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Brief Communication

Videogame and Computer Intervention Effects on Older Adults' Mental Rotation Performance

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Abstract

Objective: This article examined older adults' performance on two components of a mental rotation task (reaction time and rotation rate) in a home-based intervention study of videogame (Crazy Taxi [CT]) and computerized cognitive training (PositScience InSight).

Materials and Methods: Participants were randomized to one of three groups: one group played an off-the-shelf videogame (i.e., CT), the second group engaged in a computerized training program focused on fast perceptual comparisons, visuospatial working memory, rapid scanning of a visual array and pattern recognition, visual discrimination, and selective and divided attention and processing speed (i.e., InSight), and the third (control) group received no training. Training in the two intervention conditions consisted of 60 training sessions of 1 hour each, which were completed in 3 months (5 hours a week). As part of a larger study, participants received mental rotation testing, which was administered immediately before (baseline), after (post-test), and 3 months after (follow-up) training.

Results: Although the InSight group showed greater improvements in rotation rate at the immediate post-test, by the 3-month follow-up, the combined treatment groups (CT and InSight) had improved more than controls.

Conclusion: The improvements in mental rotation performance found at 3-month follow-up add additional support to previous research, showing visuospatial benefits of both videogame play and cognitive training in older adults. Common elements of both interventions may include expansion of the attentional field of view and faster visual comparison efficiency.

Keywords: Mental rotation, Videogames, Cognitive training, Older adults

Introduction

OFF-THE-SHELF VIDEOGAMES are tools for cognitive interventions for older adults because they are widely deployable and their fun/leisure component may encourage persistence.[1] Given age-related cognitive declines in executive functioning,[2] memory,[3] and speed,[4] a question is whether videogames help to improve function in those domains.[5,6]

This study examined the effect of an off-the-shelf game, Crazy Taxi (CT), for improving mental rotation (the skill required to determine whether a visual stimulus matches another stimulus in a different plane). Mental rotation appears to measure skills involved in real-world tasks that decline with age, supporting the importance of mental rotation as an outcome.[7] Mental rotation tasks are associated with everyday skills, including performance in science, technology, engineering, and mathematics (STEM) courses.[8,9] In addition, spatial mental representations, navigation (e.g., in map reading), and environment learning require mental rotation ability.[10–12]

Mental rotation requires visualization and mental manipulation skills, and skills requiring similar abilities have been found to decline in older adults.[7] For example, older adults have been found to report deficits in allocentric navigation and to misestimate angles.[13] Mental rotation is performed more poorly in aging.[14–17]

Several training programs have improved mental rotation,[18] including in older adults.[6] In addition, videogaming (*Tetris*), in younger adults, improved speed and accuracy and reduced the time cost per angle difference in mental rotation.[5,18] Off-the-shelf videogames (Medal of Honor, CT) improved selective visual attention/speed of processing and evinced increased engagement/flow in older adults.[19–22] In a previous article from our laboratory, mental rotation was

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evaluated as both a global accuracy score (number of correct trials) and a median reaction time over all trials (with no attention to the angles).[22] In that original article, no significant differences in mental rotation accuracy or median reaction time were found between CT and InSight or the control group and the combined intervention groups (CT and InSight) at immediate post-test and the 3-month follow-up.

This current brief communication is a follow-up to this prior study and adds new findings to those reported in this previous study,[22] by deriving a new mental rotation performance score (rotation rate), in addition to a differently derived measure of reaction time and examining whether they improve more in participants randomized to a videogame (CT) condition than in those randomized to computerized cognitive training (InSight) or a no-treatment control.

Owing to the fast-paced nature of CT, requiring rapid and precise cognitive responses, and with elements of visual scanning and speeded allocentric navigation and rotation (spatially planning and taking sharp turns, becoming familiar with the virtual city's layout, and mentally identifying one's position on a map relative to one's destination),[7] we hypothesized that CT would more substantially improve the rotation rate of a mental rotation task, relative to InSight. InSight, a computerized training suite of games that involves tasks that might potentially be associated with mental rotation (fast perceptual comparisons, visuospatial working memory, rapid scanning of a visual array and pattern recognition, visual discrimination, and selective and divided attention), but lacking the important navigational and rotational component like that of CT, was designated to serve as an active control.

