How to Improve Working Memory Capacity: An Analysis of Working Memory Training, Physical Activity, and Mindfulness Meditation

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Working memory is the part of memory that processes information before the information is stored in short-term or long-term memory. It is involved in vital cognitive functions such as the encoding, maintenance, and storage of information. These functions are important for reading comprehension, problem solving, and multitasking. Working memory is also involved in cognitive control, because it allows individuals to make decisions and to guide their goal-directed behaviors.

Working memory *capacity* is a measure of how much information can be stored in working memory at a time. This capacity predicts executive functioning ability and is highly correlated with fluid intelligence, which indicates an individual's ability to reason. Some tasks that appear to measure working memory capacity include complex span tasks, N-back tasks, and the Stroop task. However, some researchers have found a weak correlation among performances on each of these tasks, which suggests that these tasks may be measuring different constructs (Harrison et al., 2013).

The goal of this paper is to analyze factors that appear to influence working memory capacity—working memory training, physical activity, and mindfulness meditation—in an effort to improve working memory capacity. My hypothesis is that each of these factors will influence working memory capacity in a positive manner, as researchers have shown, but *combining* these factors will yield an even greater positive effect—a prediction that researchers have yet to explore in depth.

Literature Review

Previous research indicates that working memory training, physical activity, and mindfulness meditation each influence working memory capacity individually. However, researchers have not identified the *best* means of improving working memory capacity among these factors, and I have found limited research on the effect of overlapping these factors. The present study relates to previous studies because it aims to confirm the results of previous experiments that show working memory training, physical activity, and mindfulness meditation improve working memory capacity individually. In addition, the present study aims to advance the field by isolating the best method of improving working memory capacity using these factors.

The first factor the present study will explore is working memory training. Working memory can be trained through strategy training or core training. Strategy training involves teaching participants approaches to accomplish a task effectively. For example, a useful strategy for runners is to remember numeric stimuli by "chunking" the numbers into running times. Unfortunately, some researchers have found that this strategy is limited to specific tasks (e.g., chunking by running times is only useful for numeric stimuli) and direct recall for briefly presented items (e.g., remembering someone's phone number after they say it). These researchers are concerned that instead of increasing working memory capacity, strategies such as chunking merely circumvent the limit of the capacity. For instance, if your working memory capacity is 7 items, instead of remembering 7 words, chunking may allow you to remember 7 *chunks* of 2

words each, or 14 words, but you are still limited to 7 items in memory. (Morrison & Chein, 2011)

Core training, on the other hand, involves practicing tasks that require different components of working memory. For example, the N-back task requires the working memory component of updating. Unlike strategy training, which is domain-*specific*, core training influences the domain-*general* components of working memory. This different focus makes core training effects more likely to transfer to other cognitive concepts, such as cognitive control and fluid intelligence. (Morrison et al., 2011)

Working memory training has been examined in numerous research studies, which focus on different subject groups and different training methods. In one study, researchers explored the effect of verbal strategy training, visuo-spatial strategy training, and both verbal and visual strategy training on children in the third grade with math disabilities (i.e., children who scored in the lower 25th percentile on standardized math measures). The researchers found that strategy training benefited the children with a higher working memory capacity more than the children with a lower working memory capacity. This finding is consistent with previous studies on participants without math disabilities. (Swanson, 2015)

Another study focused on improving the working memory of children with Attention Deficit Hyperactivity Disorder (ADHD), which is a disorder associated with working memory deficits. Researchers randomly assigned affected children to a working memory training group or a control group. After the intervention, the training group significantly improved on measures of both visuospatial and verbal working memory,

whereas the control group did not. Additionally, this improvement remained significant at a follow-up evaluation three months later. (Klingberg et al., 2005)

In another study, researchers attempted to increase working memory span by encouraging participants to use a strategy called "chaining," in which participants make up a story using the stimulus words in order to promote associations between the words. The researchers found that the group with strategy training improved their performance on the subsequent working memory task, whereas the control group without strategy training did not. The researchers explain that although domain-specific, semantically-based strategies were more effective in their experiment than domain-general, rehearsal strategies, improvements in working memory capacity from using a domain-specific strategy are not expected to transfer to other cognitive measures. (McNamara & Scott, 2001)

Some researchers are less optimistic about the transfer of domain-*general* working memory training effects. In a controlled study, researchers randomly assigned participants to complex span training, simple span training, or visual search training. The visual search training group served as the control group because visual searching is not associated with working memory. Unlike this visual search control group, the two span groups showed improved performance on similar, untrained tasks, which indicates transfer and suggests that working memory capacity is being affected at the construct or domain-general level. Unfortunately, the improvements did not transfer to all tasks, such as fluid intelligence measures, which caused the researchers to suspect that working memory training may improve only one aspect of working memory capacity. (Harrison et al., 2013)

Because working memory training may not be the most effective way to improve working memory capacity, other factors should also be considered. A second factor the present study will explore is physical activity. Physical activity is commonly associated with improved cognitive control, working memory, and executive functioning. However, the strength and direction of the relationship between physical activity and working memory capacity is unclear, because different studies have found different results.

