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Training With Online Working Memory Games Did Not Show Transfer Across Tasks

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Abstract

Online brain training has seen an exponential recent increase due to technology and claims of widespread and transferable benefits through training. At the frontline of these brain trainers is Lumosity.com, a for-profit organization with 50 million subscribers. Lumosity makes the bold claim that, "any brain can get better," and treats the brain as a muscle that can be trained. Our study will compare the effectiveness of Lumosity to other cognitively challenging tasks in building *transferable* **c**ognitive skills across the crystallized versus fluid intelligence barrier. We will approach this analysis from a memory perspective because of the necessity of working memory in everyday functionality, its proven potential to improve through training, and its multi-dimensional uses in both fluid and crystallized systems. We recruited approximately 100 student participants aged 18-24, sorted into 1 of 4 groups: No Contact Control, Alternate Task Control (Sudoku puzzles), Crystallized Intelligence Control (Trivia), and Experimental: Memory-Focused Lumosity. Participants completed "workouts" 3-5 times per week for 20 minutes, as directed by Lumosity experts for cognitive improvement. Participants completed a Pre and Post test for analysis. Our statistical analyses determined if Lumosity's program is cognitively advantageous by comparing pre versus post tests, interaction, and skill transfer across crystallized versus fluid intelligence performance. No significant interactions were observed for any training groups across pre to post-test conditions, consistent with a lack of transfer of intelligence with online games. Our results provide insight into the mechanisms that underlie memory, how it is integrated into fluid intelligence, and overall human cognition.

Keywords: Cognitive Training, Transference, Working Memory

1. Background

Interest in the development of learning and memory, and how they can be maximized, has been on the rise. Technology is used as a mechanism to increase both physical and mental health. There has been an explosion of online brain-training programs on the market which claim to increase cognitive function, such as Happy Neuron, Cogmed, and Neuronix. Itunes and other sources have also seen the rise of many apps which claim to "train your brain" such as Elevate-Brain Training, Peak-Brain Training, Fit Brains Trainer, Eidetic-Learn, Remember, and the like. One of the most popular of these brain trainers is Lumosity.com™, with 50 million subscribers in 180 countries[1]. Its popularity, as well as the extreme claims of cognitive improvement made by the company, makes it an interesting candidate to investigate the effectiveness of online brain training in building transferable cognitive skills.

Promotional material for Lumosity.com™ makes strong claims for its improvements across all age groups, "Any brain can get better and Lumosity.com can help. It's like a personal trainer for your brain, improving your performance through the science of neuroplasticity. But in a way, it just feels like games. Start training with Lumosity.com right now and discover what your brain can do." Claims such as this indicate an expected improvement for anybody who undergoes the training, with little consideration for the multitude of other factors in cognition, such as age, health, and daily cognitive engagement. Lumosity claims to train both memory and attention.

Additionally, Lumosity has promotional material on their website indicating that their claims are supported by hard scientific evidence. One such claim is taken directly from the app description for Lumosity, "Lumosity is designed by neuroscientists to train memory, attention, and more. With foundations in the study of neuroplasticity, Lumosity games are used in research, and have been incorporated into studies done by top scientists worldwide." These are broad somewhat elusive statements, which endorse Lumosity as a legitimate, proven training program for the brain.

Limited scientific evidence exists to support the advertised claim that cognitive training can have widespread and transferable benefits. The current literature suggests that cognitive training may increase working memory, but not fluid intelligence[2,3]. Additionally, there is evidence that working memory capacity is variable, linked to differences in higher cognitive capabilities[4], but is also largely determined during early childhood, and cannot be altered later in life[5].

This lack of evidence and contradictory findings was addressed in a gathering held in 2014 by the Stanford Center on Longevity, bringing together the top psychologists and neuroscientists currently researching cognition, aging, and brain training. The majority opinion was that the claims of brain training companies are largely inflated and frequently backed by evidence that is only marginally relatable. The center published the group's conclusions in an article to which all participants committed as signatories. This indicated that, "in the judgment of the signatories, exaggerated and misleading claims exploit the anxiety of older adults about impending cognitive decline. We encourage continued careful research and validation in this field." This uncertainty within the professional community highlights the need for extensive research into the validity and reliability of brain training programs.

