Short-Term Arcade-Action Video Gaming Enhances Working Memory Precision

Ali Asgari[1], Abdol-Hossein Vahabie[2,1,3], Ehsan Rezayat[1,3*]

1- Department of Cognitive Sciences, Faculty of Psychology and Education, University of Tehran, Tehran, Iran.

2- School of Electrical and Computer Engineering, College of Engineering, University of Tehran, Tehran, Iran

3- School of Cognitive Sciences, Institute for Research in Fundamental Sciences (IPM), Niavaran, Tehran, Iran

* Correspondence: rezayat@ut.ac.ir

Abstract

Objective: Action video games are increasingly recognized for their potential to enhance cognitive capacities, including working memory (WM). However, most studies require extensive training or prior gaming experience. We examined whether a single, short-term session of “Snail Mail,” an arcade-action video game, could boost WM precision compared to a passive control condition.

Method: Thirty-six healthy adults (18–34 years) were randomly assigned to either play “Snail Mail” (Intervention) or watch episodes of “Shaun the Sheep” (Control) for 30 minutes. Two participants were excluded for unstable performance, yielding a final sample of 34. Participants completed a face emotion recognition memory task before and after the intervention, wherein the absolute error served as the primary metric of WM precision. A mixture model further characterized memory precision, and random guessing.

Results: The Intervention group showed a significant reduction in absolute error from pre- to post-test, whereas the Control group exhibited a negative effect size, indicating worsened post-test performance. Mixture-model results revealed a significant increase in precision for the Intervention group.

Conclusion: These findings indicate that a 30-minute arcade-action game session can meaningfully enhance WM precision, highlighting the feasibility of brief, targeted gaming interventions. Future research should explore longer-term outcomes, generalizability to other cognitive tasks, and optimal intervention protocols for sustained benefits.

Keywords: Working Memory, Action Videogame, Cognitive Enhancement, Short-term Intervention, Delayed-Reproduction Task

Introduction

Video games have gained widespread recognition for their potential to enhance cognitive functions. Among these, action video games have been extensively studied for their capacity to improve attention, spatial reasoning, and executive control. The dynamic and immersive nature of video games fosters cognitive engagement, making them a promising tool for targeted cognitive training (Green & Bavelier, 2012). Researchers have consistently demonstrated that video game interventions can induce significant neural and behavioral changes, particularly in domains such as working memory (WM) (Bediou et al., 2018). Furthermore, video games provide an adaptable platform that can simulate real-world demands on cognitive systems in a controlled and repeatable manner.

Working memory, a critical component of cognitive functioning, involves the temporary storage and manipulation of information for task execution and decision-making. It is a foundational capacity underlying complex cognitive tasks, including reasoning, problem-solving, and learning (Diamond, 2013). Precision in WM, often measured in tasks requiring the recall of specific details, reflects the quality of cognitive processing and is an essential metric for evaluating WM performance (Bays et al., 2009). Studies have shown that WM is modifiable through training, with video games offering a unique modality to enhance this capacity through engaging and repetitive tasks (Bavelier et al., 2012). The ability of video games to enhance WM has been a topic of extensive research. Action video games, in particular, have been shown to improve attentional control, spatial precision, and task-switching abilities, which are closely linked to WM processes (Green & Bavelier, 2006). These enhancements are thought to stem from the games' demands on real-time decision-making, rapid perceptual shifts, and sustained focus on dynamic stimuli. However, most studies investigating action video games require substantial prior experience or prolonged exposure for participants to benefit significantly (Bavelier et al., 2012). This limitation creates a need for alternatives that combine action-like cognitive demands with accessibility for participants who may lack prior gaming experience or time for extended interventions.

In this study, we address these challenges by using "Snail Mail" (Sandlot Games, 2004), a fast-paced arcade action game, as a novel intervention. Unlike other action video games, "Snail Mail" is designed with features that make it ideal for short-term cognitive training. These features include a simple interface, adjustable difficulty levels, and a high demand for attention and rapid decision-making. The game can be quickly learned, allowing participants to reach proficiency within a 30-minute session. These characteristics ensure that the cognitive demands align with the principles of WM training while minimizing barriers to entry for novice players. By incorporating elements of speed, precision, and visual-spatial challenges, "Snail Mail" offers an innovative approach to short-term video game interventions, filling a gap in the current research landscape.

