inhibit their behavior and control their body movements while alone in a room (i.e., exert self-control), they persist for less time on a subsequent unsolvable puzzle task, and search less accurately for hidden objects, relative to when they are not required to initially inhibit their behavior (Miller et al., 2010; Miller, 2010). Such performance deficits can be eliminated by the consumption of a glucose (but not calorie free placebo) drink following the exertion of self-control (Miller et al., 2010). The results of the current study suggest that search accuracy can also be affected by prior meal consumption. When dogs are given a breakfast, and tested soon thereafter (30 min) in a two-task paradigm, they search more accurately than when they are tested in a fasted state. Similar differences in search accuracy are not observed when dogs are tested after a longer delay (90 min).

The current results suggest that search accuracy (which requires attention and working memory) by dogs is sensitive to energy manipulations. Dogs search more accurately 30 but not 90 min after the consumption of a meal that increases glucose levels to a higher degree 30 relative to 90 min following consumption (Hill et al., 2009). These results are similar to those obtained with humans and rats (Messier, 2004) and argue that increased energy, glucose in particular, enhances animal cognition by invigorating cognitive processes. It deserves noting, however, that this interpretation is limited by the fact that dogs in the current study were required to perform a sit–stay before the working memory test. Thus, the results did not directly support the hypothesis that eating recency affects search accuracy.

It is argued that an increase in blood glucose levels is responsible for the energy related improvements reported in the current study. However, the mechanism might also be motivational. The Yerkes–Dodson law dictates that increases in motivational arousal affect performance in a curvilinear way (Yerkes and Dodson, 1908), such that initial increases in motivation result in increases in performance until a particular threshold is reached. Afterwards, increases in motivation decrease performance (Baldi and Bucherelli, 2005). This is especially relevant for difficult and demanding tasks that benefit from lower level of arousals (Anderson, 1994; Broadhurst, 1959). In the context of the current experiment, motivation for food rewards was arguably lower when dogs were tested 30 min after breakfast consumption. This reduced arousal may have facilitated search performance.

It is believed by many researchers that animals perform optimally when tested in a fasted state and when they are extremely motivated to obtain food reinforcement. The results of the current research suggest otherwise. The results suggest that memory for the location of a food reward, as assessed by accurate searches on a visible displacement task, was significantly better when the dogs were tested 30 min following the consumption of a meal than when tested in a fasted state. This enhancement was time limited; when dogs were tested 90 min after breakfast, their performance was not better than when tested in a fasted state. These results were expected given that glucose levels increase and then decrease following meal consumption, moreover, they are similar to those obtained when 12 year olds were administered a memory task at different intervals following the consumption of breakfast cereal (Vaisman et al., 1996).

The results of the current experiment have both theoretical and practical import. Theoretically they extend the research suggesting that cognitive function is dependent on glucose and can be positively enhanced by the consumption of a breakfast by both human and nonhuman animals in a time dependent fashion. Practically, these results suggest that current research methodology (that advocates testing animals in a fasted state) may not be appropriate if the goal is to optimize cognitive performance by animals. The latter may be most relevant for research with dogs since they will perform even when satiated, however, it implies that other animals may perform more accurately when they are less food deprived. In extension, if the time of meal consumption is not controlled, it may be possible to observe differences in performance that may be attributable to differences in glucose levels.

These findings can be more broadly applied to the training and maintenance of animals. Dogs that are trained for law enforcement, bomb detection, search and rescue, and service for handicapped individuals may perform optimally following a breakfast meal. Other means of elevating blood glucose levels, such as distributing food throughout the day (e.g., snacks), may offer additional improvements. Given that the current trend is to feed dogs once at the end of the day, the findings reported here deserve attention. Contrary to common belief, performance by dogs is greater following the consumption of a breakfast meal and when dogs are presumably less hungry.

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