2. Working Memory

Lumosity and other brain training programs characterize working memory as a somewhat flexible cognitive resource which can either store a large number of representations at a low quality, or a small number of representations at a high quality[4]. However, most of the past and present research on this question of whether or not working memory capacity can be increased or decreased based on the quality of representations, has found that it cannot. The capacity of working memory is best defined as a limit on the number of items which can be stored. This limited capacity is a strong factor in cognition, and the variability of working memory capacity between individuals can be associated with a wide range of cognitive differences. This illustrates the significant role that working memory plays in daily functioning, as well as the potential benefits of discovering a mechanism to increase its capacity. As of yet the vast majority of scientific evidence has seen no such method capable of increasing working memory across all intelligence barriers.

2.1 Crystallized Intelligence

Crystallized intelligence is observed to be localized in the Temporal Poles of the brain[6]. It encompasses semantic knowledge, and can be characterized as "thinking inside the box." It is the type of knowledge which can be produced and enhanced in typical academic classes, with training. It is known to encompass topics such as math, rules, procedures, facts, and language. It is the equivalent of a computer-based algorithm for knowledge. A good example of crystallized intelligence is chess. Chess is a fixed game with a defined set of rules; as long as there is sufficient knowledge of those rules, problems presented can be solved, thus winning the game[6.]

2.2 Fluid Intelligence

Fluid intelligence is thought to be located in the Temporal-Parietal junction in the brain[6]. It is characterized as "thinking outside of the box" and solving problems abstractly. It is comparable to "insight" intelligence and can be associated with taking creative liberties and solving novel problems. Unlike crystallized intelligence, it is not documented that this knowledge can be taught, and it is unclear how to train this kind of "reasoning". A good example of fluid intelligence is when a chimpanzee has the realization to stack the present boxes in order to reach the reward of the banana. This is done with no prior knowledge, no conditioning, and no prompting. It is the "aha" moment of science. These two mechanisms, in combination with the Central Executive, which is located in the Frontal Lobe and is known to switch cognition from one mechanism to the other, comprise working memory[6.]

Similar to scientific evidence that claims working memory is immutable later in life, most of the scientific world is in agreement that fluid intelligence is largely dictated in childhood and highly unalterable later in life[5]. There is also consensus that substantial and specific gains can be achieved on trained tasks for working memory. However, there is little evidence of transfer effects that improve any non-trained mechanisms. Adaptive working memory training appears to be unable to improve working memory capacity in non-trained tasks, fluid intelligence, or other cognitive abilities[5].

2.3 Research Question

The necessity of fluid intelligence for everyday functionality highlights the reason that mechanisms for its improvement are so widely and readily sought after. The fixedness of this form of intelligence was widely accepted until evidence of plasticity emerged. Jaeggi and colleagues reported plasticity in adult fluid intelligence, and the transference of skills developed during working memory training to growth in fluid intelligence. Additionally, they defined a cognitive training mechanism for this improvement. This training incorporated working memory training tasks, similar to the mechanisms employed by Lumosity.

Our research question is whether or not working memory training can transfer to broader cognitive functions, namely fluid intelligence. Are these mechanisms of intelligence truly fixed, or can brain training programs like Lumosity help improve them? If so, can training in Lumosity for one task, such as memory, automatically transfer to overall intelligence? Studies have found results supporting both sides. Some have reported working memory increasing fluid intelligence, reading comprehension, mathematical abilities, and even neural changes. Other studies have failed to observe any such transfer of skills via working memory training[5].

3. Lumosity

Lumosity™ training consists of a combination of "games," some that are based on common cognitive and neuropsychological tasks, while others are designed by in-house scientists, as stated by a Lumosity™ promotional email. The games are reportedly set up to provide a complete and exhaustive exercise regimen for the entirety of the brain. The question that remains unanswered is, does training with these games actually increase overall cognitive function and intelligence? And if so, do these games increase this functionality any more than other kinds of mentally challenging endeavors? Are these games only improving working memory, or can they also increase fluid intelligence?