The rationale for having an active control group, as mentioned in a prior study from our laboratory,[22] was to address some concerns from prior videogame training and cognitive intervention research.[23,24] This will allow for group comparisons, in which the groups are more closely matched in experimental attention.[22] Owing to the nature of both CT and InSight containing ''active ingredients'' in the mental rotation task, we also hypothesized that the combined treatment groups (CT and InSight) would confer faster rotation rate performance than the no-treatment control group.

Owing to the conceptual similarities in our newly derived measure of reaction time (see our Design and Procedure section) and the previous measure of median reaction time from our prior study and the lack of significant differences found between these groups on median reaction time in our prior study,[22] we did not hypothesize any differences between the groups in reaction time.

Materials and Methods

Ethics statement

All research was approved by the institutional review board of the University of Florida. Informed consent was obtained from all participants, and the investigation was conducted according to the principles expressed in the Declaration of Helsinki.

Participants

Fifty-four community-dwelling cognitively normal (Mini-Mental State Examination [MMSE] scores ≥ 23, following the guidance of prior studies from Advanced Cognitive Training for Independent and Vital Elderly [ACTIVE][25,26]) older adults completed the study (control, $n=18$; InSight, $n=19$; CT, $n=17$). In ACTIVE, the MMSE cutoff was used to ensure that, without using age- and education-adjusted norms that would have been difficult during real-time field screening, under-represented minorities and those with fewer years of education were not over-excluded. Participants were novice videogame players, free of frank cognitive impairment, with adequate vision—visual acuity 20/40 or better, as measured with a standard Snellen chart presented on an Optec® Vision Screener (Model 2500)—mean age of 73 years (standard deviation [SD] = 6), and 16 years of education (SD = 3). Participants were 89% white and 63% women.[22]

Design and procedure

This study is a follow-up to a prior study[22]; here we focus on mental rotation assessment at baseline, immediately after training (post-test), and 3 months later (follow-up). After baseline, participants were randomly assigned to one of three groups: CT, InSight computerized training,[27] or a no-treatment control group. CT and InSight groups were given three to four 1-hour sessions of orientation to gameplay or task performance, respectively, in our laboratory located at the University of Florida, followed by 60 hours of home-based practice for 3 months. Training program details are found in the original study.[22]

Our outcome measures were derived from a variant of the Shepard and Metzler mental rotation paradigm.[28] Participants compared two simultaneously presented figures to judge whether they were the same or mirror images. Figures were displayed at 30–180° of difference, in 30° increments. The task was administered through PsyScope X B53D (http://psy.ck.sissa.it). We extracted two dependent variables: (1) reaction time, an estimate of the average time to correctly compare two images, across all units of angle difference; and (2) rotation rate, a participant's estimated increased comparison time needed for a unit increase in angular difference between two figures.

Reaction time was defined as intercept, and rotation rate as linear slope, when participants' median response times were regressed on each degree of difference through linear mixed effects models. After other intervention trials,[22,25,29] and to increase conformity with parametric assumptions, reaction time and rotation rate were normalized through Blom transformation.[30]

Statistical analyses

Analyses of variance were conducted as linear mixed effects models using the Statistical Package for the Social Sciences (SPSS) version 26.0 (SPSS Inc., Chicago, IL). Occasions (baseline, immediate post-test, and delayed follow-up) represented level 1 and were nested under persons (level 2). Group (CT, InSight, and no-treatment) was a person-level predictor. Contrasts representing treatment group differences and change (described below in 'Between-subjects effects' and 'Within-subjects effects' paragraphs) were evaluated as main effects and in interaction with one another. The interaction effects evaluated the critical study hypotheses (i.e., whether change before and after training was different for treated and untreated groups).

Baseline covariates of age, education, and gender were adjusted. Standardized net effects were computed as the value of each contrast ("estimate") divided by pooled baseline SD to express the contrasts in a standardized metric, analogous to Cohen's *d*. Our critical value for statistical significance was $\alpha = 0.05$; by using planned contrasts and eschewing the less meaningful omnibus tests of effects (thereby reducing familywise type 1 error), we did not perform alpha adjustments (such as a Bonferroni correction), but we note that with two contrasts per main effect, only effects with *P*-values ≤ 0.025 would be considered significant under such correction.