This study focuses on the precision of WM as a primary metric, evaluated through a face emotion recognition memory task. Precision, defined as the accuracy of recall and response alignment with target stimuli, is a critical indicator of WM capacity and quality (Bays et al., 2009). Previous research has demonstrated that precision is highly sensitive to cognitive interventions, with improvements reflecting enhanced resource allocation, memory encoding, and retrieval processes (Fougnie et al., 2012). By leveraging a task that directly assesses these parameters, this study aims to investigate the potential of "Snail Mail" as a tool for WM enhancement through short-term exposure. This approach contributes to the growing field of video game-based cognitive training, providing evidence for the feasibility and efficacy of brief but targeted interventions.

To study WM, researchers often use paradigms that require participants to determine if a presented object matches a previously seen one, yielding binary outcomes (correct or incorrect) (Bays et al., 2009). However, these methods can limit the assessment of memory retention quality. Alternative paradigms, such as "delayed-reproduction" tasks, offer continuous measures of WM performance, allowing for a more nuanced understanding of how items are retained and manipulated (Gorgoraptis et al., 2011). Our study employed a delayed-reproduction facial emotion N-Back task using morphed emotional faces to investigate WM performance.

Materials and Methods

Participants

A total of 36 healthy undergraduates and graduate students, (9 female & 9 male in each group of Intervention and Control , age: [18, 34], mean ± SD: 23.8 ± 3.83) volunteered to attend this experiment after providing written informed consent to procedures approved by the local ethics committee. After the data acquisition 2 participants (one from Intervention group and one from Control group) excluded due to unstable general condition during the task. All participants had normal health states. All procedures were approved by the University of Tehran Science Committee (Approval ID IR.UT.PSYEDU.REC.1403.019) and were in accordance with Helsinki declaration of 1964 and its revisions.

Procedure

Upon arriving at the laboratory, participants were briefly screened by a doctor to ensure their health and ability to enroll in the study. About 30 minutes were then devoted to setting up. Once the equipment was in place, participants began the pre-test session of the behavioral task. Immediately following this initial assessment (lasting around 20 minutes), they underwent a 15-minute rest. After the rest, participants in the Intervention group engaged in 30 minutes of “Snail Mail,” (an arcade-action-videogame requiring rapid perceptual shifts and decision-making), while those in the Control group watched episodes of “Shaun the Sheep.” Moderate movement was allowed, including hand or foot adjustments, though they were asked to avoid unnecessary

motion. Following this interval, all participants performed the same behavioral task once again as a post-test under conditions mirroring those of the pre-test. This was then succeeded by another 15-minute rest. The full session took approximately two hours, and participants were thoroughly informed of each procedural step, both verbally and through consent form, before the experiment began.

Behavioral Task

We created a neutral face (emotion and sex-neutral) using FaceGen Modeler 3.5 (Singular Inversions, ON, Canada). This face was then morphed into two categories, sad and happy, at 10% intervals using InterFace software (Kramer et al., 2017). This process resulted in 19 morphed face stimuli, ranging from 90% happy to 90% sad (Figure 1B). All morphed faces were then cropped into oval shapes, using Adobe Photoshop software and presented on a screen with a gray background. Luminance was controlled for faces using the SHINE toolbox in MATLAB (Willenbockel et al., 2010). We considered a series of images, with Image 1 depicting 90% sadness and Image 19 depicting 90% happiness, while the intermediate images were arranged sequentially. Face stimuli (3.33°× 4.76°) were presented on the center of a 23-inch TFT monitor with a resolution of 1920 × 1080 pixels and a refresh rate of 60 Hz. The experiment was programmed using the PsychToolbox 3 extension (Brainard, 1997) running in MATLAB (2022a) (MathWorks, Natick, MA, United States).

Participants sat comfortably on a chair at a fixed distance of ~60 cm from the screen in a dimly lit room. Before the main task, instructions were displayed on the screen, and the examiner explained the procedure to each participant. Participants completed five practice trials to familiarize themselves with the task. Each trial began with a fixation spot (black, 0.3° diameter, Figure 1C), on which participants were instructed to maintain their gaze. After 0.7 a second, three face stimuli ("sample faces") appeared on the screen respectively, each for 0.7 a second, with numbers 1, 2, and 3 displayed above the respective faces. These faces were selected pseudo randomly from 0%, 20%, 40%, 60%, or 80% morphed faces, with one of the three faces serving as the target face. Following the presentation of the sample faces, a fixation cross (black, 0.2° length of each line) appeared at the center of the screen for a delay period of either 1.5 or 3 seconds, chosen pseudo randomly for each trial. Participants were instructed to maintain their gaze on the fixation cross during this delay. After the delay, a number (1, 2, or 3) corresponding to one of the sample faces was displayed on the screen for 0.7 a second. Subsequently, a random face ("response face"), which could be any of the 19 morphed faces, was presented. Participants were instructed to use the "Up" and "Down" arrow keys on the keyboard to adjust the "response face" through the morphs to match it to the "target face" corresponding to the displayed number (1, 2, or 3). They pressed the "ENTER" key to submit their responses. Each block consisted of 30 trials (2 delays × 9 sample faces × 3 repetitions). Each participant completed three blocks, with the option of taking a break between blocks. We recorded participants' choices and reaction times for each trial. No feedback was provided regarding their responses or reaction times.