3.1 Current Debate

Research that shows the positive effects of Lumosity™ training in middle aged adults comes from employees of Lumosity's™ research division Lumos Labs, and thus must be evaluated for bias[7,8]. Current research regarding other modes of working memory training is unresolved, with some studies able to see improvement in fluid intelligence and problem solving[9,10], while others are unable to see any such improvements outside the gaming platform[3,5,11,12]. This presents a clear need for unbiased studies that probe the effectiveness of Lumosity™ training compared to other cognitively challenging tasks. We aim to assess the effectiveness of Lumosity compared to other challenging tasks, and determine whether working memory training in Lumosity™ can build transferable cognitive skills in college students at the University of North Carolina Asheville. Additionally, we seek to elucidate the relationship between working memory and fluid intelligence.

4. Procedure

University of North Carolina Asheville college students were recruited. The criteria for participation was that college students be between the ages of 18-24 years old, and have less than one consecutive week of formal brain training experience prior to participation. Upon joining Lumosity, the website offers a variety of options outlining specific skills, which can be targeted for improvement. These include "Memory", "Attention", "Speed", "Problem solving" and "Flexibility." We chose to focus on memory because much of the previous work investigating fluid intelligence improvement is focused on training working memory. Many of these studies view working memory as a cognitive construct associated with fluid intelligence[5]. Additionally, working memory is essential in everyday functionality, has shown recorded improvement through training, and can be converted into an adaptive design.

4.1 Participant Requirements

Once recruited, all participants signed a consent form and completed a series of pre-tests. We employed four tests, all drawn from the literature and approved as reliable and valid measures of working memory and fluid intelligence. We wanted to employ transfer measures assessing fluid intelligence, multi-tasking, working memory capacity, and crystallized intelligence. One of our four pre-tests was the Stroop Test, as a measure of cognitive flexibility and attention[14]. We also used the Memory Span test, similar to a running letter span or word-span task to measure working memory span and crystallized intelligence[3]. Additionally, we used a Paper Folding test to measure fluid intelligence and spatial reference memory, and the Ravens Matrix as a measure of fluid intelligence and visual inductive reasoning[3]. After pre-testing, participants were randomly assigned to one of four groups for cognitive training. Three groups were control groups, the No Contact Control, in which no formal brain training was employed, Alternate Task Control, where participants completed Sudoku puzzles, a commonly accepted cognitively challenging task, and Crystallized Intelligence Control, where participants completed trivia as their training to work their crystallized intelligence. Our experimental group was Lumosity Memory Training, where participants completed Lumosity training. Descriptions of the regimens kept by each group are detailed in Table 1.

This set up allowed us to test how other cognitively challenging tasks, in our case, Sudoku puzzles or trivia, compare to Lumosity™'s specifically designed brain-training games. Additionally, we were able to monitor if the learned skills from the cognitive training are transferable to overall intelligence through our pre and post test mechanisms.

Table 1: Description of the three control groups and experimental group. Participants were randomly assigned to one of these groups after completing pre-tests.

Control 1: No Contact	**Control 2: Alternate Task Sudoku**	**Control 3: Crystallized Intelligence Task Trivia**	**Experimental: Memory Lumosity**
- Will complete pre/post tests - Will **not** engage in any "brain-training"	- Will complete pre/post tests - Will engage in "brain-training" by completing medium difficulty Sudoku puzzles 3-5 times per week	-Will complete pre/post test -Will engage in "brain-training" by completing trivia tasks 3-5 times per week	- Will complete pre/post tests - Will engage in "brain-training" by completing 20 minutes of Memory-Focused Lumosity™ training 3-5 times per week

All formal training was completed 3-5 times a week for 20 minutes over 6 consecutive weeks. Training was monitored and confirmed by undergraduate researchers. Full access Lumosity accounts were provided to the participants randomly assigned to the Memory Lumosity group. These accounts were purchased in order to appropriately track the training habits of participants, as well as monitor their progress. Yearly Family Access plans were purchased, each allowing up to 5 different people their own accounts. Accounts were set-up under fictitious names and emails, also created by undergraduate researchers. Participants assigned to the alternate and crystallized task groups were provided with app names and login information for both sudoku and trivia.

