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RESEARCH ARTICLE

Efficacy of Corsi Block Tapping Task training for improving visuospatial skills: a non-randomized two-group study

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Abstract

Even though impaired visuospatial abilities can negatively affect daily functioning, there are very few training programs that attempt to improve visuospatial abilities. The purpose of this study was to examine if a single training session with a computerized version of the Corsi Block Tapping Task could improve mental rotation skills. Fifty-three young adults were assigned to one of two groups: (1) control group (mean age = 21.4; 10 females), who had 20 min of rest after their baseline assessment, or (2) training group (mean age = 21.5; 17 females), who had 20 min of training on the Corsi Block Tapping Task after their baseline assessment. The primary outcome was reaction time on a computer-based mental rotation task, and it was assessed both before and after the rest or training. There was a significant interaction between time (pre vs. post) and group (control vs. training) on mental rotation performance ($p = 0.04$), with the training group performing on average 124 ms faster on accurate trials than the control group at post-test. This preliminary study suggested that improving mental rotation may be feasible through targeted cognitive training. Future studies will consider multiple sessions of Corsi Block Tapping Task training to maximize training benefits (i.e., dose–response), as well as longer term retention in cognitively intact and impaired individuals.

Keywords Corsi Block Tapping · Visuospatial working memory · Mental rotation · Cognitive training

Introduction

Visuospatial deficits negatively impact daily functioning and quality of life (Bosma et al. 2020; Burdick et al. 2005; Edmans et al. 1991; Fukui and Lee 2009; Lau et al. 2015; Maeshima et al. 1997; Rodriguez et al. 2015). For example, poor mental rotation and other visuospatial abilities can negatively affect driving (Aksan et al. 2015; Kunishige et al. 2020; Ma'u and Cheung 2020; Mathias and Lucas 2009; Overton et al. 2015; Tinella et al. 2021). Visuospatial perception and construction (which relies on mental rotation) have also been predictive of a range of performance-based activities of daily living (e.g., health and safety, managing money, home, and transportation) in older adults with Mild Cognitive Impairment (Duff et al. 2020). Visuospatial deficits are associated with slower recovery and long-term outcomes following stroke (Kalra et al. 1997; Kotila et al. 1986; Lincoln et al. 1989), and deficits in mental rotation and visuoconstruction have been shown to be predictive of eventual Mild Cognitive Impairment and Alzheimer's disease, up to 20 years prior to diagnosis (Caselli et al. 2020; Johnson et al. 2009; Rizzo et al. 2000). Despite the significant impact visuospatial deficits have on daily life, there are relatively few behavioral therapies for mild-to-moderate visuospatial impairment. Thus, there is a need for developing ways to improve visuospatial abilities.

Computerized cognitive training programs are becoming popular because of their ease of administration, minimal personnel requirement for the training, and control over factors such as the frequency and duration of training. However, very

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few studies (such as (Belchior et al. 2019) have targeted visuospatial ability specifically, and general computerized cognitive training programs has not shown efficacy in targeting the visuospatial domain (Bonnechère et al. 2020). Regarding computer-based methods for improving visuospatial abilities specifically, some video games have been developed as cognitive training tools (Sanchez 2012), and recreational videogame play has been shown to promote visual skills (e.g., acuity, processing speed) (Green and Bavelier 2003; Jacques and Seitz 2020; West et al. 2008). However, these games may not impact more complex visuospatial abilities (Appelbaum et al. 2013; Blacker et al. 2014; Milani et al. 2019; Toril et al. 2016; Wilms et al. 2013), because they lack specificity in targeting or engaging critical visuospatial features (Oei and Patterson 2013) like mental rotation or visuospatial working memory. The ability to target mental rotation is of interest for improving activities of daily living (Meneghetti et al. 2018; Moen et al. 2020), as well as other focused areas such as computational thinking (Città et al. 2019) and fine motor skill (Harrington et al. 2018; Tansley et al. 2007; Wanzel et al. 2002).

