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Cognitive Flexibility Training May Indicate Evidence Of Training Effect But Does Not Show Transfer To General Fluid Intelligence In College Students

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Abstract

Recently, there has been an increased interest in cognitive training due to claims of widespread and transferable benefits of online brain training games. At the frontline of these training programs is Lumosity.com, a commercially available product with 50 million subscribers. A growing body of literature supports the idea that working memory and cognitive flexibility, two skills on which Lumosity™ training can be focused, are linked with fluid intelligence and academic success. The literature is less consistent, however, on whether or not lasting improvements in cognition can be made through training these skills. Our study compared the effectiveness of cognitively challenging tasks, including Lumosity™'s program, in building transferable skills that contribute to improvements in fluid intelligence. We recruited approximately 100 student participants aged 18-24, randomly sorted into 1 of 5 groups: No Contact Control, Alternate Task Control (Sudoku puzzles), Crystallized Intelligence Control (Trivia), and Flexibility-Focused Lumosity™. Participants completed "workouts" for cognitive improvement 3-5 times per week for 20 minutes, as recommended by Lumosity™'s website. Pre- and post-test measures of flexibility and fluid intelligence were compared after six weeks of training. Our results showed improvements in measures of flexibility and fluid intelligence, but no significantly greater improvement for any particular training group. Our data suggests that adding brain training programs to college classrooms would likely not be an effective pedagogical tool to increase cognitive skills. This finding agrees well with the most current research on cognitive training programs as well as the emerging expert consensus recently illustrated by an open letter from the Stanford Center for Longevity, and charges of misleading advertising brought against Lumosity™ by the Federal Trade Comission[1,2].

Keywords: Cognitive training, fluid intelligence, working memory

1. Introduction

1.1 Cognitive Training Games

Interest in the development of learning and how it can be maximized has been on the rise. Some of the greatest focus has been on the use of games to train specific cognitive functions due to the ease of use, inherent motivating factors, and accessibility on digital platforms. If game-based interventions are proven to be effective in improving cognition, the findings would have profound implications in many domains including education, therapies for patients with neurological injuries, and combating age-related cognitive declines[3,4,5,6].

An increasing presence of personal electronic devices has been followed by a growing number of digital game-based products that are claimed to improve cognitive function and even increase overall intelligence. One of the front-runners of these programs is Lumosity™, which claims to improve brain performance through the puzzles and games offered on its website and app. Although Lumosity™ continually asserts that their product is backed by science, there is actually little scientific evidence to support the advertised claims. In fact, many of the papers referenced in Lumosity™'s marketing are authored by scientists from the company's very own, Lumos Labs, and so must fall under special scrutiny[7,8]. There has been some research to support claims of transferrable training benefits in specific populations such as older adults, but little to support the broader claim that any brain can get better.

The findings on cognitive training in healthy individuals reported by independent research groups are mixed. The most promising support originally came from a study by Jaeggi et al. (2008) that produced novel evidence of improvements to measures of general fluid intelligence through computer-based working memory puzzles[9]. That study spurred an increased interest in working memory training games as tools for improving overall cognition. However, several studies have since been conducted that incorporated direct critiques of the findings of Jaeggi et al.'s original paper, and the case surrounding working memory interventions is weaker than it originally appeared[9,10,11,12].

1.2 Cognitive Flexibility

When signing up for Lumosity™, the program provides a series of options outlining skills that can be targeted for improvement. These include "Memory", "Attention", "Speed", "Problem solving" and "Flexibility." The "Attention", "Speed", and "Problem solving" options contain games aimed at improving these cognitive abilities. The "Flexibility" option contains games geared towards improving cognitive flexibility. For the purposes of this study, it was determined that cognitive flexibility is a skill central to success in the classroom, and that there would be some overlap between this cognitive ability and general fluid intelligence.

Cognitive flexibility is the ability to switch back and forth between multiple goals, rules, or pieces of information. Current research supports the idea that flexibility is closely related to learning, at least in young school children[13,14,15,16]. In studies looking at groups affected by various psychological disorders, flexibility has also been shown to be an important factor in emotional health. Very few studies have looked at explicitly training flexibility, especially in the general population, but the limited research seems to indicate that flexibility is a skill that can be enhanced[17,18,19,20,21]. However, there is little evidence to suggest that the relevant training would result in widespread improvements in cognition and in fact, flexibility may not be correlated with general intelligence at all[22].