Intervention

Snail Mail is a fast-paced action game originally developed by Sandlot Games in 2004. Despite the studio's closure, the game remains freely accessible and is recognized for its compelling arcade-like mechanics. In Snail Mail, players guide a space-traveling snail who navigates through increasingly challenging tracks filled with obstacles, enemies, and collectibles. This dynamic and visually engaging environment demands rapid decision-making, sustained attention, and continuous working memory updates. These features align closely with the core cognitive constructs being examined in the present study. Snail Mail's intuitive controls and straightforward objectives allow participants to grasp the basics quickly, within three minutes. The game's Challenge Mode was utilized for this research, wherein difficulty and speed can be adjusted in increments of 20% (ranging from 0% to 100%). Participants began gameplay at 0% for both difficulty and speed. Upon successfully completing a stage, they advanced to the next increment (e.g., from 0% to 20%, then 40%, etc.). This gradual escalation was designed to keep players engaged and cognitively challenged throughout the 30-minute intervention. Most participants reached the 60% or 80% difficulty level by the end of the session, although none exceeded 80%. Snail Mail was chosen for its capacity to elicit high levels of cognitive engagement over a short time frame. It combines rapid perceptual shifts, quick decision-making, and continuous attentional demands, all of which are key constructs in measuring potential improvements in working memory. Its simple interface and built-in training module ensure that all participants begin gameplay with comparable competency levels, enhancing the reliability and reproducibility of the intervention. Moreover, free accessibility facilitates broader applicability in cross-laboratory studies.

To provide a visually engaging but comparatively low-interaction alternative, participants in the Control group watched segments from the non-verbal animated series Shaun the Sheep. This comedic production relies primarily on visual cues and slapstick humor rather than dialogue, mirroring the minimal verbal input of Snail Mail and thereby reducing confounds related to language processing. Participants viewed four sequential episodes totaling approximately 30 minutes, aligning with the duration of the Snail Mail intervention. As with the game-based condition, brief intervals occurred between episodes (paralleling the game's stage transitions), ensuring an engaging yet passive viewing experience. This design aimed to control overall exposure time and visual engagement, while limiting the cognitive load that might arise from active gameplay mechanics. The episodes were selected for their consistent format and pacing, maintaining participant attention without introducing explicit training or problem-solving components. By offering Shaun the Sheep as the Control activity, the study preserves consistency across both groups in terms of visual stimulation, time on task, and entertaining content. The primary difference lies in the degree of participant interaction and cognitive demand: while Snail Mail involves continuous user input and escalating challenge levels, the animated series remains passive and places minimal demands on working memory or executive control. This contrast allows the study to more precisely isolate the cognitive effects attributable to active gameplay.

Data Analysis

We assessed working memory precision by computing the absolute value of the error on each trial. Specifically, signed errors were computed as $Error = Response - Target$, but only the absolute values $|Error|$ (ranging from 0 to 18) were used in subsequent analyses to capture precision rather than directional bias. Preliminary visual inspection of the data (histograms, Q–Q plots) suggested non-normality in absolute error scores. Formal Shapiro–Wilk tests confirmed deviations from normality, and Levene's tests indicated a lack of homogeneity of variances for some comparisons. Consequently, nonparametric tests were employed for group-level analyses of $|Error|$.

Within-group (pre vs. post) comparisons were conducted using the Friedman test, given the repeated-measures nature of the data. Kruskal–Wallis tests were used to examine between-group differences (Intervention vs. Control). Post-hoc pairwise tests were then carried out when omnibus effects were significant: Wilcoxon signed-rank tests for paired contrasts (pre vs. post) within each group and Mann–Whitney U tests for independent contrasts (Intervention vs. Control) at each time point. All reported p-values were two-tailed, and corrections for multiple comparisons were applied (e.g., Bonferroni). Following JARS–Quant guidelines, we report associated p-values and derive r for effect size from the standardized Z statistic. Larger r values indicate stronger effects, with conventional benchmarks of .10 (small), .30 (medium), and .50 (large).