Some researchers have found a positive correlation between different forms of physical activity and working memory capacity. For example, in one study, researchers examined the relationship between physical activity and working memory capacity in preadolescent boys. Using a questionnaire to assess physical activity and digit span tasks to assess working memory capacity, the researchers found a positive correlation between working memory capacity and both organized sports and outdoor play. (Verburgh, Scherder, Lange, & Oosterlaan, 2016)

In a similar study, researchers used a physical activity questionnaire and various working memory span tasks to study the correlation between physical activity and working memory capacity in undergraduate students. They also found similar results: moderate physical activity (more than three hours per week) was positively correlated with working memory capacity. In addition, the researchers found that sedentary behavior (more than three hours per day) was *negatively* correlated with working memory capacity, and this correlation persisted after adjusting for physical activity. This suggests that physical activity should not be used to compensate for a sedentary lifestyle. (Felez-Nobrega, Hillman, Cirera, & Puig-Ribera, 2017)

Although these two studies provide a promising *correlation* between physical activity and working memory capacity, in order to determine *causation*, researchers must conduct randomized, controlled experiments. Some researchers have conducted such experiments, but their findings differ. One study found that random assignment to a six-week high-intensity training regimen improved participants' performance on various working memory measures (Moreau, Kirk, & Waldie, 2017). Meanwhile, another study found that increasing cardiovascular fitness from two to five hours per week did *not* increase the participants' performance on measures of working memory (Sjöwall, Hertz, & Klingberg, 2017). Many variables can account for this discrepancy, and further research is necessary to identify the correct relationship between physical activity and working memory capacity.

Further research is also necessary to investigate other factors that may affect working memory capacity. In addition to studying working memory training and physical activity, the present study will explore a third factor: mindfulness meditation. Researchers speculate that mindfulness meditation improves working memory capacity by enhancing attentional control and reducing mind wandering (Mrazek, Franklin, Phillips, Baird, & Schooler, 2013). Although randomized, controlled experiments do not specify how mindfulness meditation affects working memory capacity, these experiments do tend to show that mindfulness meditation improves working memory capacity.

In one study, researchers randomly assigned participants to either a mindfulness meditation training group, a yoga group, or a control group. Participants in the mindfulness meditation group practiced mindfulness meditation for 45 minutes, twice per week, for 4 weeks. This training was based on the Mindfulness Based Stress Reduction

(MBSR) program. After the four weeks, all participants completed an automated operation span task, and researchers found that the mindfulness meditation group significantly improved their working memory capacity, whereas neither other group did. (Quach, Jastrowski Mano, & Alexander, 2016)

In a similar study, researchers randomly assigned participants to either a mindfulness meditation training group or a nutrition class. Participants in the mindfulness group completed the same amount of training as the previous study, and training was also based on MBSR program, but the sessions were for 45 minutes, *four* times per week, for *two* weeks. Subsequent operation span tasks revealed the same effect: the mindfulness meditation group significantly increased their working memory capacity, whereas the control group did not. (Mrazek et al., 2013)

A third study found similar results but with an exception. Researchers randomly assigned military cohorts to a mindfulness meditation training group or a control group. The mindfulness meditation group completed the 8-week course Mindfulness Based Mind Fitness Training, which covered similar topics and had a similar protocol to the MBSR program; in addition, the group's instructor was trained in MBSR. The subsequent operation span task revealed that mindfulness meditation participants with a *high* mindfulness meditation practice time increased their working memory capacity, whereas those with a *low* practice time *decreased* their working memory capacity. Researchers explain that these negative performance results were likely due to participants' having low expectations and therefore exerting less effort on the mindfulness meditation tasks—not a negative result of the mindfulness meditation training. (Jha, Stanley, Kiyonaga, Wong, & Gelfand, 2010)

Although these three factors are all promising and worth studying individually, the present study also plans to explore the effect of overlapping different factors. One study compared unimodal working memory training to multimodal working memory training *and* high-intensity cardiovascular training (and other comparison groups that are out of the scope of this literature review); after three 70-minute sessions, participants who received multimodal training significantly enhanced their performance on various cognitive tasks (including a task based on working memory updating) compared to the unimodal and control groups (Ward et al., 2017). Nonetheless, more research is required to corroborate these results and identify the relationship between the overlap of physical activity and mindfulness meditation, and of mindfulness meditation and cognitive training.

In conclusion, some research supports the positive effects of working memory training, physical activity, and mindfulness meditation on working memory capacity, individually. Some research also supports combining working memory training with physical activity to affect working memory capacity. Even so, more research is still necessary to identify which of these factors best improves working memory capacity and also the effects of overlapping each factor. The present study aims to address these matters.

Experiment

To reiterate, my hypothesis is that working memory training, physical activity, and mindfulness meditation will influence working memory capacity in a positive manner, and combining these factors will yield an even greater positive effect. To test this

hypothesis, I will conduct a randomized, controlled experiment with the following eight groups: (1) working memory training group, (2) physical activity group, (3) mindfulness meditation group, (4) working memory training and physical activity group, (5) physical activity and mindfulness meditation group, (6) mindfulness meditation and working memory training group, (7) working memory training, physical activity, and mindfulness meditation group, and (8) active control group.