1.3 Current Study

In the current study, we seek to further clarify the effects on general cognition that result from exercises that target specific cognitive abilities. Specifically, we compare several forms of digital game-based training strategies including the Lumosity™ training program. This study focuses on the effects on cognitive flexibility and fluid intelligence after exposing college students (ages 18-24) to these brain training games, in addition to whether training in cognitive flexibility transfers to improvements in general fluid intelligence. Many of these brain training platforms are advertised as providing training benefits for all age groups. If improvements are seen in this group in particular, whose members are assumed to be at their peaks in cognitive performance, an effect would likely be seen in all other age groups as claimed by the advertising. Given the extensive body of literature supporting the idea that fluid intelligence is generally an untrainable cognitive skill, it is expected that any improvements that may arise from training will not be significantly different from practice effects.

A major concern regarding previous studies on cognitive training has been the use of inadequate control groups. Comparing an active training group to a no contact control group may show misleadingly inflated effects resulting from the difference between cognitively engaged participants and cognitively stagnant participants, rather than effects resulting from the nature of the training itself. To control for this issue, we used two different active control groups in addition to the inactive, no contact control group.

2. Methods

2.1 Participants

Upon IRB approval, participants were recruited from UNCA's undergraduate student body. New groups were recruited at the beginning of each semester from the Fall of 2014 to the Fall of 2015, for a total of four separate periods. Recruitment was conducted via flyers that advertised a "brain training" study, in-class sign-up sheets, and UNCA's psychology research participation shell on Moodle. Participants were offered "Psychology and Life" event participation credits, a requirement for most psychology classes at UNCA, and were entered into a drawing to win a $20 gift certificate to a local ice cream shop to decrease attrition and promote adherence to the training requirements. All participants were given an informed consent to sign before participation in this study and told they could withdraw at any time for any reason.

2.2 Procedure

Participants were given a battery of tests to measure cognitive flexibility and fluid intelligence before and after six weeks of completing training exercises for the Lumosity™ prescribed minimum requirement of 20 minutes a day for 3-5 days a week. At the end of the pre-testing session, participants were randomly placed into one of four different groups, including a no contact control group that required participants to not complete any form of brain training exercise for the six weeks. The remaining four groups included two active control groups (crystallized intelligence "trivia" and alternate task "Sudoku") and an experimental group (Lumosity™ "Flexibility").

A total of 87 participants were recruited over the course of 4 semesters. 23 participants were excluded from the study either due to voluntary withdrawal or failure to complete a sufficient number of training sessions. Total number of participants that completed the experiment was 64, n = {15, 17, 17, 15} for no contact, alternate task, crystallized intelligence, and flexibility groups, respectively.

2.2.2 *stroop task*

The Stroop Task is one of the most prolific tasks in psychological study with more than 700 related articles relating to attention, conflict, decision making, and automaticity since J.R. Stroop's original dissertation[23]. In this study, the scores on the Stroop task are meant to index the level of cognitive flexibility in participants. The classic Stroop task and/or variations of it have been used to measure flexibility in many studies before, either independently or as a component of a battery of tasks[20,24]. The Stroop task was also conducted using CogLab 2.0. The participant begins a trial by pressing the spacebar and a fixation dot appears in the middle of the window. After less than a second of staring at the dot, a word for one of three different colors appears on the screen, RED, GREEN, or BLUE, with each of the font colors of these words presented in either red, green, or blue. The participant is asked to identify the font color of these words as quickly as possible. An incorrect response is presented again at a later trial. This task contained 48 trials, 24 with matching font color and word, and 24 in which they don't match. The difference in response times between congruent trials and incongruent trials were calculated and are presented as Stroop savings scores.