Mixture Model Analysis

To further characterize memory errors, each participant's pre- and post-intervention data were fit to a mixture model based on the framework proposed by Bays et al. (2009). This model partitions the observed distribution of recall errors into multiple components: a Gaussian centered on the target (with some spread reflecting memory noise), and a uniform component capturing random guesses. Although Bays et al. (2009) describe additional sources of error (notably "swap errors" for non-target items), these were not estimated here due to randomization of non-target stimuli and the focus on absolute errors. Three parameters were estimated via maximum likelihood in MATLAB for each participant: **pT:** The proportion of trials on which the participant recalls the correct target (with Gaussian variability). **pU:** The probability of random guessing, modeled as a uniform distribution over the range of possible errors. **K:** A precision parameter inversely related to the standard deviation of the Gaussian; higher values imply narrower, more precise recall.

Each participant's pT, pU, and K estimates were subjected to repeated-measures analyses examining changes from pre- to post-intervention. In keeping with APA (JARS–Quant) guidelines, we tested for normality of the estimated parameters; if they met normality assumptions, repeated-measures ANOVAs were conducted. If normality was violated, Friedman tests replaced ANOVA, with subsequent paired or between-group comparisons (Wilcoxon or

Mann–Whitney) as needed. Effect sizes were computed, and two-tailed p-values are reported throughout

Results

The Intervention group showed significantly improved precision (lower error) from pre- to post-intervention (Figure 2), while the Control group unexpectedly worsened, yielding a negative effect size for that comparison. Consequently, at the post-test, the Intervention group outperformed the Control group by a substantial margin (Figure3). And in the Mixture Model results, Memory Precision (K) increased significantly in the Intervention group only (Figure 4). Group differences in pT and pU were not statistically conclusive but trended in directions consistent with reduced random guessing for the Intervention. Table 1 summarizes the key comparisons for absolute error. Positive r indicates that post-intervention errors were lower (i.e., performance improved), whereas negative r indicates that post-intervention errors were higher (i.e., performance declined). While both groups showed a statistically significant pre–post difference, the direction of change differed. The Intervention group exhibited a marked reduction in absolute error (positive r, Figure 3A), indicating increased precision after playing "Snail Mail." In contrast, the Control group had a negative effect size, meaning that its post-test absolute error was higher than at baseline (Figure 3B). This suggests that, although the difference was statistically significant ($p<0.01$), it represented a decline in performance rather than an improvement. No significant difference emerged between groups at baseline ($p=0.164$), indicating similar performance prior to their respective activities. However, at post-test, the Intervention group demonstrated a significantly lower error than the Control group ($p=<0.001$), reflecting superior precision following the gaming intervention.

To unpack these changes further, mixture-model parameters were estimated per participant for both pre and post sessions: K (memory precision), pT (probability of target recall), and pU (probability of random guessing). Table 2 provides a concise overview of these parameters, along with the relevant ANOVA and t-test results. A trend toward an interaction effect was observed for K ($F(1,32) =2.87, p=0.10$, Figure 4), suggesting the Intervention might differentially affect precision relative to the Control. Paired t-tests confirmed a significant improvement in the Intervention group ($p=0.042$), but no change in the Control ($p=0.458$). Although between-group change scores did not reach statistical significance ($p=0.10$), the Intervention group's higher post-intervention K aligns with the reduced absolute error noted above. Neither the main effects nor the interaction term reached significance for pT . The Intervention group showed a nonsignificant increase ($p=0.259$), and the Control group displayed a slight (also nonsignificant) decrease ($p=0.293$). Despite a trend-level group effect ($F(1,32)=3.42, p=0.074$ in some analyses), the overall pattern indicates no robust difference in target recall probabilities between groups. Analyses of Probability of Random Guessing (pU) paralleled those of pT , with neither the main effects nor interaction reaching significance. The Intervention group's nonsignificant decline ($p=0.259$) contrasted with the Control group's nonsignificant increase ($p=0.293$), again

suggesting a possible pattern favoring the Intervention that did not meet conventional thresholds for significance.