Computerized training programs that do selectively target visuospatial ability have shown efficacy in younger children in improving mental rotation (Cheung et al. 2020; Rodan et al. 2019) and visuospatial working memory (Gizzonio et al. 2022). Visuospatial-specific training for adults has also been beneficial, but it has only been piloted in small samples (i.e., $n \leq 15$) (Cerasa et al. 2014; Folkerts et al. 2018; Smith et al. 2019; Tippett and Rizkalla 2014). Although most cognitive interventions span multiple days, there is evidence of improvement in visuospatial scores from a single session (Sanchez 2012). Furthermore, session-by-session data have shown that the positive benefits of training may be realized as early as one or two sessions (Kulzow et al. 2017). With the long-term goal of developing effective computerized visuospatial training for adults, this study tested the efficacy of training on a computerized version of the Corsi Block Tapping Test (CBTT) (Kessels et al. 2000) for improving mental rotation. Since both tasks involve visuospatial working memory (Berch et al. 1998; Hyun and Luck 2007; Prime and Jolicoeur 2010) and share common neural correlates (i.e., superior and inferior parietal lobules Carpenter et al. 1999; De Renzi et al. 1977; Gauthier et al. 2002; Gogos et al. 2010; Jordan et al. 2001; Vingerhoets et al. 2002) and hippocampal regions (Guariglia 2007; Toepper et al. 2010)), we hypothesized that a single session of CBTT training would improve mental rotation performance in an adult sample compared to a no-training control group.

Methods

Participants

Fifty-three adults (aged 23.74 ± 4.37 years, 37 females and 17 males; 53% Black/African, 11% Asian, 32% White, 6% Hispanic/Latino) were recruited through campus flyers and university announcements. Inclusion criteria included: at least 18 years old, right-handed, and without diagnosed neurological disorders. No additional exclusion criteria were applied. Informed consent was obtained prior to study participation. The study was approved by the Arizona State University Institutional Review Board (Study #00,013,577 and #00,009,764).

Mental rotation task

The mental rotation task, available as open-source from the Psychology Experiment Building Language (Mueller and Piper 2014), was chosen as the primary visuospatial outcome. The mental rotation task is computer-based, and very similar to the classic Shepard and Metzler's mental rotation task (Shepard and Metzler 1988) in which participants were presented with a pair of 2D asymmetrical objects, either identical or mirroring each other, on a laptop screen. Participants were instructed to respond as quickly as possible (by pressing either the left or right 'shift' keys on the keyboard) about whether the two objects were identical but rotated (left shift), or different from each other (mirror images) (right shift). The objects could be one of two 2D shapes, either resembling the letters "L" or "Z" (Fig. 1). We note that these are not actually the letters L and Z, minimizing concern that these shapes are overly familiar to participants. The pairs of objects were presented at one of eight possible rotational angles with respect to each other (− 135 to 180° degrees, at 45° increments). For each trial, stimulus shape ("L" or "Z"), condition (identical or mirror), and angle was randomly combined. Each combination was presented two times, resulting in 64 trials per session. Each stimulus was presented for 3000 ms, and feedback of response accuracy (correct or incorrect) was presented for 500 ms after each response. A trial with no response within 3000 ms was registered as incorrect. Reaction time, which was analyzed for correct trials only and was collapsed across all angles of rotation, was the primary outcome on the mental rotation task.

Corsi Block Tapping Task (CBTT)

The Corsi Block Tapping Test (CBTT) (Kessels et al. 2000), also administered through the Psychology Experiment