4.2 Analysis

After 6 weeks of training, participants were recalled for post-testing. Post-testing consisted of the same 4 cognitive tests used as pre-tests, and was used to analyze participant improvement due to training. Data was then examined using a Two-Factor ANOVA analysis. Results were analyzed across the four groups, across pre versus post tests, and across interaction. A significant relationship via interaction would indicate the ability to increase cognitive function in multiple facets. Therefore, any significant relationship of interaction would inversely indicate an increase of fluid intelligence through working memory training, or transfer of skill through training.

5. Results

We recruited 89 participants, randomly distributed across the four training groups. No group displayed significantly higher pre test scores, suggesting that differences in post test scores would be unrelated to initial performance, and therefore due to online training mechanisms. Statistical analyses indicated significant differences between training groups on pre to post test scores across all four tests. However, there were no significant interaction effects across any of the four training groups. A significant interaction would have inversely indicated the ability for one training task to increase intelligence across the fluid, crystallized intelligence barrier, indicating skill transfer. This was not seen. For the Stroop test of fluid working memory a main effect of, $F(3,95) = 9.37$ $P<0.05$, was observed; although, no levels of significance were reached between pre and post test differences $F(3, 95)=0.80$ $P>0.05$ (Figure 1). In the Paper Folding Task, our second measure of fluid intelligence, there was a significant main effect of, $F(3, 95) = 4.35$ $p<0.05$ (Figure 2). Additionally, this test did reach levels of significance in pre to post test improvements, $F(1, 95) = 6.12$ $p<0.05$, across the experimental training groups versus the no contact control group. However, there was still no significance between interaction $F(3, 95)=2.29$ $P>0.05$. The Memory Span task, as a measure of working memory capacity and crystallized intelligence, did not reach levels of significance considering pre to post test changes across training groups; however, it did display a significant main effect on scores between training groups, $F(3, 95) = 4.74$ $p<0.05$ (Figure 3). The Ravens Matrix, as a measure of fluid intelligence did not reach levels of significance regarding pre to post test changes across training groups, or display any significant main effects on scores between training groups, $F(3, 95) = 2.02$ $p>0.05$ (Figure 4). No interaction effects were significant for any one training group or pre to post test mechanism, indicating the lack of transference across intelligence.

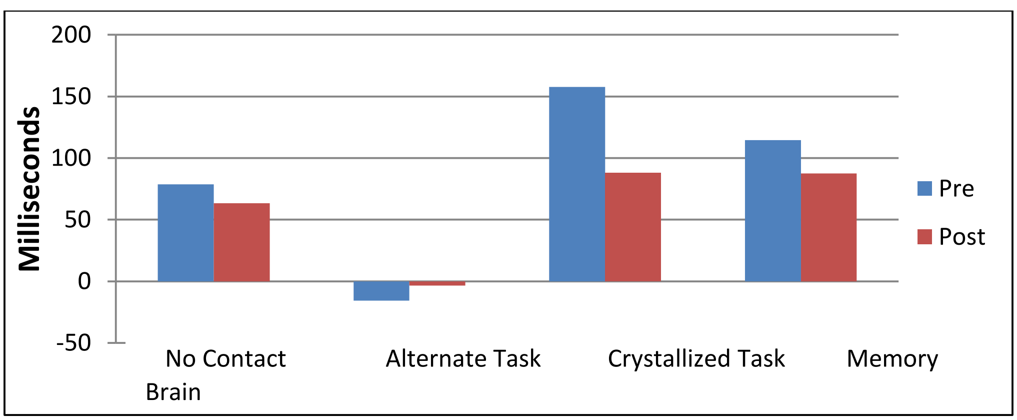

Figure 1: Pre to post test changes in Stroop Test. Participants tested before and after a 6-week training program. Analysis indicated no significant differences between pre and post test results $F(3, 95)=0.80$ $P>0.05$. No Contact n=12 , Alternate Task n=12, Crystallized Task n=12, Memory Brain Training n= 12.

