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Reproducibility of Incentive Motivation Effects on Standard Place Task Performance of the Virtual Morris Water Maze in Humans: Neuropsychological Implications

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The Virtual Morris Water Maze (VWM) is a computerized task used to assess spatial learning and memory in humans. Previous research indicated that monetary incentives increased performance in the VWM task (Murty et al., 2011). The present study attempted to replicate positive effects of incentive on spatial memory in the VWM (Murty et al., 2011) and to determine if competition and levels of monetary incentive would have a differential effect upon overall escape latency performance in the standard place task used in the majority of published studies. The present series of studies did not find any facilitating effects of incentive on escape latency. We conclude that the virtual spatial navigation performance using the standard place task (single platform goal) in the VWM is unaffected by incentive/motivation.

General Area of Psychology: Comparative Neuropsychology
Specific Area of Psychology: Incentive Motivation in Human Virtual Navigation
Keywords: Motivation, Spatial Learning, Reward, Virtual Water Maze, Behavioral Neuroscience

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A PubMed database search conducted by McDonald, Hong and Devan in 2004, estimated that over 2,800 studies were published using the water maze paradigm. A recent search using the same parameters reveal over 10,000 studies. Adding the term "virtual" to the search, showed nearly 100 published studies. The use of the virtual water maze (VWM) task for comparative analysis has a wealth of basic and preclinical research to screen systems-level drug development for age-related neurodegenerative diseases, as well as other neuropsychological conditions (Devan et al., 2014; Mueller, Grissom, & Dohanich, 2014). The VWM task is also useful for targeting multiple memory systems in the mammalian brain that contribute to different associative learning, mnemonic and other cognitive, and performance components that contribute to spatial navigation (Devan et al., 2016; Devan, Hong, & McDonald, 2011; Hamilton, Driscoll, & Sutherland, 2002; Kolarik et al., 2018; Kolarik et al., 2016; McDonald, Hong, & Devan, 2017; Rice, Wallace, & Hamilton, 2015; Ye et al., 2018). A recent study comparing humans with hippocampal damage or more widespread medial temporal damage, found that all groups demonstrated partially intact allocentric memory relative to controls, with an impairment specifically in the spatial precision of search behavior directed to the hidden target (Kolarik et al., 2018). This and other evidence (Kolarik et al., 2016) support the "precision and binding model" of hippocampal system domains of perceptual information processing. For example, recent discovery of grid and other functionally specialized cells in the medial entorhinal cortex suggest that parameters such as speed and temporal synchronization in entorhinal-hippocampal circuits may play an important role in the dynamics of movement-related spatial processing and possibly in the precision of place representations (Ye et al., 2018).

Virtual Water Maze

The Virtual Water Maze (VWM) is a visuospatial task that is designed to simulate the Morris water maze task typically used to assess spatial memory with rats (Morris, 1984; Morris, 1981). The VWM displays a simulated pool in a virtual environment through which participants must navigate to find a hidden escape platform (Astur, Ortiz, & Sutherland, 1998; Jacobs, Laurance, & Thomas, 1997; Jacobs et al., 1998; Sandstrom, Kaufman, & Huettel, 1998). While the different methodologies vary, generally the goal is to find the platform or goal box hidden somewhere within the pool by using spatial cues in the environment. The platform may or may not remain in the same location across trials (Hamilton et al., 2002). Over the past decade investigators have used the VWM task to study a variety of independent manipulations including: gender differences in search strategy and ability (Astur et al., 1998; Burkitt, Widman, & Saucier, 2007; Sandstrom et al., 1998; Woolley et al., 2010), the effects of localized brain damage on spatial memory and navigation performance (Astur et al., 2002; Driscoll et al., 2003; Hamilton et al., 2003; Hanlon et al., 2006; Hufner et al., 2007), and most extensively, to examine spatial learning and navigational strategies used by intact, non-brain damaged participants (Artigas, Aznar-Casanova, & Chamizo, 2005; Chamizo, Aznar-Casanova, & Artigas, 2003; Hamilton et al., 2002; Hamilton et al., 2009; Hamilton & Sutherland, 1999; Jacobs et al., 1997; Jacobs et al., 1998; Redhead & Hamilton, 2007; Redhead et al., 2013).