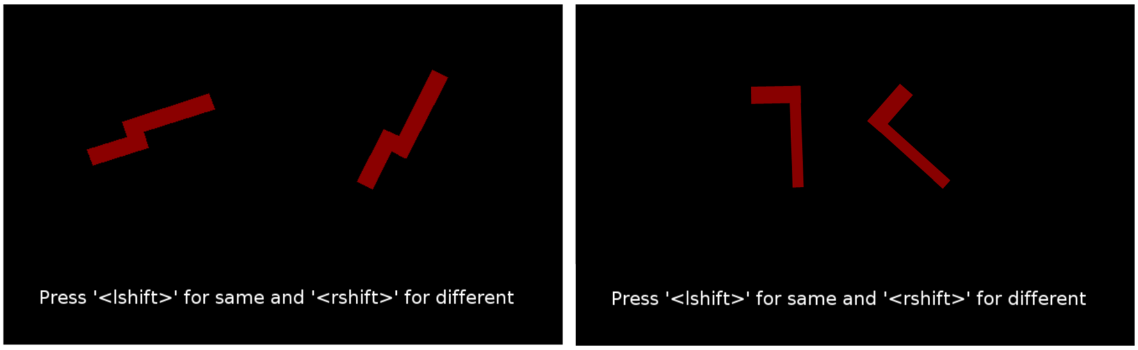

Fig. 1 Stimulus shapes for the mental rotation test

Building Language, was used for visuospatial training. This visuospatial working memory task instructs participants to memorize sequences of locations for squares on the screen. For any trial, nine blue square blocks were presented on the screen, and then, a certain number of the squares sequentially lit up in yellow, one at a time. Participants were instructed to memorize the sequence, and then click on the blocks in the same sequence. Difficulty of the task was manipulated through the number of blocks to be memorized per trial (i.e., ‘span’), the maximum of which was nine blocks. Its difficulty level was continuously adjusted based on performance to ensure challenge and cortical engagement (Thibaut et al. 2017), but set to 20 min to minimize participant boredom while maximizing repeated exposure. Three practice trials at a sequence length of three blocks introduced the task for each participant. Following practice, all participants started with a sequence of four blocks, and increased by one when participants completed two correct trials in a row until maximum difficulty of nine blocks was reached. Once a nine-block sequence was reached, it remained at nine-block sequences per trial for the rest of the training. The longest sequence reached during the training session and the accuracy for each trial (i.e., percentage of blocks correctly tapped out of the total) were measured.

Experimental design

Participants were assigned to one of two groups: a control group ($n = 28$; mean age = 21.4; 10 females) or a training group ($n = 25$; mean age = 21.5; 17 females). Due to protocol limitations associated with COVID-19, group assignment was not randomized and groups were collected at two different time periods at two different sites. Mental rotation was assessed before and after a 20-min period. For the training group, this included a 20-min session of the CBTT. For the control group, this included a 20-min session where participants completed a 21-question personality trait survey on suggestibility (the short version of the Multidimensional Iowa Suggestibility Scale) (Kotov et al. 2004), an active control condition to keep participants in the control group engaged on a computer screen with minimal visuospatial demands.

Statistical analysis

Our primary analysis used a linear mixed-effects model to analyze how average reaction time on the mental rotation task changed as a function of group (CBTT training vs. control). In the model, we tested for fixed effects of time (pre vs. post) and group (control vs. CBTT training), as well as an interaction between time and group, with sex as a control variable. To ensure that variances in the response variable, reaction time, were equal between groups we log-transformed the data. A Levene test was used to examine if the assumption of homogeneity of variance was met. Sex was a control variable based on previous research indicating sex differences in mental rotation (Falter et al. 2006; Jansen and Heil 2009; Kail et al. 1979; Tapley and Bryden 1977; Zapf et al. 2015). Random effects included intercepts by participant.

Two additional exploratory analyses were also conducted to test for training responsiveness. One exploratory analysis used a multivariable regression to predict post-training mental rotation reaction time with an interaction term between best span and average percent correct on the CBTT, with pre-training average mental rotation reaction time and sex as control variables. This analysis was performed only for the training group to examine whether more improvement on the CBTT during training was associated with more improvement on the mental rotation task (i.e., do participants who improved more on the CBTT also improve more on mental rotation?). We modeled an interaction term between best span and percent correct to account for the various strategies that participants employed during CBTT training (i.e., participants who achieve a high span with high accuracy versus participants who achieve a high span with low accuracy). A second exploratory analysis used a linear mixed effect model to examine if performance on the CBTT improves with training as well. The purpose of this analysis was to simply confirm the lack of ceiling effect on the CBTT, such that performance could actually improve with practice. We estimated how best span changes as a function of elapsed time and sex modeled as fixed effects, with random slopes and intercepts by participant. Due to variation in the total number of trials that participants completed during the 20-min CBTT training session, we used elapsed time during training (modeled as a continuous variable) as a proxy for trial number to indicate progression through training. This allowed for better estimation of improvements in best span as a function of practice compared to using strictly the trial number. This was because the training session was relatively unstructured in terms of the number of trials a participant completed throughout the course of training. Because the duration of CBTT training was constant across participants (i.e., 20 min), the number of trials and each trial duration was variable across participants. For example, if participants successfully completed the first two trials with a span length of 4, their third trial would have a span length of 5, which would take longer to complete than a participant whose third trial remained a span length of 4. Participants were not also required to complete any given trial within any specified time window. We also note that the time point of when each trial commenced during the 20-min session was converted to its logarithm to allow for comparison across participants, because participants experienced large gains in performance early on in training, followed by smaller gains later in practice; thus, a linear model may not be appropriate. We compared linear and logarithmic models using analysis of variance to determine which fit the data best.