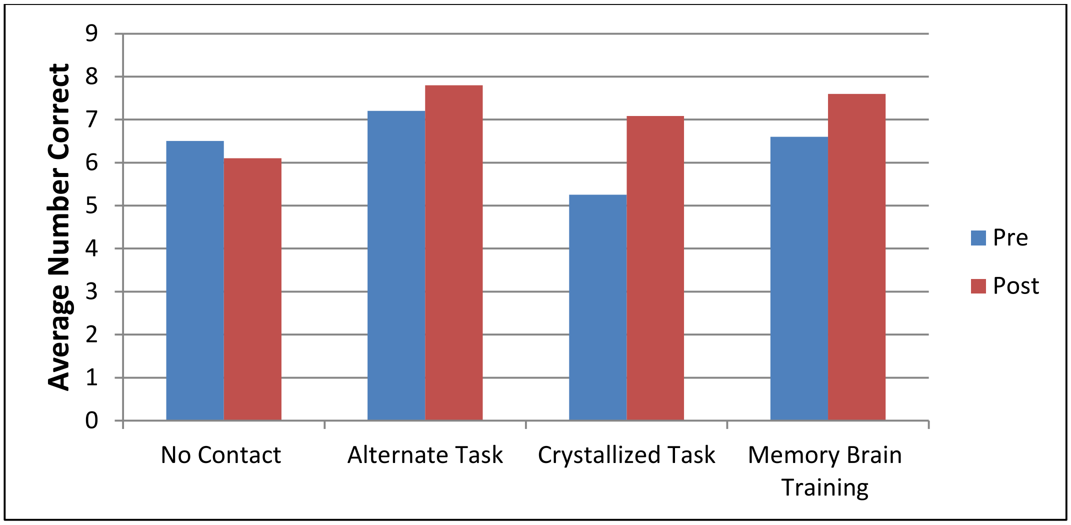

Figure 2: Pre to post test changes in Paper Folding Test. Participants tested before and after a 6-week training program. Analysis indicated significant differences between pre and post test improvements $F(1, 95) = 6.12$ $p<0.05$. No Contact n=12 , Alternate Task n=12, Crystallized Task n=12, Memory Brain Training n= 12.

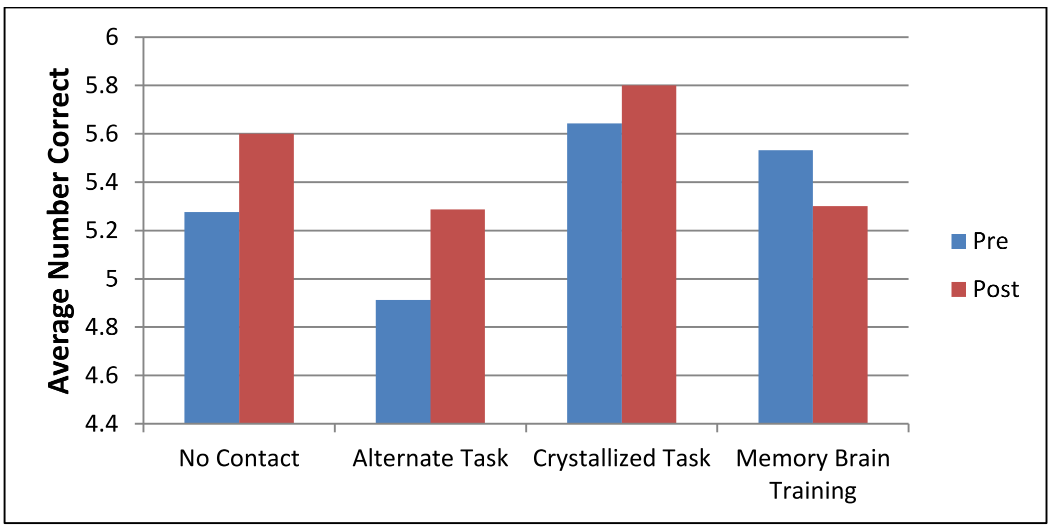

Figure 3: Pre to post test changes in Memory Span Test. Participants tested before and after a 6-week training program. Analysis indicated a significant main effect between training $F(3, 95) = 4.74$ $p<0.05$. No Contact n=12 , Alternate Task n=12, Crystallized Task n=12, Memory Brain Training n= 12.