2.2.3 *paper folding and matrix reasoning*

Fluid intelligence was measured with two tasks: the matrix reasoning subtest of the Wechsler Adult Intelligence Scale-III (WAIS-III), and the paper folding task. Due to a positive inter-correlation between them, both tasks have been successfully used together in batteries to measure general or fluid intelligence[25,26]. Matrix reasoning tasks have been widely used in measuring general intelligence[27]. In this task, participants are shown a set of patterns arranged in a grid, with one cell of the grid empty. They must choose from five possible choices the shape that would best complete the pattern if it were placed in the empty grid. Paper folding is used to assess an individual's spatial reasoning abilities which have been linked to general cognitive factors[28,29,30,31]. In the paper folding task, participants are shown an image of a piece of paper that has been folded in a specific pattern, and then had a hole punched through it. They then choose from a selection of images what the paper would look like if it were unfolded again, based on how the holes would be arranged. In both tasks, scores were calculated by summing the number of correct responses.

2.2.4 *training groups*

In the first active control group, participants completed online trivia games at the site, Sporcle.com. Unlike fluid intelligence, crystallized intelligence, or knowledge of facts and figures, can be improved through training. A group that is explicitly training crystallized intelligence should not show any improvements to fluid intelligence beyond those effects that may arise from general engagement and stimulation. Thus, any improvements to fluid intelligence in the other training groups must show improvements beyond those of the crystallized intelligence group. Participants in the second active control group completed Sudoku puzzles regularly. There is a long held belief that practicing puzzle games such as Sudoku helps to maintain cognitive function, and Sudoku contains many elements of cognition and intelligence including spatial and numerical reasoning, making the puzzles an appropriate paradigm to which to compare Lumosity[TM]'s program. The experimental group required participants to play any of the games on the Lumosity[TM] website using accounts that were set up to prioritize flexibility training.

3. Results

Improvements can be observed from pre- to post- test in each testing measure for each group in (Figure 1). One-way analyses of variance (ANOVAs) indicated that there were no significant difference in scores among groups at pre-testing (paper folding: $F(3,60)= 1.625$, $p> 0.05$; matrix reasoning: $F(3,60)= 0.269$, $p> 0.05$; Stroop: $F(3,60)= 1.313$, $p> 0.05$). Scores in each of the four tasks were analyzed by 4x2 mixed-effect ANOVAs, with a between subjects factor of training group (no contact, crystallized intelligence, alternate task, or flexibility), and a within subjects factor of testing time (pre- or post-training). F-scores from the ANOVAs were tested for significance at an alpha level of 0.05. Results from the ANOVAs are compiled in (Table 1).

Table 1. Significance testing results for cognitive measures. Significant p-values denoted with asterisks

	Group				Testing Time				Group X Testing Time		
	F	p	η_p^2		F	p	η_p^2		F	p	η_p^2
Paper Folding	0.677	0.569	0.033		5.675	0.020*	0.086		2.079	0.112	0.094
Matrix Reasoning	0.352	0.788	0.017		9.762	0.003*	0.140		0.501	0.683	0.024
Stroop	2.562	0.063	0.114		1.917	0.171	0.031		0.254	0.858	0.013

The ANOVAs revealed a main effect of testing time for two of the three cognitive ability tests (paper folding: $F(1,63)= 5.675$, $p= 0.020$; matrix reasoning: $F(1,63)= 9.762$, $p= 0.003$), with no main effect of testing time for the task, $F(1,63)= 1.917$, $p= 0.171$. There was no main effect of training group for any of the tasks, nor were there significant interactions between training group and testing time.

Normalized mean gain scores were also calculated to further compare the improvements observed between groups from pre- to post- test with the results displayed in (Figure 2).