Motivation and Incentive

One equivocal question, however, concerns the motivational characteristics of participants in animal and human versions of the water maze task. College students who receive course credit for participating in a VWM study may not experience the same level of motivation to find a hidden platform as do rodents immersed into a pool of cool water. Students will receive the extra credit regardless of their performance on the task, while the rodents must search for the platform to find reprieve from swimming in the cold water. One might argue that rodents are more motivated than human participants and would therefore exert more effort to find the platform. As with any learning task, it is important to ensure that performance on the VWM accurately reflects spatial learning and memory ability and is not affected by the participants' motivation to perform.

Parente and Herrman (2010) noted factors of incentives that affect performance, for example, the size, quality, and time of delivery of the reward; therefore, a large, high quality, and immediate incentive should increase motivation. Large monetary incentives ($100) for patients with Traumatic Brain Injury (TBI) have been shown to increase performance on tasks of attention and memory, such as the digit span (Parente, 1994). TBI patients typically perform very poorly on these tasks without incentive; however when a $100 incentive was placed in front of them, their performance increased to a level comparable to normative college student samples. Performance was shown to be contingent on the monetary incentive, as the removal or lack of incentive resulted in reduced levels of performance.

Murty, LaBar, Hamilton, and Adcock (2011) found similar effects of monetary incentive in a VWM task using approach and avoidance motivation. Healthy adult participants were assigned to either an approach group, in which they were rewarded with five dollars for distinguishing a correct platform from a second incorrect platform within the pool, or an avoidance group where finding the incorrect platform resulted in mild shock. Murty et al. reported that participants felt more motivated in both reward and punishment conditions. Further, those participants who received the monetary reward found the correct platform more often and spent more time in the correct quadrant during a probe task relative to those who were punished. However, the experimental design involved a comparison of differences between each participants' performance under approach and avoidance versus their "unmotivated trials." It is, therefore unclear how much performance in the reward and punishment conditions differed relative to an independent control condition that received neither.

Reproducibility

A recent trend in the psychological literature concerns the reliability of published research findings (Asendorf et al., 2013; Baker, 27 August 2015; Koole & Lakens, 2012; Open Science, 2015; Wagenmakers et al., 2012; Wier, 2015; Young, 27 August 2015). This body of research indicates that only 36/100 of published research findings, in what are considered "quality journals," were reproducible. This issue is especially important in the development of the VWM research domain because most participants in these experiments are college students whose primary motivation to participate is extra course credit they receive. The results of the research outlined above (Murty et al., 2011) suggests that incentive effects may complicate the interpretation of VWM results. The present study was inspired by this evidence (Murty et al., 2011) and was designed not only to replicate the facilitating effects of monetary incentive on spatial memory in the VWM but also to extend it by assessing whether other types of incentive, e.g., competition among participants, would also improve performance.

Study 1

The first study was designed to replicate the basic finding reported by Murty et al. (2011) that a monetary incentive would affect participants' performance in the VWM task. The researchers then revised the experimental procedures to correct any procedural and sample size issues in the first study prior to recruiting participants for a larger, follow up study.

Method

Participants

Twenty-five Towson University undergraduate students with no prior VWM experience were recruited to participate in this study. Nineteen females and six males between the ages of 18 and 26 participated.

Materials

We used a version of the NeuroInvestigations software (version 1.2, Lethbridge, Alberta, Canada) (website: http://neuroinvestigations.com/home.htm) initially purchased as single site license, and then acquired a new version through a collaborative agreement with Dr. Derek Hamilton, the software developer who provided the 3.0 version. Dell desktop computers were used to run the software in a quit experimental room containing several computer terminals.

