The State Effects of Subtle Physiological Arousal on Visual Working Memory Capacity: Sitting, Standing, and Cognition

David Grady
Psychology

Faculty Mentor: Edward K. Vogel
Psychology

Mentor: Irida Mance
Psychology

Sitting, Standing, and Cognition

While many studies examining the effects of physiological arousal on cognitive performance have sought to add to or modify existing theory, most inquiries in this field still rely heavily on derivative versions of the longstanding Yerkes-Dodson Law for the formulation of research questions and hypotheses (Chang, Labban, Gapin, & Etnier, 2012; Tomporowski, 2003). Yerkes and Dodson (1908) postulated that reaction time and accuracy on cognitive tasks should improve as physical arousal increases, then decline after an optimal level of arousal is surpassed. A plot of the relationship resembles an inverted "U" pattern that should be more linear with simpler tasks and lower rates of arousal. Although originally formulated and tested in the context of sensorimotor reaction times or long-term learning at near maximal levels of acute exertion, these principles have lately been employed as researchers have sought to assess more subtle, concurrent arousal effects on short-term memory and the more complex cognitive functions of working memory.

Working memory is a short-term, limited capacity memory system that involves higher aspects of executive cognitive control of selective attention for filtering, focusing on, manipulating, maintaining, and synthesizing a limited amount of sensory information. Although working memory is clearly important for recent recall, its role extends to the broader issues of reasoning, problem solving, and eventual long-term learning (Baddeley, 2010; Cowan, 1998; Drew & Vogel, 2009). Conceptually, working memory is further divided into two subsystems. One subsystem, verbal working memory, utilizes long-term memory to encode and maintain items that can be verbalized. The verbal working memory subsystem has a limited capacity that may be as few as seven items (Miller, 1956). The second subsystem, visual working memory, maintains items that cannot be easily verbalized and has been found to have a capacity of only three to four items (Luck & Vogel, 1997). Subjectively, visual working memory corresponds to the metaphorical mind's eye, while verbal working memory represents one's inner voice.

The current study examines the effects of the subtle physiological arousal evoked by standing, as opposed to sitting, on concurrent visual working memory cognitive tasks. By beginning to establish the arousal threshold, researchers can find out how little arousal is required to affect cognition, and constrain theory in the ongoing study of acute and concurrent neurophysiological state effects of arousal on cognition and brain function.

Some studies have indicated that attentional energy resources are shared between motor tasks used to promote arousal through physical activity and concurrent cognitive tasks resulting in a decrease in some measures of cognitive function. For example, exercise kinesiologists Ohlinger, Horn, Berg, and Cox (2011) used a treadmill workstation to test the effects of walking on concurrent measures of verbal working memory and motor skill. They observed no significant difference in performance for the working memory tasks, while measures of motor skill declined significantly during the walking condition. In another experiment, ergonomic researchers Schraefel, Jay, and Andersen (2012) administered a battery of tasks designed to assess six different domains of cognitive function: complex attention, executive function, cognitive flexibility, psychomotor speed, reaction time, and processing speed. Subjects carried out the tasks first while sitting and again while standing. They found a significant decrease in complex attention measures during the standing condition but no significant differences between conditions for any of the other five cognitive domains.

More results have suggested that physiological arousal activates the sympathetic autonomous nervous system, increasing heart rate and blood pressure to supply more oxygen and nutrients to the brain while stimulating neuroelectric and neurochemical mechanisms, which induces a state of increased attention and alertness that may increase cognitive performance. Exercise kinesiologists Chang and Etnier (2009) found that acute resistance exercise had a significant positive effect on automatic and executive function processes, while fellow kinesiologists Hillman, Snook, and Jerome (2003) observed that acute cardiovascular exercise stimulates neuroelectric processes resulting in corresponding significantly higher measures of verbal working memory. Developmental psychologists Schaefer, Lövdén, Wiekharst, and Lindenburger (2010) used N-back tasks and a treadmill to assess cognition while sitting or walking at fixed and subject preferred speeds. They found that cognition was significantly better only at speeds that the subjects chose. Social psychologists Esmaeili, Karimi, Tabatabaie, Moradi, and Farahini (2011) used movies to evoke positive emotional arousal and observed that subjects primed in that way performed better than the controls on a self-designed, analog short-term memory task.