Each group will receive 45 minutes of intervention per factor, twice a week, for four weeks. The groups involving working memory training will be trained in the N-back task, which is associated with working memory and general intelligence. The groups involving physical activity will conduct a cardiovascular fitness regimen in which exertion will be assessed using a heart rate monitor. The groups involving mindfulness meditation will be trained using the Mindfulness Based Stress Reduction (MBSR) program. The control group will be active and receive visual search training (which is unrelated to working memory capacity) and conduct mild physical exercise, such as walking at a leisurely pace.

To assess working memory capacity, all participants will complete an operation span task before and after intervention. Furthermore, researchers will use an electroencephalograph (EEG) as participants complete the operation span task to detect changes in electrical activity from before and after the intervention. Researchers will use an EEG, as opposed to another neuroimaging technique, because EEGs are relatively fast and non-invasive, which is most convenient for a large number of participants. An EEG may also provide insight into other domains that the interventions may influence. For example, one group may activate brain regions associated with working memory *in*

addition to brain regions associated with emotional regulation. Such a finding may have important implications for individuals who struggle with emotional control.

Each group will consist of 50 participants, for a total of N = 400 participants. Participants will be recruited from various universities and compensated with extra credit—in participating courses—for completion of the experiment. The goal of this means of compensation is to provide motivation and prevent attrition of participants so the experiment can have a large number of participants without needing a large amount of funding.

In addition, participants will be screened for disorders or conditions that affect working memory capacity or their ability to participate in the conditions of the experiment. This screening minimizes the chance that a confounding variable or subject-by-treatment interaction might influence the results instead of only the independent variable(s).

Results

My hypothesis is that working memory training, physical activity, mindfulness meditation, and especially the combinations of these factors will increase working memory capacity. Specifically, I predict that the combination of all three of these factors will increase working memory capacity the most, followed by the multimodal groups, then the unimodal groups, and lastly the control group.

In terms of each factor, I predict that the mindfulness meditation factor will have the greatest influence, followed by the working memory training factor and then the physical activity factor. This prediction is based on the consistency of these factors being effective in the literature review.

I also predict that the multimodal groups will be more effective at increasing working memory capacity than the unimodal groups because this finding was observed in a previous study. Furthermore, another study speculated that different methods may affect different *components* of working memory. If this speculation is true, increasing the number of factors may increase the number of components of working memory that are affected, thus increasing overall working memory capacity to a greater degree. Moreover, if each component is associated with a different brain region, the EEG could assess which brain regions are currently being activated and which ones require further activation, so all regions can ultimately be activated.

Discussion

Significant results of this study would potentially have great implications for individuals who seek to improve their working memory capacity (or a related concept such as problem-solving ability, attentional control, or inhibition). Although the ability to improve working memory capacity could benefit *all* individuals, this ability is particularly useful for individuals with deficits in working memory—for example, individuals who have suffered a stroke, aging adults, and individuals with disorders such as ADHD, multiple sclerosis, down syndrome, schizophrenia, and fetal alcohol spectrum disorders (Morrison et al., 2011). This ability is also useful in specific *environments* that may impair working memory—for example, a high-stress environment such as being in the military (Jha, 2010).

However, in addition to having many important implications, this study also has many limitations. For instance, the participants' expectations and motivation may be a

confounding variable. High expectations or motivation might improve performance whereas low expectations or motivation (e.g., boredom) might worsen performance.

Another limitation of the present study is that individual factors such as sedentary behavior or initial working memory capacity may affect improvements. One study found a negative correlation between sedentary behavior and working memory capacity even after controlling for physical activity (Felez-Nobrega et al., 2017). Another study found that individuals with higher working memory capacities benefited more from working memory training than individuals with lower working memory capacities (Swanson, 2015).

Furthermore, the present experiment cannot confirm that improvements on the working memory measure correspond to improvements in working memory capacity. Perhaps the factors affect a concept other than working memory capacity, but one that affects the working memory task, such as improved control over attention. Or perhaps improvements are limited to the specific measure being used to assess working memory and these improvements are not representative of improving the underlying construct of working memory. Including more measures of working memory could confirm that improvements are not specific to a single task but they might introduce a new confounding variable: the "test taking" effect, in which participants improve performance through practice of similar tasks (Morrison et al., 2011).

Finally, the study is limited by its pool of participants (e.g., perhaps only college-aged participants are affected by working memory training) and the measures of each factor (e.g., perhaps the participants in the physical activity group are not active *enough* to experience the positive effects).

In addition to attempting to overcome these limitations, I recommend that future studies also explore the effects of different durations of each variable (e.g., maybe physical activity is most effective in the short-term but mindfulness meditation is most effective in the long-term), explore additional factors that may improve working memory capacity (e.g., brain stimulation), and assess the transfer and persistence of the present and future effects. Such improvements will assist researchers in assessing the best way to improve working memory capacity. And subsequent findings will assist the world, by allowing all individuals to reap the numerous benefits of an improved working memory capacity.

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