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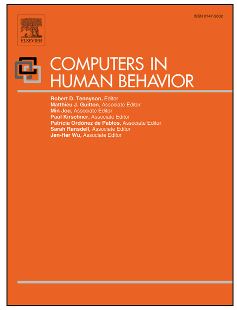

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CRediT author statement

Mark Campbell and Adam Toth: Conceptualization, Methodology, Data Collection **Fazilat Hojaji**: Data processing, Python programming, Cluster analysis, Machine learning. **Mark Campbell, Adam Toth and Fazilat Hojaji:** Writing- Reviewing and Editing

Exploring the mechanisms of target acquisition performance in esports: the role of component kinematic phases on a first person shooter motor skill.

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Abstract

When quantifying elements of performance in bimanual tasks, such as surgery or sports, it is important to understand the errors that participants make to facilitate skill improvement. Esports lags behind when quantifying the motor skills that differentiate elites and amateurs. The purpose of this study was to leverage a large existing kinematic dataset to identify whether previously observed differences in end point performance among gamers of varying expertise, across training days within expertise groups and between stimulation conditions resulted from differences in performance during specific phases of target acquisition movements. Specifically, we evaluated the position and velocity of cursor movements to show for the first time the differences in the component phases of target acquisition movements among first person shooter gamers of various expertise and non-gamers. We also established the dose-response of these components to deliberate practice and the effect of neurostimulation on the improvement of these components in each expertise group. Overall, gamers of higher expertise show evidence of superior motor planning and sensory-motor integration and that these qualities can be improved with training. Future work should more closely examine the sub-movements and classify biomechanical movement strategies of target acquisition skills among gamers.

Introduction

Motor learning, the process of acquiring and refining skilled movements, is an essential human capacity (Fitts & Posner, 1979). The acquisition of motor skills is typically achieved with prolonged training, and the resulting performance gains often comprise an improved speed-accuracy relationship and/or a reduction in performance variability (Shmuelof, Krakauer, & Mazzoni, 2012). To facilitate training-induced motor skill improvements, it is important that appropriate error feedback is provided so that motor programs can be updated to refine subsequent movements. Thus, quantifying the different elements of performance in manual or bimanual tasks, such as surgery or sports, is important to understand the errors that participants make so that they can improve and refine their skills (Krakauer & Mazzoni, 2011). However, esports, the competitive play of video games, lags behind when quantifying the motor skills that differentiate elite and amateur players.

Toth and colleagues (2021) recently provided one of the first investigations of the motor skills displayed by esports players of first person shooter (FPS) games, quantifying the magnitude of performance difference in target acquisition tasks among low skill and elite FPS gamers and non-gamers as well as the dose-response of this skill to deliberate practice over the course of 5 days (Toth, Ramsbottom, Constantin, Milliet & Campbell, 2021). More recently, Listman and colleagues (Listman, Tsay, Kim, Mackey & Heeger, 2021) examined motor learning of the same skill outside of the lab using video game data. While this work has begun to unveil the importance of determining the value that individual performance skills have on the overall expertise or rank of an esports athlete and the improvement to be made with dedicated training, the evaluation of these target acquisition skills can extend well beyond the endpoint performance metrics examined to date (Shadmehr, Smith & Krakauer, 2010).

When considering the fundamentals of target acquisition skills across similar contexts in the literature (i.e., pointing/reaching tasks), there are distinct and well classified kinematic events that occur between the presentation of a target and its destruction (Keele & Posner, 1968; Woodworth, 1899; Meyer, Abram, Kornblum, Wright & Smith, 1988; Thompson, McConnell, Slocum & Bohan, 2007). Specifically, three predominant phases of the target acquisition process have been described. The first phase (the initiation or recognition phase) describes the recognition of a target, including its allocentric location, and the neural planning of a motor program to move to acquire it (Bizzi & Ajemian, 2020). The second phase comprises the ‘response’ or the ballistic movement toward the target and the use of visual and/or kinesthetic feedback during various sub-movements as one homes in on the target. The final verification phase describes the time to verify that the target has been acquired before selecting it. By uncovering the differences among these phases of the target acquisition process, we now have a better understanding of the motor learning process, and the contributions that refining the motor plan in premotor areas and increasing the efficiency of online sensory-motor processes have on improvements in motor skill.