Procedure

Participants arrived at the computer lab in groups of three and underwent a brief training session designed to familiarize them with the VWM program. Participants were instructed to use the forward, left, and right arrow keys on the keyboard to navigate through the virtual environment according to the instructions provided in the software user's manual. Immediately following training, participants were tested in three separate competition blocks, each comprised of four trials with the hidden platform in the northwest quadrant of the pool and start points pseudo-randomly selected (sampling without replacement) from the four compass points at the pool wall. Each competition block took place in a novel virtual environment with standard distal cues on the walls of the outer room. The hidden platform location remained at a fixed spatial location within each virtual environment. Upon completion of one trial, the screen went black for approximately two seconds, and then the next trial began automatically. Upon completion of all four trials, the participant was prompted to await further instructions to ensure that everyone began each competitive block at the same time.

The winner was the participant who completed the four trials the fastest. The winners from each block were immediately rewarded with either a $1, $5, or $10 cash prize. All participants competed for all reward levels, and the order in which the rewards were offered was counterbalanced across groups. Whereas Murty et al. (2011) had used a $5 incentive, this study manipulated the size of the incentive to assess a dose/response relationship.

Results

Performance on the VWM was measured by escape latency, or total time to complete all four trials of one competitive block. However, during the first trial of each competitive block, participants were not aware of the location of the hidden platform and thus escape latency on trial one was at chance level. Therefore, a repeated measures analysis of variance (ANOVA) was performed on the time it took participants to complete trials two through four, eliminating trial one. The analysis indicated that while escape latency times decreased as the monetary incentive increased, the difference was not significant, $F(2, 44) = 1.94$, $p > .17$, $\eta_p^2 = .08$, Power = .33 (see Figure 1). The effect of incentive accounted for only 8% of the variance. The estimated 95% confidence interval for the $1 dollar condition was 39.86–114.56; for the $5 condition the confidence interval was 26.16–100.86 and for the $10 condition the confidence interval was 23.88–98.49. These intervals do not show any significant differences among the various conditions.

Discussion

The purpose of Study 1 was to determine if monetary incentive would motivate students to perform better on the virtual water maze task. Results indicated that participants'

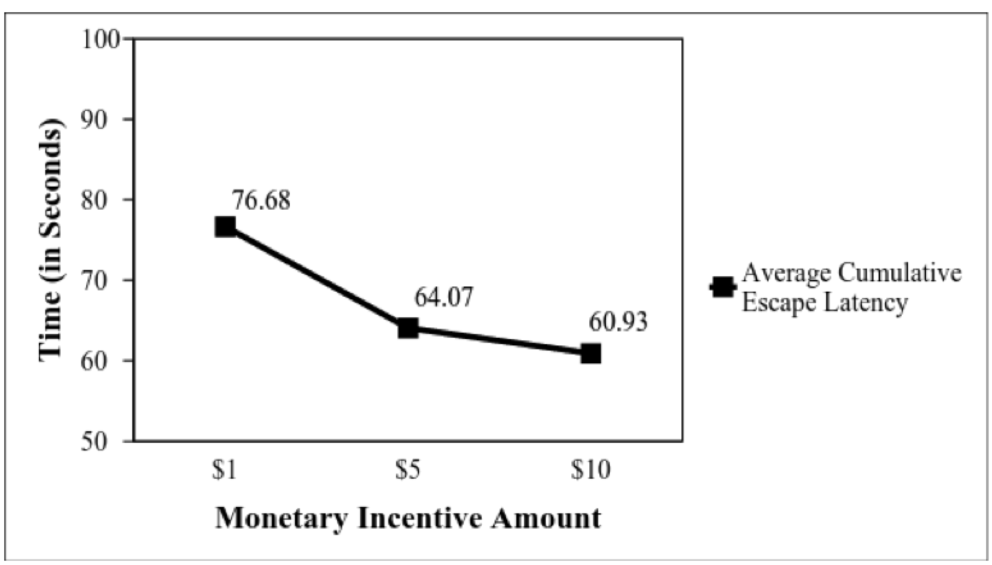

Figure 1. *Comparison of average escape latencies across incentive levels. Order of blocks was randomized.*

escape latency did not lessen significantly across the three competitive blocks as the monetary incentive increased. This finding came as a surprise given previously published results (Murty et al., 2011). To assess why the results did not replicate, we administered a post-experimental questionnaire that queried the students' motivation level. Eighteen of the twenty-five participants indicated that the money had motivated them to try harder; however, the participants asserted that the reward would have to be considerably higher to significantly increase their effort. The participants also indicated that their primary incentive was to compete with one another and to decrease their response latency.