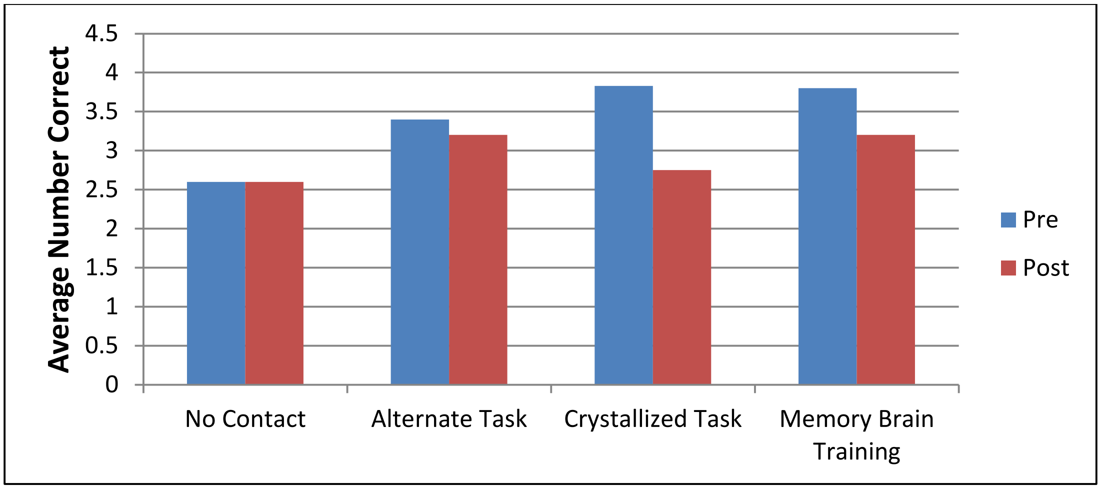

Figure 4: Pre to post test changes in RAVENS Matrices Test. Participants tested before and after a 6-week training program. Analysis indicated no significant main effects on scores between training groups $F(3, 95) = 2.02$ $p>0.05$. No Contact n=12 , Alternate Task n=12, Crystallized Task n=12, Memory Brain Training n= 12.

6. Discussion

We found that one can improve their cognitive ability in practiced or trained tasks. This is consistent with the majority of previous findings, and highlights the necessity of practice and training. However, we saw no transference of intelligence or skill across the fluid versus crystallized intelligence barrier. Our data was in accordance with Redick et. al. (2013) and in disagreement with Jaeggi et. al. (2008). Our results suggest that one can improve one's ability to complete specific tasks, but these tasks seem to have no transference to overall intelligence. There is an obvious need for continued studies to investigate all parameters and demographics that could potentially influence the effects of online brain training. The lack of skill transfer may be a result of the high degree of cognitive engagement and resource depletion typical in college students. Further research is warranted examining these systems in populations that are potentially less cognitively challenged and engaged than college students are in their daily life.

However, high school and college students, as well as the elderly, are target populations of the brain training industry. For example, MindSparke advertises that after 19 days of training, college students exhibited a 40% increase in "visual and aural working memory" compared to a control group. They cite this finding as being proof that their regimen can boost SAT scores. Additionally, HighIQpro asserts that scores on SAT and GRE tests are highly correlated with IQ. One of the best ways, they suggest on their website, to improve IQ and "overall levels of cognitive performance" are brain training apps**.** These claims are much like those of the Lumosity app, "Designed by neuroscientists, a brain training approach such as Lumosity builds on breakthrough concepts such as neuroplasticity and fluid intelligence." These programs make very bold statements under the premise of science ensuring results, and our results, as well as much of the primary literature[3] indicate that the benefits of brain training are limited and may be as easily achieved through other domains, such as exercise. This highlights the need for unbiased studies, like ours, measuring the potential of transferability and increase of performance through brain training.

Lumosity experts refer to the brain much like a muscle in the sense that it can be trained. This is not necessarily the case; rather, it seems that only certain systems, namely crystallized intelligence, can be improved through training. An appropriate analogy for the difference between crystallized and fluid systems, is the difference between weight training and distance running. In weight training, strength increases, but there is no transference of the ability to lift more weight to the ability to run further. Similarly, in practicing Lumosity for 20 minutes 3-5 times a week, scores will go up; however, this does not mean that novel problems will be able to be solved quicker or more efficiently outside of the gaming platform.

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