Between-subjects effects. Following the same statistical analysis described in our previous research,[23] hypotheses about intervention effects were analyzed using a sequentially rejective multiple test procedure, specifically through two planned orthogonal (Helmert) contrasts[31–33]: Contrast 1, "Is any training better than no training?" (which compared the average of the two treatment groups with the average of the control group), and Contrast 2, "Do the two treatment conditions differ from one another?" (which compared the two intervention conditions directly). This follows the recommendations that when defined hypotheses were directly about the pattern of group differences, direct tests of those planned contrasts should be made.[34] This serves to reduce family-wise error, by reducing the number of unnecessary statistical tests, and increases power of the design.[35] Schad and colleagues showed that contrasts defined a priori yield far more useful confirmatory tests of experimental hypotheses than standard omnibus *F*-tests.[33]

Within-subjects effects. Also following our previous work,[23] dummy codes were used for the immediate post-test and the delayed follow-up, with baseline as the reference value; thus, two time segments were evaluated: (1) short-term change (difference between baseline and immediate post-test) and (2) long-term change (difference between baseline and delayed follow-up).

Results

Analysis results are displayed in Table 1 and Figure 1. We computed reaction time and rotation rate, and the individual curves fit most participants well with a median R^2 of 0.57 (range = <0.01–0.97) at baseline, 0.60 (range = 0.01–0.94) at immediate post-test, and 0.51 (range = < 0.01–0.93) at delayed follow-up. Furthermore, to assess reliability, we examined the Cronbach's α of a scale consisting of the median reaction time of only the correct responses at each of the six angles of rotational difference (30, 60, 90, 120, 150, and 180), separately at each occasion: baseline = 0.96 (95% confidence interval [CI]: 0.95–0.97), immediate post-test = 0.97 (95% CI: 0.95–0.98), delayed follow-up = 0.96 (95% CI: 0.94–0.98). Graphs of rotation rate and reaction time means at each occasion using raw untransformed data are shown in Supplementary Figures S1 and S2.

Reaction time

The analyses revealed no group differences in change from baseline to immediate post-test, or from baseline to delayed follow-up (p's > 0.05). Of our covariates (age, education, and gender), older age at baseline was associated with slower reaction time ($b = 0.05$, standard error [SE] = 0.02, $\beta = 0.26$, $P = 0.02$) and more years of education was associated with faster reaction time ($b = -0.16$, SE = 0.08, $\beta = -0.22$, $P = 0.04$). Gender was not related to reaction time ($b = 0.11$, SE = 0.22, $\beta = 0.05$, $P = 0.63$). The convention is that *b* represents the unstandardized regression weight, and β represents the standardized regression weight.

Table 1. Statistical Summary Table: Effects of Intervention Group and Time on Mental Rotation

	Reaction time					Rotation rate				
Parameter	*Estimate*	*SE*	df	P	*Effect*	*Estimate*	*SE*	df	P	*Effect*
Intercept	−2.67	1.53	53.80	0.09		1.77	1.44	53.49	0.22	
Main effects										
Time										
Post-test—baseline	0.09	0.13	102.51	0.46	0.14	−0.07	0.15	102.12	0.66	−0.13
Follow-up—baseline	−0.12	0.13	103.12	0.37	−0.17	−0.22	0.15	102.98	0.15	−0.44
Group										
Training—control	−0.04	0.27	103.98	0.87	−0.06	0.39	0.27	125.35	0.16	0.77
CT—InSight	0.51	0.32	102.50	0.11	0.76	−0.43	0.32	123.64	0.18	−0.87
Time × group interactions										
(Post-test – baseline) × (training – control)	0.11	0.27	102.38	0.67	0.17	−0.06	0.31	101.94	0.85	−0.12
(Post-test – baseline) × (CT – InSight)	−0.54	0.32	102.63	0.09	−0.81	0.84	0.37	102.28	0.02	1.68
(Follow-up – baseline) × (training – control)	0.08	0.27	102.70	0.77	0.12	−0.69	0.32	102.38	0.03	−1.40
(Follow-up – baseline) × (CT – InSight)	−0.29	0.32	103.51	0.36	−0.44	−0.05	0.37	103.53	0.89	−0.11

Main effect of group is decomposed into two planned orthogonal contrasts, following Helmert coding, the first comparing the average of the two intervention groups with the control group, the second comparing the two intervention groups with one another. Interaction estimates address whether the group contrasts evinced differential change from baseline to post-test or from baseline to follow-up. *Estimate* represents the unstandardized regression weight. *Effect* represents the standardized net effect, which was computed as the value of each contrast ("estimate") divided by the pooled baseline standard deviation. All effects were adjusted for the covariates of age, education, and gender.