Study 2

Method

Participants

Because the power in Study 1 was low (.33), the sample size was increased in Study 2. Murty et al. (2011) obtained significant results with less than 50 participants. We, therefore, increased the sample size to 95 participants, (77 females, 18 males, Mean age = 21.1 years).

Materials

We used a version of the Neuroinvestigation software initially purchased as single site license, then acquired a new version through a collaborative agreement with Dr. Derek Hamilton, the software developer who provided the 3.0 version. Dell desktop computers were used to run the software in a quiet experimental room containing eight computer terminals.

Procedure

Participants completed the study in randomly assigned groups of four to six in the computer lab. An initial eight training trials were conducted in a virtual environment where the hidden platform was in a fixed location (the SE quadrant) and the starting points randomly varied between one of four compass positions. Upon completion of the training trials, participants were randomized to one of three conditions: Control (C), Competition Only (CO), or Monetary Incentive (MI). Participants in the C condition were simply told to complete the eight test trials as fast as they could. Participants in the CO condition were encouraged to finish the eight test trials faster than the other participants in their group, but no incentive for "winning" was offered. Finally, participants in the MI condition were told to compete with one another and that the person who finished the eight test trials the fastest (i.e. had the lowest average escape latency) would win a $50 cash prize. Participants completed these test trials in a new virtual environment, where the platform was hidden in a different location (the NW quadrant) and the room cues differed from training. None of the participants were informed whether the platform location moved or remained in a fixed location. This information was omitted to equate the situation to the rodent version of the task.

Results and Discussion

A 3 (Condition) × 8 (Trials) mixed ANOVA did not reveal any significant interactions of condition by trials or main effect of condition ($p > .05$). For the Training trials, the 95% confidence interval for the Incentive condition was 20.79 – 29.40. For the Competitive group the confidence interval was 22.85 – 31.46 and for the Control group the confidence interval was 21.91–30.51. Participants in each of the three conditions performed at approximately the same level during the training phase and there was no significant change in average escape latency times from the training to the testing phase (See Figure 2).

The results indicate that the monetary incentive did not significantly improve escape latency performance on the VWM task in Study 2. For the Training data, the 95%CI for the Incentive condition was 20.80–29.40; for the Competitive condition the CI as 22.85–31.46 and for the Control condition, the 95% CI was 21.91–30.51. For the Test data, the Incentive CI was 11.3–24.47. For the Competitive condition, the CI was 12.73–25.47 and for the Control condition the 95% CI was 14.03–27.57. These confidence intervals do not indicate any significant differences among any of the training or test conditions.

Participants in Study 2 completed a post-experimental questionnaire that assessed their motivation level. Only participants in the CO condition indicated they were trying harder during the task than the other two conditions. Competition with other students did increase motivation, but did not result in better performance.