Taking together, these results suggest that short-term engagement with a rapid-action video game enhanced core aspects of working memory precision. Although the Control group initially performed similarly at baseline, their post-test decline underscores the selective benefits associated with the Intervention condition.

Discussion

This study investigated whether a brief, 30-minute session of the arcade-action video game *Snail Mail* could significantly enhance working memory (WM) precision compared to a passive visual control condition (*Shaun the Sheep*). Using an emotion-morphed face memory task (Figure 1), we measured absolute error in reproducing the target face's emotional intensity before and after the intervention. Our principal finding was that participants exposed to the action game exhibited a marked improvement in WM precision (Figure2 &3), whereas those in the Control group showed a decline. Although group-level differences in more nuanced mixture-model parameters (e.g., pT and pub) did not reach conventional significance, the Intervention group showed a significant increase in the precision parameter (K, Figure 4), suggesting a narrower, more accurate memory distribution for facial expressions following gameplay.

Our results align with broader evidence that action video games can enhance core cognitive capacities, including attention and WM (Bediou et al., 2018; McDermott et al., 2014; Wilms et al., 2013). In particular, Wilms et al. (2013) noted that intensive video gaming can speed the encoding of visual short-term memory. Similarly, McDermott et al. (2014) observed that action game players often outperform non-players in tasks tapping memory precision. Our findings extend this literature by demonstrating that even a single, short-term session of an action-like game may elicit observable gains in memory precision. This suggests that the cognitive mechanisms linked to rapid visual processing such as efficient encoding and increased neuroplasticity in attention-related cortical areas, can become active relatively quickly (Bediou et al., 2018).

Fast-paced games impose continuous demands on visuomotor coordination, attentional control, and real-time decision-making (Zhang et al., 2020). These demands likely heighten cognitive load, requiring individuals to filter task-relevant information swiftly and hold critical details in an active state (Baniqued et al., 2014). Over even a short duration, repeated exposure to these demands may facilitate modest, but measurable, gains in memory encoding and precision (McDermott et al., 2014; Wilms et al., 2013). By contrast, participants who merely watching an animated series likely experienced passive stimulation, insufficient to provoke the adaptive neural changes associated with active engagement (Ballesteros et al., 2017; Baniqued et al., 2014).

It is noteworthy that the Control group showed a statistically significant, yet negative, effect size from pre- to post-test, reflecting increased error at post-test. This decline may stem from tiredness, as both groups remained in the laboratory for approximately two hours. Whereas the Intervention group benefited from an engaging, cognitively stimulating activity that may have offset or even reversed fatigue, the Control group's passive viewing could have exacerbated boredom or reduced motivation when returning to the post-test (Baniqued et al., 2014). Additionally, attentional fatigue may accumulate more readily without active engagement, leading to diminished performance in a subsequent demanding memory task (Ballesteros et al., 2017).

Although the absolute error results strongly favor the Intervention condition, the mixture-model parameters (pT ,pU) showed only trends toward improvement or decline and did not reach statistical significance. Nevertheless, the precision parameter (K) significantly increased in the Intervention group, suggesting that Gaussian variability around the target decreased. This pattern is consistent with prior studies indicating that action game training primarily enhances perceptual fidelity or "focal" memory precision (McDermott et al., 2014; Wilms et al., 2013). Larger sample sizes and, possibly, longer intervention periods might reveal stronger effects in other mixture-model parameters, such as the probability of target recall (pT) and random guessing (pU).

Despite these promising findings, certain limitations must be acknowledged. Short Intervention: Although the use of a 30-minute training session is novel, demonstrating the potential feasibility of a quick and accessible cognitive intervention, it remains uncertain whether these effects persist or generalize over time. Future studies should compare short-term vs. long-term interventions to determine the retention of benefits and the potential for extended or repeated gaming sessions to amplify effects. Sample Size: Our sample size, though adequate for initial hypotheses, may limit the statistical power to detect subtle differences in mixture-model parameters or interaction effects. Larger samples are recommended to verify these preliminary outcomes and allow for covariate analysis (e.g., age, prior gaming habits). Task-Specific: The focus on emotional face recognition may limit generalizability to other WM tasks. Additional research is needed to verify that improvements observed here transfer to broader cognitive domains (Baniqued et al., 2014). Passive Control: Relying on purely passive, visual control condition offers a meaningful baseline but does not exclude the possibility that other active or semi-active controls might yield different comparisons. Investigating how "Snail Mail" compares with alternative intervention activities (e.g., puzzle games) could reveal whether the pace and action elements are the key drivers of WM improvement.