While there is some conceptual and theoretical agreement in this field of study, most research examining the effects of physiological arousal on cognition has produced mixed, inconclusive results. These differences may be a result of the many varied perspectives and disciplines represented by the studies and the corresponding vast differences in experimental design, methodology, participant samples, task types and timing, exercise types, intensity, and duration, as well as the differing research questions and hypotheses that the experiments tested. Even with these many various viewpoints, contexts, and seemingly ambiguous results, several recent meta-analytic reviews of relevant research have concluded that as little as twenty minutes of low to moderate intensity acute or concurrent physiological arousal produces a significant but small positive effect on verbal working memory measures of cognition regardless of the diversity of methods used (Chang et al., 2012; Frazier & Mitra, 2006; Lambourne & Tomporowski, 2010; Tomporowski, 2003).

The current research examines the effects of standing versus sitting on visual working memory capacity (VWMC). Rather than rely, as previous studies have done, on verbal working memory tasks, which depend heavily on long-term memory (Luck & Vogel, 2013), we use estimated VWMC as a measure of cognition. The active maintenance of neural representations on which VWMC relies creates a profound bottleneck in short-term memory and therefore provides a more sensitive estimate of contemporaneous capacity than measures of verbal working memory (Luck & Vogel, 2013). This capacity-limited visual memory system exhibits more bottom-up, automatic, and trait-like characteristics than its verbal counterpart. Also, the three to four item capacity of VWMC has a complex relationship with higher cognitive functions, such as executive attentional control, and strongly correlates with measures of fluid general intelligence (Fukuda, Vogel, Mayr, & Awh, 2010; Luck & Vogel, 2013; Mance & Vogel, 2013).

Additionaly the current research uses a counter-balanced, within-subjects, repeated-measures experimental design in which posture and arousal are manipulated by having the participants stand in the experimental condition and sit in the baseline control condition while concurrently administering two computer-generated tasks to estimate VWMC. The results of this study were expected to support the hypothesis that there is an effect on cognition of the subtle neurophysiological arousal provided by standing so that predicted VWMC scores would be significantly higher for the experimental standing condition than for the sitting control condition. While individual studies on this topic show mixed results, these expected results are consistent with meta-analytic reviews and align with the theory and models of both cognitive neuroscience and neurophysiological arousal represented in the existing literature.

Methods

Participants

Twenty-nine young adults were recruited from the University of Oregon Human Subjects Pool to take part in this experiment. The data for two individuals were excluded because of self-reported brain trauma, leaving 27 participants ranging in age from 18-24 years (M = 19.90, SD = 2.88).

Materials

Participants completed two computer generated tasks to assess VWMC. Both tasks have consistently exhibited good to excellent validity and reliability with strong correlations to each other. The first task is a change detection task developed by Luck and Vogel (1997). In this task, participants are briefly presented with arrays of one to eight colored squares in various locations. Following a short period for retention, a single colored square "probe" then appears in one of the formerly occupied locations. Participants use keystrokes to indicate whether the color of the probe square has changed or remained the same, with one-half of the trials actually containing a change. The second task is a whole report task that is currently being developed and rigorously tested by researchers in Vogel's cognitive neuroscience lab at the University of Oregon. In this task, arrays of six colored squares in various locations are briefly presented to participants. Following a short retention period, each square is then replaced by a square of the same size divided into a grid of eight smaller colored squares that represents all of the possible color choices. Participants use a mouse to select one of the smaller squares to indicate the color of the square that formerly occupied that location. Participants also receive instructions to "left click" to indicate that they are confident of their responses and "right click" to indicate that they are guessing.