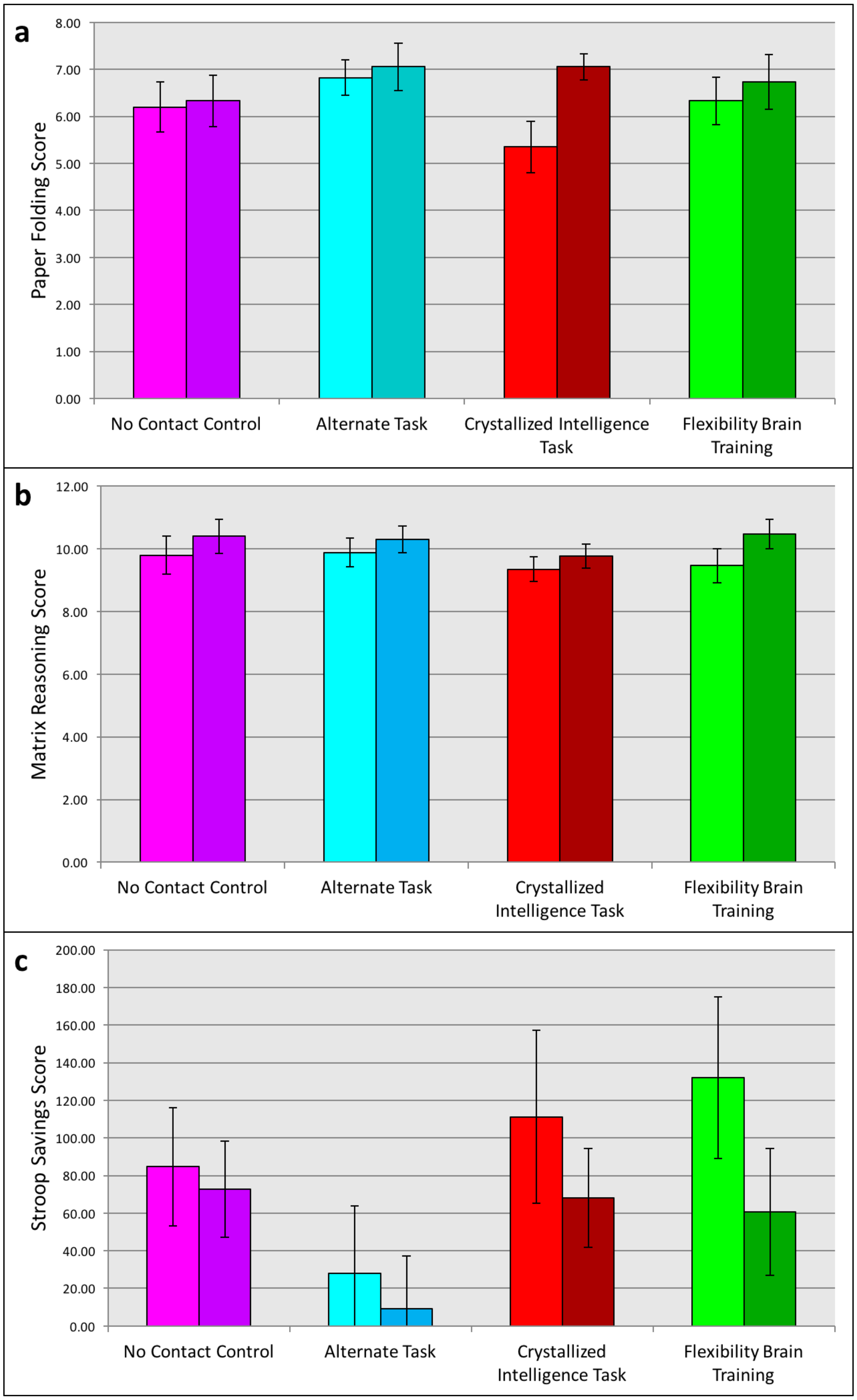

Figure 1. Average test scores for each training group, before training and after training. Left, lighter bards indicate pre-test scores and the right, darker bards indicate post-test scores. Error bars represent one standard error. a) mean number correct responses in paper folding task. b) mean number of correct responses in matrix reasoning task. c) mean difference in response time between congruent and incongruent trials in the Stroop task.