This study underscores the potential for short yet intensive action-based gaming to enhance working memory precision. As attention and WM underpin a range of everyday tasks, even modest improvements could have practical relevance, from academic performance to professional multitasking. The brevity of the intervention highlights accessibility: Many individuals, including those without gaming experience, could feasibly benefit from short, engaging sessions that offer cognitive challenge without extensive training. An important future

step is to determine the optimal frequency and duration of gameplay required for sustained WM benefits. Testing multiple sessions or extended training periods could reveal whether the enhancement plateaus or continues to grow with ongoing ‘Snail Mail’ engagement. Additionally, examining how participants adapt to progressively complex or faster game levels could shed light on the trajectory of cognitive gains and whether an adaptive game design can maximize WM improvements.

In summary, our results suggest that a single session of “Snail Mail”, a simple yet cognitively demanding arcade-action game, can produce immediate gains in face memory precision. By contrast, a passive visual experience may contribute to fatigue that impedes subsequent cognitive performance. These findings align with broader evidence on action video games improving memory and attention, illuminating an approachable avenue for cognitive enhancement interventions. Further longitudinal work is warranted to clarify the mechanisms underlying these rapid improvements and to explore the long-term feasibility of such brief gaming paradigms in diverse populations.

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References

Ballesteros, S., Mayas, J., Prieto, A., Ruiz-Marquez, E., Toril, P., & Reales, J. M. (2017). Effects of video game training on measures of selective attention and working memory in older adults: Results from a randomized controlled trial. Frontiers in Aging Neuroscience, 9, Article 354. https://doi.org/10.3389/fnagi.2017.00354

Baniqued, P. L., Kranz, M. B., Voss, M. W., Lee, H., Cosman, J. D., Severson, J., & Kramer, A. F. (2014). Cognitive training with casual video games: Points to consider. Frontiers in Psychology, 4, Article 1010. https://doi.org/10.3389/fpsyg.2013.01010

Bavelier, D., Green, C. S., Pouget, A., & Schrater, P. (2012). Brain plasticity through the life span: Learning to learn and action video games. Annual Review of Neuroscience, 35, 391-416. https://doi.org/10.1038/nrn3241

Bays, P. M., Catalao, R. F. G., & Husain, M. (2009). The precision of visual working memory is set by allocation of a shared resource. Journal of Vision, 9(10), 7.1-7.11. https://doi.org/10.1167/9.10.7

Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. Psychological Bulletin, 144(1), 77-110. https://doi.org/10.1037/bul0000130

Brainard, D. H. (1997). The psychophysics toolbox. Spatial vision, 10, 433–436.

Diamond, A. (2013). Executive functions. Annual Review of Psychology, 64, 135–168. https://doi.org/10.1146/annurev-psych-113011-143750

Fougnie, D., Cormiea, S. M., & Alvarez, G. A. (2012). Top-down modulation of visual working memory precision. Psychonomic Bulletin & Review, 19(4), 655-661. https://doi.org/10.3758/s13423-011-0163-6

Gorgoraptis, N., Catalao, R. F. G., Bays, P. M., & Husain, M. (2011). Dynamic updating of working memory resources for visual objects. Journal of Neuroscience, 31(23), 8502-8511. https://doi.org/10.1523/JNEUROSCI.0208-11.2011

Green, C. S., & Bavelier, D. (2006). Effect of action video games on the spatial distribution of visuospatial attention. Cognition, 101(1), 73-81. https://doi.org/10.1016/j.cognition.2006.01.002

Green, C. S., & Bavelier, D. (2012). Learning, attentional control, and action video games. Current Biology, 22(6), R197-R206. https://doi.org/10.1177/1529100612454917

Haghian, Z., Vahabie, A.-H., & Rezayat, E. (2024). Emotional content effects the precision of visual working memory. *bioRxiv*. https://doi.org/10.1101/2024.12.01.626217

McDermott, A. F., Bavelier, D., & Green, C. S. (2014). Memory abilities in action video game players. Computers in Human Behavior, 34, 69–78. https://doi.org/10.1016/j.chb.2014.01.018

Willenbockel, V., Sadr, J., Fiset, D., Horne, G. O., Gosselin, F., & Tanaka, J. W. (2010). Controlling lowlevel image properties: The SHINE toolbox. Behavior Research Methods, 42(3), 671-684. https://doi.org/10.3758/BRM.42.3.671