CT, Crazy Taxi; SE, standard error.

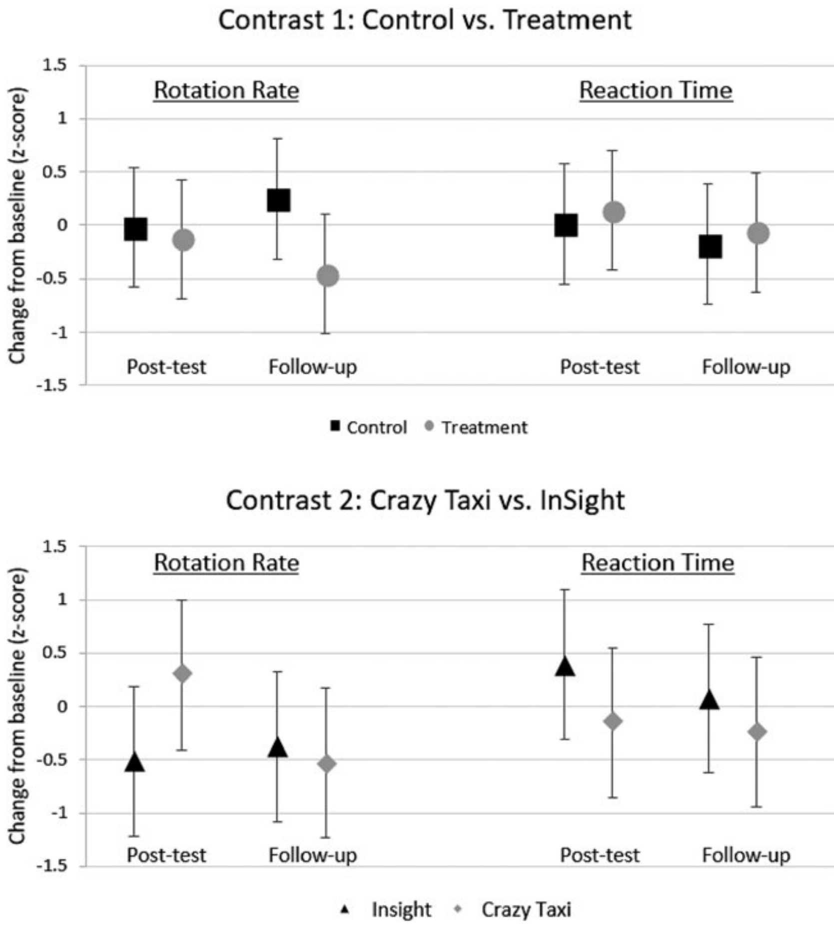

FIG. 1. Planned contrast results are presented as standardized effect sizes. *y*-Axis represents difference from (i) baseline to immediate post-test or (ii) difference from baseline to 3-month follow-up, as labeled. Contrast 1 (top panel) compares the mean change score of untrained control participants (black square) with the average mean change score in both intervention groups (gray dot). Contrast 2 (bottom panel) compares the mean change score of the videogame intervention (Crazy Taxi, gray diamond) with the computerized training (InSight, black triangle). Error bars represent 95% confidence intervals. Negative values represent improvements from baseline (i.e., becoming faster).

Rotation rate

The analyses revealed that the InSight group improved significantly more on rotation rate (less time cost per larger angle difference) than the CT group at immediate post-test ($b = 0.84$, SE = 0.37, $P = 0.02$, standardized net effect = 1.68; this effect would remain significant after Bonferroni correction). However, by follow-up, the average of treatment groups together was more improved than the control group ($b = -0.69$, SE = 0.32, $P = 0.03$, standardized net effect = −1.40; this effect would not remain significant after Bonferroni correction, though alpha adjustments were not performed in the context of planned contrasts), but the two treatment groups did not differ significantly from one another. Of our covariates (age, education, and gender), more years of education was associated with faster rotation rate ($b = -0.16$, SE = 0.07, $\beta = -0.21$, $P = 0.03$). Age ($b = -0.02$, SE = 0.02, $\beta = -0.08$, $P = 0.41$) and gender ($b = 0.15$, SE = 0.20, $\beta = 0.08$, $P = 0.45$) were not related to rotation rate.