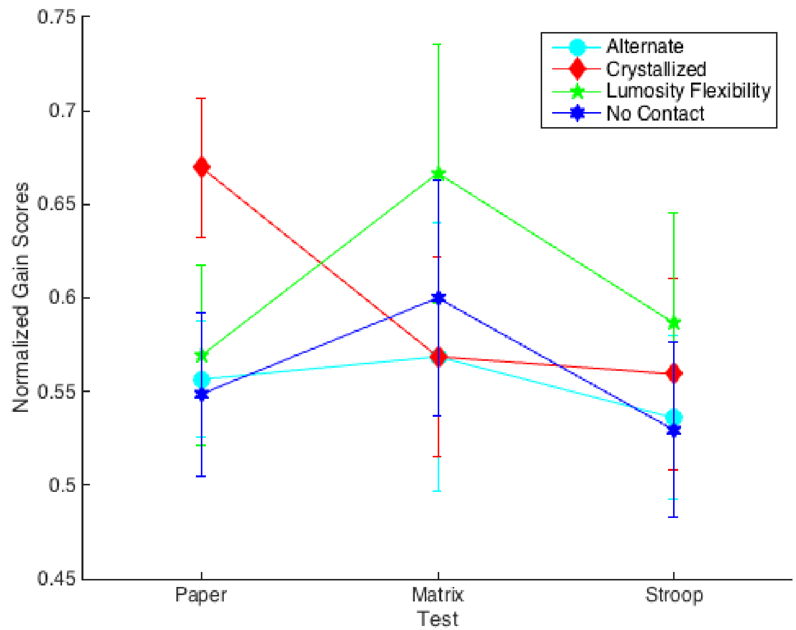

Figure 2. Normalized mean gain scores for all groups in each task. Error bars represent one standard error. Raw scores were normalized to account for differences in scaling among the testing methods. Normalized scores for each group were calculated by the formula $(X - X_{min})/(X_{max} - X_{min})$, where X is each score raw score, X_{min} is the minimum score for the group, and X_{max} is the maximum score for the group.

4. Discussion

Our study revealed no significant improvements in cognitive flexibility or fluid intelligence as a result of cognitive training programs. While there were improvements in some measures of cognitive ability during the training period, none of the tested training programs appear to be more effective than any other. The gain scores in the experimental group and the active control groups did not significantly differ from the gain scores of the no contact control group, possibly indicating that the improvements were merely practice effects in the pre- and post-test tasks themselves. Another possibility is that participants experienced some level of cognitive enhancement that inherently occurs for college students over the semester as a result of the curriculum.

These results agree with the most robust findings of other studies on cognitive training programs. Although there have been numerous claims of training related improvements to measures of general intelligence, many of those claims have since failed to hold up to critical reexamination[32,33]. Studies that employ sound methodological practices such as using adequate sample sizes, active control groups, appropriate pre- and post-test measures, and proper statistical analysis have typically failed to find evidence that cognitive training is effective[12,32].

4.1 Limitations

In order to create tests of manageable length, only subsets of full intelligence testing batteries were used. Fluid intelligence consists of a wide array of specific cognitive abilities that share complex interactions that depend on current goals and context. Ideally, many different tests would be conducted to provide greater power, sensitivity, and reliability to measures of changes in intelligence. In a critical analysis of multiple working memory training studies, Redick et al. (2015) urges researchers to compile multiple outcome measures to reduce error variance[32]. It should be noted that, in an earlier paper by Redick et al. (2013), 17 different tasks were used in the pre- and post-test batteries yet still did not detect significant training-related improvements to cognitive ability[12].

5. Conclusion

The findings of this study add to the growing body of research that opposes the claim that training specific cognitive skills such as working memory or cognitive flexibility induces widespread improvements to cognition. One of the main critiques of many studies that have shown improvements from cognitive training has been the lack of appropriate control groups. This study addressed that concern, allowing comparison of the experimental group to active and inactive control groups. It is shown here that game-based cognitive training programs, based in improving cognitive flexibility, do not produce significant transferable improvements to fluid intelligence in college-age participants.

The scientific community and regulatory entities seem to be coming to a similar consensus on the true nature of commercial cognitive training programs. In 2014, an open letter from the Stanford Center on Longevity challenged the claims of companies that claim to provide effective brain training programs. Signed by a long list of esteemed scientists, the letter objects to the claims of brain training companies that their products offer scientifically-backed solutions for combating cognitive decline[1]. Additionally, the Federal Trade Commission (FTC) just recently charged Lumosity™ with deceiving its users by claiming that its products would improve cognitive health, and subjected the company to a heavy fine[2]. Our results support the sentiment increasingly expressed by experts across the field; there is little evidence to suggest that cognitive training programs are effective in improving or protecting general cognitive ability.

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