Wilms, I. L., Petersen, A., & Vangkilde, S. (2013). Intensive video gaming improves encoding speed to visual short-term memory in young male adults. Acta Psychologica, 142(1), 108–118. https://doi.org/10.1016/j.actpsy.2012.11.003

Zhang, B., Liu, S., Hu, C., Luo, Z., Huang, S., & Sui, J. (2020). Enhanced memory-driven attentional capture in action video game players. Computers in Human Behavior, 107, Article 106271. https://doi.org/10.1016/j.chb.2020.106271

Table 1. Nonparametric Comparisons of Absolute Error (|Error|)

Comparison	p-value	Effect Size r	Interpretation
Intervention Pre vs. Post	<0.001	+0.145	Significant improvement in Intervention group (lower post-intervention error).
Control Pre vs. Post	0.005	-0.072	Significant change in Control group, but effect size is negative, indicating higher post-test error (i.e., performance worsened).
Intervention Post vs. Control Post	<0.001	-0.110	Significant difference at post-test; Intervention group outperformed Control (Control's median error rank was higher).
Intervention Pre vs. Control Pre	0.164	+0.025	No significant baseline difference.

Table 2. Mixture Model Parameter Estimates and Statistical Tests

Measure	Group	Pre Mean (SD)	Post Mean (SD)	ANOVA (Group × Phase)	Paired t (df = 16)	BetweenGroup t (df = 32)
K (Precision)	Intervention	4.24 (3.53)	5.01 (2.67)	F(1,32)=2.87 p=0.10	−2.21,p=0.042	1.69 p=0.10
	Control	5.70 (3.87)	5.19 (4.30)		0.76,p=0.458	
pT (Target)	Intervention	0.80 (0.13)	0.85 (0.09)	F(1,32)=2.54 p=0.12	−1.17,p=0.259	1.59 p=0.12
	Control	0.78 (0.15)	0.73 (0.15)		1.09,p=0.293	
pU (random Guess)	Intervention	0.20 (0.13)	0.15 (0.09)	F(1,32)=2.54 p=0.12	1.17,p=0.259	−1.59 p=0.12
	Control	0.22 (0.15)	0.27 (0.15)		−1.09,p=0.293	

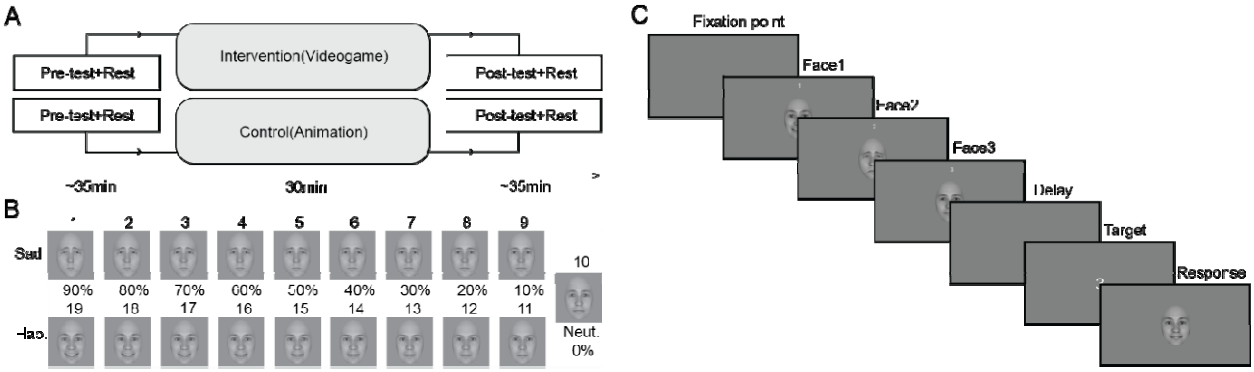

FIGURE 1 | Experiment procedure and task. (A) The protocol of study in both groups of intervention and control (B) Continuum of Morphed Facial Stimuli. A series of facial stimuli created through a morphing process. (C) The schematic description of the trial sequence for behavioral task. Each trial began with presenting a fixation dot for 0.7 second, followed by three ‘sample face’ presentation (0.7 second for each one) and a delay (1.5 or 3 seconds). A number appeared on screen to show which image would be remembered. Then a ‘test face’ was presented and the subject had to change the stimulus to match it to the remembered ‘target face’.