Results

CBTT training improves mental rotation

Levene's test demonstrated that homogeneity of variance between groups was not significantly different ($p = 0.58$). The primary analysis for this study indicated that there was a significant interaction between time (pre vs. post) and group (control vs. training) on mental rotation performance ($p = 0.04$), with the training group performing on average 124 ms faster on accurate trials than the control group at post-test (Fig. 2). Importantly, post hoc pairwise comparisons by time and group demonstrated that there was no difference in average reaction time between groups at the pre-training measurement (control: 1474 ms vs. training: 1479 ms). Additionally, the control group did not improve on mental rotation simply due to re-testing (mean difference from pre- to post-test: 34 ms; $p = 0.86$). This indicates that this version of the mental rotation test shows minimal practice effects due to test/re-test. There was no statistically significant effect of sex ($p = 0.25$) nor race ($p = 0.32$) on mental rotation performance.

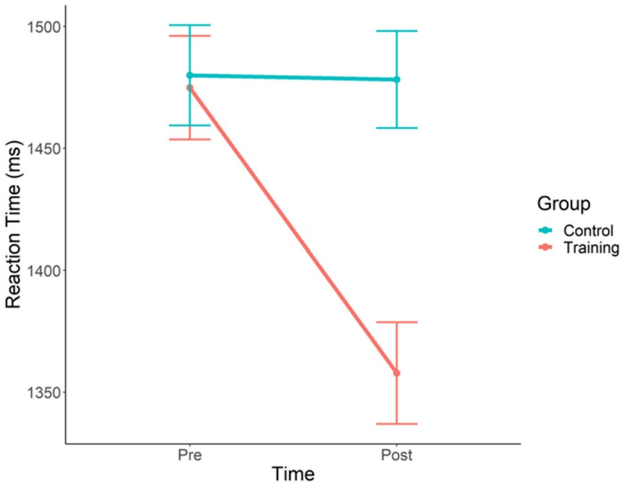

Fig. 2 Mean (SE) reaction time for the Mental Rotation task at pre- and post-test for the control and training groups

Improvements in CBTT correlate with improvements in mental rotation

Within the training group, exploratory analyses showed a significant interaction effect between best span and percent correct during training on post-training reaction time on the mental rotation test ($p = 0.002$, $\beta = -$ 106.5 ms, 95% CI [$-$ 168.77, $-$ 44.22]), while controlling for sex and average pre-training reaction time on mental rotation. For example, a person who had an average best span of 8 and an average accuracy of 80% correct over the course of training would have a predicted post-training mental rotation reaction time of 1192 ms, whereas a person with a best span of 8 and 70% correct would have a predicted value of 1358 ms post-training; a person with a best span of only 7, but an average accuracy of 80% correct would be predictive to have a post-training reaction time of 1463 ms, all while holding pre-training reaction time and sex constant. This indicated that participants who achieved a higher average span *and* higher percent correct on the CBTT during training (i.e., were more responsive to training) showed more improvement in reaction time on the Mental Rotation Task from pre- to post-training. This analysis relates the magnitude of mental rotation improvement to how responsive participants were to the CBTT training. There was no effect of sex on average post-training mental rotation ($p = 0.63$).

Lack of ceiling effect for CBTT

The analysis of variance comparing model fits of training data demonstrated that improvements on the CBTT followed a logarithmic trend rather than a linear trend (BIC log = 2170 vs. BIC linear = 3741; $p < 0.0001$), meaning that participants improved their best span early on in practice with smaller improvements later on, rather than improving incrementally over time. Exploratory analyses also showed that there was a significant effect of elapsed time on CBTT performance, such that best span improved as time in training progressed (log(trial time) = 0.85, $p < 0.001$) (Fig. 3). This suggests even in healthy younger adults, CBTT performance is not subject to ceiling effects and instead can improve with practice. This is the case for both males and females, as there was no statistically significant effect of sex on best span as a function of elapsed time during training ($p = 0.35$). Furthermore, we identified that only 10 of the 25 (40%) training participants reached the maximum 9-block span. Thus, practice on this task yields improvements in CBTT performance, and overall, the CBTT was challenging enough that the majority of participants did not reach the highest possible span.