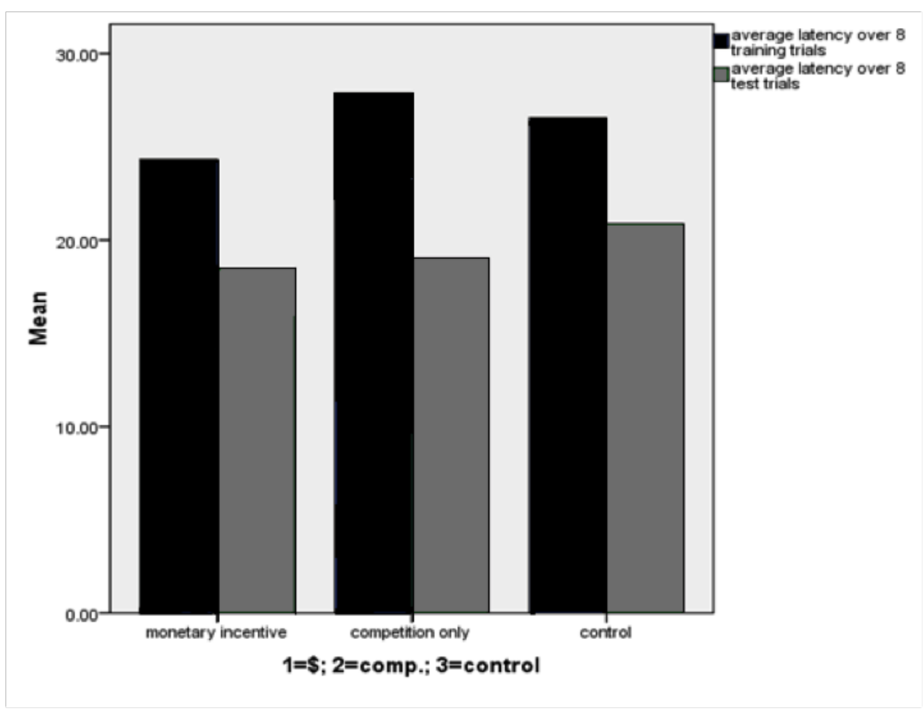

Figure 2. *Performance on training and testing trials. The Mean escape latency was the dependent measure of performance.*

General Discussion

Both studies indicated that participants' performance was not improved by the presence of a monetary incentive or by competition with one another. Although participants reported increased effort when offered a monetary reward or when given the opportunity to compete with their peers, there was no actual impact on their performance. Feedback from participants in Study 1 led to several methodological changes in Study 2. Notably, participants were given the opportunity to compete with one another and the level of incentive was increased to $50, an amount that was 5 times the maximum reward in Study 1. Although these changes may have increased motivation, neither increased performance. Although Murty et al. (2011) reported that monetary incentive produced better performance in the VWM task relative to punishment it did not improve performance in either of the present experiments. The Murty et al. (2011) study found that aversive training also improved performance but that approach training provided a stronger effect. Our results say nothing about the effects of aversive motivation on performance in the VWM.

These results suggest that incentive effects on performance in the VWM are not generally reproducible using the standard VWM place task parameters in the present study. The null findings in these studies are important because they speak to a fundamental question regarding the purity of experimental results that derive from VWM studies. Although it is perhaps impossible to create an exact analogue of the aversive experience that a rat experiences in a water tank with humans in a virtual environment, it is, perhaps, safe to suggest that the human experience is not substantially affected by the reward characteristics of the task.

The question remains concerning the difference between the results reported in the Murty et al (2011) study versus those reported here. One reason for the difference may be the experimental procedures used in each study. Murty et al (2011) analyzed differences between performance in approach and avoidance conditions versus the same participants' "unmotivated performance." It was unclear, however, when the unmotivated performance occurred in the treatment sequence for each group of participants. The present study involved a comparison of performance with reward versus no reward obtained from independent groups. We chose the independent groups model because it is more similar to what is usually reported in the literature on VWM place learning. We also wanted to avoid the possibility that performance levels in unmotivated or low motivation conditions would be influenced by partial reward or partial punishment that accrued during the treatment conditions. Another possible reason for the discrepant results may be that the effect size in these studies is not large (8–16% by our estimates). However, Study 2, included almost the sample size used by Murty, et al. (2011) and more than tripled the sample size use in Study 1 without any noticeable change in the results. It is therefore reasonable to suggest that the effect of incentive may only appear in strictly controlled studies with high internal validity.

It should be noted that the participants in both studies had no prior VWM exposure. Future research may want to consider if previous exposure to the task could serve as a motivation factor to compete for the incentive. In comparison to the neuropsychological results noted earlier in the Introduction, the failure to support a general incentive effect in college students suggest, parametric differences compared to Murty et al (2011) may positively influence incentive motivation, however without prior impairment of motivation due to TBI, positive incentive motivation may not improve control performance on the standard VWM task.

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