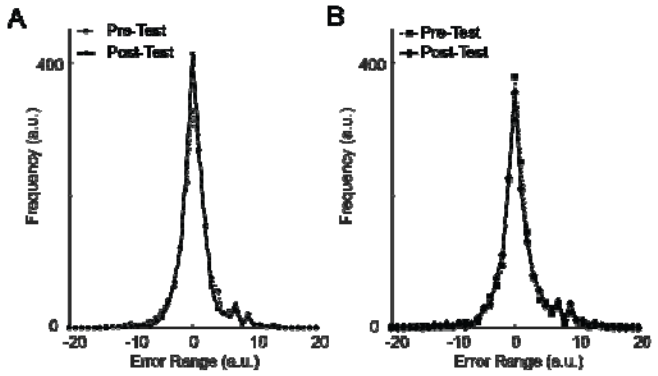

FIGURE 2 | Distribution of Errors shows the increase of performance after intervention. The figure displays the frequency distribution of errors in both intervention (A) and control (B) groups, assessed during pre-test and post-test phases. Errors represent the deviation between participants' responses and the correct target, with negative values indicating underestimation and positive values indicating overestimation. The data is presented separately for the intervention group and the control group across pre- and post-test phases.

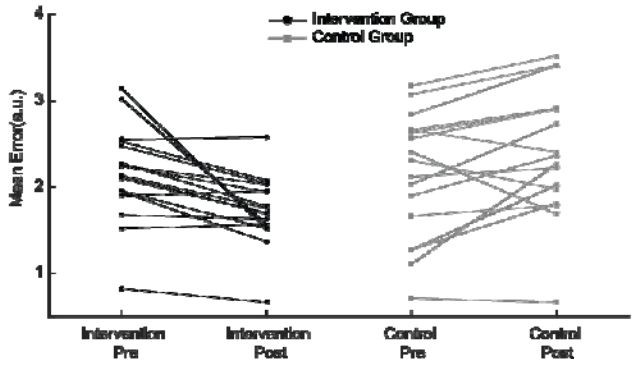

FIGURE 3 | Total Mean Error decreased after intervention. This plot illustrates the mean error per participant across two experimental phases (pre and post) within two study groups: Intervention(left) and Control(right). Each line represents the trajectory of a single participant, showing the change in their mean error from the pre-test to the post-test phase. Mean error is calculated as the average absolute deviation from the target, providing an overall measure of performance accuracy.

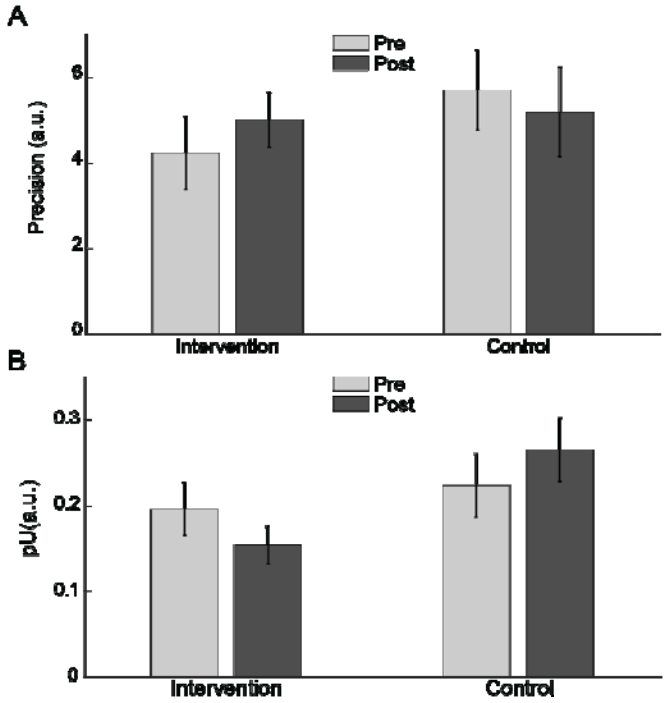

FIGURE 4 | The precision is increased and the random guess were decreased intervention and control groups, measured during pre and post phases. Each plot provides insights into different aspects of participant performance: (A)This figure represents the mean memory precision (K) for the intervention and control groups across pre- and post-intervention phases. Memory precision (K) is a measure of the resolution of visual working memory, reflecting the allocation of memory resources to individual items. Bars indicate mean values, and error bars represent the standard error of the mean (SEM). (B) This figure depicts the mean probability of uniform (random) responses (pU) across pre- and post-intervention phases for intervention and control groups. pU reflects trials where no target information was stored, often due to insufficient memory allocation. Error bars represent SEM.