Discussion

Since visuospatial skills are important to some activities of daily living and are affected in neurological disorders, there is a need for training programs to remediate deficits in this cognitive ability. The current study tested an intervention designed to improve these visuospatial skills. Specifically, we chose the Corsi Block Tapping Task (CBTT) because of its established protocol and relationship to visual working memory (Berch et al. 1998; Kessels et al. 2000), as well as its capability to be deployed digitally (Arce and McMullen 2021). In this quasi-clinical trial (meaning that participants were not randomized between groups) (Harris et al. 2006), we demonstrated that a single session of training on a computerized version of the CBTT improved performance on a mental rotation test, compared to an active control group. This study therefore expands on previous research in several ways. First, we note that this study tested a much larger sample size ($n = 53$) than previous experiments that examined visuospatial training in adults (which had samples ranging from $n = 4$ to 15) (Cerasa et al. 2014; Folkerts et al. 2018; Smith et al. 2019; Tippett and Rizkalla 2014). Second, exploratory analyses also indicated that within the training group, more improvement on the CBTT was associated with more improvement on the mental rotation test. This suggests that the benefits of (and responsiveness to) training were scalable, meaning that the extent of an individual's mental rotation improvement was related to the extent of their CBTT learning. To our knowledge, this study is the first to show this effect of individual responsiveness within a training group, rather than just showing differences between groups (Terlecki et al. 2008). Third, our findings demonstrate that even in young, healthy adults, CBTT performance can improve with practice, suggesting that visuospatial memory can improve with targeted training. Fourth, in agreement with previous work (Stephenson and Halpern 2013; Terlecki et al. 2008), this study suggests that improving visuospatial ability (specifically mental rotation) may be feasible through targeted visuospatial working memory training.

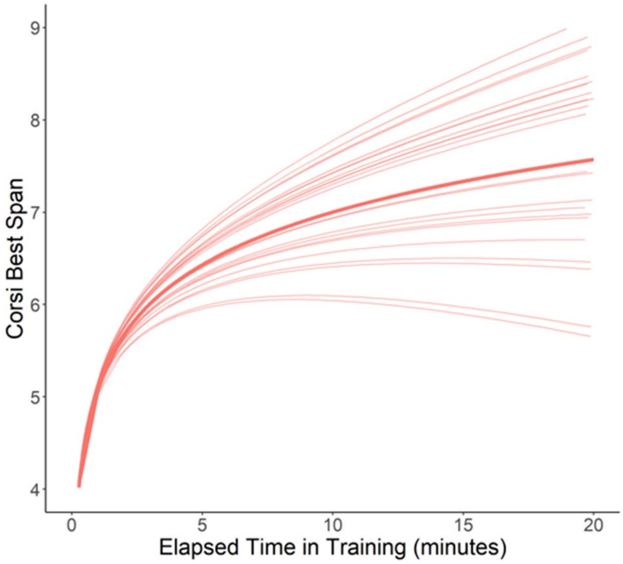

Fig. 3 CBTT best span over the course of training for each participant (thin line) and the training group overall (thick line), modeled as a logarithmic function

Very few computerized cognitive training intervention studies even report visuospatial scores as an outcome, as most focus on memory and processing speed (Ball et al. 2002; Lampit et al. 2014). In the studies that do, general cognitive training may not have significant visuospatial benefits (Barnes et al. 2009; Edwards et al. 2002; Leung et al. 2015; Miller et al. 2013; Sitzer et al. 2006), leaving open the question of how malleable visuospatial ability is. At minimum, results from this study indicate that visuospatial memory and mental rotation can improve with training, consistent with findings from exercise-based and virtual reality interventions (Kang et al. 2021; Nemoto et al. 2020). By demonstrating improvements in mental rotation following visuospatial working memory training, the current study informs how future interventions can address visuospatial aspects of daily function. For example, mental rotation is critical for driving (Aksan et al. 2015; Kunishige et al. 2020; Mathias and Lucas 2009; Overton et al. 2015; Sun et al. 2018; Tinella et al. 2021, 2020), since mental rotation is critical for correctly move in an intended movement direction (Pellizzer and Georgopoulos 1993); however, most training programs for improving driving in older adults do not target visuospatial needs (Castellucci et al. 2020). Thus, a salient application of our study would be including Corsi Block Tapping, or a similar visuospatial working memory task, as part of a driving program from older adults. Next steps for this work will determine the optimal dose and frequency of CBTT training to maximize and maintain improvements in mental rotation, and explore other 'active ingredients' of visuospatial training that may be beneficial. For example, playing a puzzle game like Tetris has been shown to be superior to a commercial brain training game (Brain Age) for improving visuospatial ability (Nouchi et al. 2013), but it is necessary to determine which aspects of the puzzle game are most critical to optimize the intervention. Future research should also explore the extent to which visuospatial training could improve upper limb motor control. Previous research has linked visuospatial deficits to upper limb motor deficits in people with Parkinson's disease (Haaland et al. 1997; Richards et al. 1993), and more recently, to upper limb motor learning in older adults generally (Hooyman et al. 2022; Lingo VanGilder et al. 2018, 2019; Wang et al. 2020). Thus, the results of this study may offer possible interventions not only for cognitive outcomes, but motor outcomes as well, whereby improving visuospatial function could have downstream effects on motor control.