Procedure

When participants arrived at the lab for their appointments, they received standard consent forms assuring them of the confidentiality of the proceedings and their right to withdraw from the study without penalty. Lab personnel outlined the basic procedures and potential risks and benefits involved in participation. Participants were escorted to either a stand-up computer station for the experimental condition or a standard sitting computer station for the control condition. They received detailed instructions and demonstrations of both tasks outlined above. Half of the participants began in the standing position, and the other half began in the sitting position, with each set of tasks lasting approximately 45 minutes. When participants completed the first set of tasks, they were ushered into another room to complete the same set of tasks in the complementary postural condition. After participants completed the second set of tasks, lab personnel led debriefing sessions that explained the background, design, purpose, and rationale of the study. At that time, participants were encouraged to ask questions or provide comments, and they were thanked for their participation. Participants also received a written debriefing form that outlined all the information they had just received and provided contact information for the lab, Human Subject Pool and Research Compliance Services staff.

Results

Reaction time and accuracy aggregates from each task are recorded and averaged into a single VWMC score for each task, condition, and individual. A repeated measures, two-tailed Student's t-tests indicated that there were no significant differences in VWMC scores between the sitting condition ($M = 2.37$, $SD = .1.23$) and the standing condition ($M = 2.29$, $SD = .83$) using the change detection task, $t(26) = .582$, $p = .566$. Also, there were no significant differences in estimated VWMC between sitting ($M = 2.80$, $SD = .347$) and standing ($M = 2.80$, $SD = .47$) when using the whole report task, $t(26) = .053$, $p = .958$.

Discussion

The results of this study do not support the hypothesis that there is a significant effect on cognition arising from the subtle physiological arousal provided by standing as opposed to sitting. While these results may seem to add even more mixed results to an already ambiguous field of study, the validity and reliability of the methods and tasks employed align with the principles and models of both cognitive psychology and neurophysiological arousal provided in the current literature. Given the diverse perspectives and disciplines ranging from kinesiology and ergonomics to developmental, social, and sports psychology that have thus far been involved this area of study, as well as the mixed results and differing conclusions, it may seem that little real, cohesive progress is being made in this area of research. Yet, all of these studies contribute to and extend the body of knowledge in this field, and most have begun to incorporate methods, techniques, and theory from cognitive psychology, a tendency that suggests a promising way to have more consistent results in this line of research. Through the ongoing examination of the connections and interplay between physiological and neurological systems, cognitive psychology and neuroscience offer a theoretical framework to constrain and focus inquiry into mind and body interactions and effects. That theoretical framework may provide important conceptual advantages. First, it could provide much needed organization, structure, and context to guide future formulation of pertinent research questions and hypotheses. Second, cognitive psychology and neuroscience could potentially promote more consistent methods tied to guiding central theories. Third, greater theoretical unity could lead to increasingly consistent, definitive, and usable results from future experiments on this topic by placing them within the context of a well-developed paradigm specifically devised to quantify, analyze, and assess cognitive function.

Therefore, this research team concludes that standing simply does not supply enough physiological arousal to produce significant differences in VWMC, and that future experiments should focus on higher levels of arousal to establish a baseline threshold. While this experiment did not produce significant results, it does indicate that there is no significant difference in the higher cognitive processes of working memory performance between sitting and standing. Also, this experiment provides an impetus for change in the technology and knowledge industries where many recent studies have indicated that prolonged occupational sitting is associated with deleterious long-term health outcomes independent of leisure time, physical activity, or overall level of fitness (Chomistek et al., 2013; Katzmarzyk, Church, Craig, & Bouchard, 2008; Seguin et al., 2014). Therefore, although we have been unable to establish a baseline threshold of physiological arousal effects on cognition to show that sedentary workers can literally think faster on their feet, we have provided evidence that standing while performing mental work does not detract from cognitive performance.

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