Discussion

The results thus add further support that mental rotation performance could be improved through cognitive training and through videogame interventions[5,22]; specifically (1) both interventions could improve rotation rate (but not reaction time), but that (2) improvements were earlier and sustained for those receiving InSight computerized training, but did not emerge until later (3 months postintervention) for the CT videogame group; effect sizes for rotation rate were large (>0.8).[36] Specifically, for the finding that the InSight group improved significantly more than the CT group from baseline to post-test, that effect size was 1.68. For the finding that the training groups combined improved more than the control group from baseline to the 3-month follow-up, that effect size was 1.40. The major caveat to these findings is the low sample size (and correspondingly low statistical power).

In our prior study with this sample,[22] mental rotation was only considered as a global accuracy score (number of correct trials), and as a median reaction time over all trials (with no attention to the various angles of difference between the displayed figures). In that original study, no intervention effects were found, a result that is consistent with the current reaction time findings.

The new approach in this article enabled us to extract two common parameters of mental rotation performance using a growth curve approach. This permitted separation of an intercept (which we have labeled reaction time) and a slope of change over angles (which we have called rotation rate). It is the new rotation rate variable that was responsive to treatment, suggesting that perhaps training more specifically targeted processing efficiency (by reducing the comparison time needed for increases in angular difference between the two figures) rather than general speed.

It is difficult to speculate what the effective ‘‘ingredient’’ of each intervention was. For the computerized training, which emphasized fast perceptual comparisons and rapid scans of the full visual array, it is plausible that training improved speed and efficiency of comparisons and attentional field of view. With regard to the videogame condition, several past studies have also found increased speed and expanded temporal and spatial distribution of visual attention from action videogames, both in younger adults[37] and in older adults,[20] and CT was among the action games named by experienced videogamers who also evinced better speeded visual attention performance.[37]

We thus propose that the current findings are consistent with prior evidence that CT, as an exemplar of a fast-paced action game, may yield increased speed and expanded temporal and spatial distribution of visual attention benefits for older adults, which may have contributed to the rotation rate improvements. An important unanswered question, however, is why the effects of CT were not detected until the 3-month follow-up. One possibility is that sustained gameplay introduced new habits of visual awareness, environmental scanning, speeded visual comparisons, and allocentric navigation and rotation that individuals could then continue to ''practice'' in real-world situations, including driving, building on game-specific improvements that occurred immediately.[22] We acknowledge the highly speculative nature of this interpretation but have no additional process data by which we can account for the apparent delayed benefit of CT on mental rotation.

The relatively small sample size in this investigation clearly limited statistical power, such that only effects with large effect sizes emerged as significant. This further impacted our ability to explore gender differences in response to intervention, even though these have been found in prior research, with women profiting from training more than the men.[38,39]

Videogames remain promising avenues for intervening with older adults because they can operate at two levels. At the level of improving a complex skill (e.g., driving), the more a game functions as an authentic simulation of the real-world skill, the more the game will serve as a practice opportunity for coordination and execution of myriad performance components. However, at a different level, if games could isolate specific elements of performance (e.g., a gaming situation where only visual scanning is practiced, or only fast perceptual comparisons are practiced), it would enable interventionists to use games as narrow drills to remediate deficient single skills. In this study, our CT intervention clearly represented something closer to a real-world simulation of driving.

InSight, with a game-like interface, nonetheless was designed to isolate and train specific elements of performance (speed, divided and selective attention). Despite these differences, by the 3-month follow-up, both groups had experienced greater rotation rate improvements than untrained controls. This study, therefore, cannot provide greater clarity on the best route for improving mental rotation rate, or the underlying processes. Future research involving resting-state and task-specific functional magnetic resonance imaging (fMRI) may help to better elucidate the critical brain regions and neural circuits most affected by the two different training approaches.

Our finding that training in an off-the-shelf videogame transferred to gains on a visuospatial task, mental rotation, is important because mental rotation abilities are associated with achievement in STEM courses,[8,9] in addition to spatial mental representations, navigation, and environment learning.[10–12] This study, and its predecessor,[22] provides further support for the cognitively beneficial effects of videogame training in older adults.[19–22]

Author Disclosure Statement

No competing financial interests exist.

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Supplementary Material

Supplementary Figure S1
Supplementary Figure S2

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