This study included an active control group, which completed a written questionnaire on the computer in a 20-min period in between test and re-test on the mental rotation Task. We acknowledge that for many participants, however, the written questionnaire did not take the full 20 min, which left some participants in the control group sitting quietly and unengaged for longer than others. As such, it is possible that the CBTT training led to greater arousal or engagement of attention than the written questionnaire, which could also explain our results. At minimum, however, this study does show that improvement in the mental rotation task is not merely a practice effect, given that the post-test performance for the control group was not significantly different from pre-test (Geng et al. 2011). Furthermore, the results from this study demonstrate how training on CBTT transferred to mental rotation, suggesting that improvements in CBTT generalize (and scale) to other visuospatial skills. The ability to generalize training effects has been argued as an essential process for learning (Shepard 1987).

There are several limitations of this study. First, it only included a single, 20-min session of CBTT training and did not investigate longer term retention of mental rotation improvements. Thus, it is unclear how durable or persistent such improvements may be. However, the fact that the majority of participants did not achieve the maximum span of 9 during the training session suggests, based on the challenge point framework (Guadagnoli and Lee 2004), that the training benefits may be retained for longer. Evidence from a meta-analysis by Uttal and colleagues 2013 further suggest that the improvements in mental rotation may persist beyond the training period (Uttal et al. 2013). Future studies will include a prolonged training period and a retention assessment following a period of consolidation in cognitively intact and impaired individuals (Adduri and Marotta 2009; Perrochon et al. 2014) to better understand if there are lasting effects of the intervention. Second, the participants were not randomly assigned nor blinded to their groups, which were collected at two different sites, potentially leading to group differences related to other experimental factors besides the intervention. Future studies will adhere to greater scientific rigor, including randomization and blinding, as well as considering additional visuospatial outcomes beyond mental rotation reaction time. Third, we did not collect information on participants' prior video-game experience, which could influence their baseline mental rotation or overall visuospatial ability (Terlecki et al. 2008). Fourth, we cannot conclude from this study whether the directionality of transfer would be equivalent had participants trained on the mental rotation task (i.e., would there be significant improvements on the CBTT?), which might give further insight into the exact mechanism of action underlying the results. For example, it could be that training on either task would engage attentional resources more than an active control group or condition (Bauer et al. 2015; Lancia et al. 2018; Luerding et al. 2008), which would suggest that transfer of training would occur in either direction. However, it is also plausible that the mental rotation task may be less difficult or may recruit visuospatial memory to a lesser extent than the CBTT, which would then lead to less transfer to the CBTT if participants practiced the mental rotation test instead. Future neuroimaging or lesion studies are necessary to further identify the underlying mechanism(s) that may explain the behavioral results from the current study.

In conclusion, this study provides a preliminary proof-of-concept for developing a training approach for improving visuospatial working memory, which also generalizes to improved mental rotation. Moreover, this study shows that the benefits to such training vary between individuals, such that participants who improved more during visuospatial working memory training (i.e., CBTT training) also improved more on mental rotation from pre- to post-training. Given that young, healthy adults benefited from a single session of CBTT training in this study, future research will consider various doses and frequencies of training across multiple sessions in populations with visuospatial impairments to develop optimal rehabilitative strategies.

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Author contributions All authors contributed to the study conception and design. Material preparation and data analysis were performed by SS, AH, KL, and KD. Data collection and initial processing were performed by NH, RE, and PW. The first draft of the manuscript was

written by SS and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Data availability The data that support the findings of this study are openly available in Zenodo at https://doi.org/10.5281/zenodo.6395089.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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