In the experiment conducted by Toth and colleagues (2021), it was found that the time to destroy targets during a target acquisition task could be differentiated by first person shooter expertise and improved through both training and neurostimulation. However, by looking deeper into the various phases of the target acquisition process, we may better understand where the differences between players of various skill manifest, how improvements come about via training and the mechanism by which neurostimulation exerts its effects. While we know a great deal about the composite phases of kinematic processes in various sport and motor contexts (Clark, Barnes, Holton, Summers & Stratton, 2016; Langdown, Bridge & Li, 2012; Sharp, 2009; Welch, Banks, Cook & Draovitch, 1995; Wu, Lin, Chen, Chen, & Hong, 2007), no investigation to date has been conducted on the kinematic processes of motor skills in esports.

The purpose of this study was to leverage a large existing kinematic dataset to identify whether previously observed differences in end point performance (time to destroy; TTD) among gamers of varying expertise, across training days within expertise groups and between stimulation conditions resulted from differences in performance during specific phases of target acquisition movements. For a detailed description of the experimental protocol used to create the dataset leveraged for this study, please see Toth et al., 2021. We first hypothesized that Elite gamers would react to targets more quickly, move more rapidly, and show faster verification of their movements compared to Low Skilled gamers, who would also show superior performance compared to Non-Gamers. Secondly, we hypothesized that all expertise groups would improve their performance across training days, particularly during the movement response and verification phases of target acquisition. Finally, we hypothesised specifically that Non-Gamers who received neurostimulation (tDCS; STIM group) would further reduce their TTDs compared to Non-Gamers in the NoSTIM and SHAM groups and that this would be demonstrated across the movement response and verification phases of target acquisition.

Methods

Participants

One hundred and forty-nine young healthy adult participants were recruited from the University of Limerick and Limerick Institute of technology student populations and provided informed written consent prior to participating in the study. Participants attended the Esports Science Research Lab at a similar time from Monday to Friday consecutively and again the following Monday. The experiment was approved by the University research ethics board in accordance with the Declaration of Helsinki. Baseline, Post and Retention tests were administered on the first Monday, Friday and second Monday respectively. Training sessions were administered on five consecutive days with the first training session occurring immediately following the

Baseline test on the first Monday and the last training session occurring immediately prior to the Post test on the Friday. Participants were excluded if they dropped out of the study prior to completing the Post test or if they missed at least two of the training sessions on Tuesday, Wednesday and Thursday (15 participants were excluded in this way).

Questionnaires

Upon entering the Esports Science Research Lab on Day 1, participants were presented with a questionnaire that captured various demographic data, including the number of hours they reported gaming on average per week, the game they predominantly played and, for those that played the game Counter-Strike: Global Offensive (CS:GO), their current and highest competitive rank. After gathering this initial information, participants were categorized into one of three groups. Those who dedicated less than 1 hour per week to action video games (game genres including first-person shooter (FPS), third-person shooter (TPS) and massive online battle arena (MOBA)) and did not hold any CS:GO competitive ranking were assigned to the *Non Gamer* Expertise group (n=42). Seventeen classified *Non Gamers* (*NGs*) were excluded upon learning they had prior experience playing alternate FPS or MOBA games despite them failing to report playing them currently. Those who reported spending more than 5 h per week specifically playing CS:GO and maintained a current competitive rank between Silver 1 and Gold Nova 3 were assigned to the *Low Skill Gamer* (*LSG*) Expertise group (n=39). Finally, those who reported spending more than 5 h per week specifically playing CS:GO and maintained a current competitive rank between Gold Nova Master and Global Elite were assigned to the *High Skill Gamer* (*HSG*) Expertise group (n=36). For a full description of participant demographics, please see Toth et al., (2021).

Training Groups

In addition to their classification into an Expertise group, each participant was also randomly allocated to one of four Training groups. Participants in each Training group differed by their exposure to a bespoke FPS Flick Training Software and transcranial Direct Current Stimulation (tDCS). These groups were Control, NoStim, Sham and STIM training groups. However, for the following analyses, only data from the training task were considered, and therefore, only STIM, NoSTIM, and SHAM training groups are included in this study.

Participants trained using the FPS Flick Training Software for 5 consecutive days. The training software was designed and developed using the CS:GO architecture and game mechanics.

For a full description of the training software, neurostimulation protocol and all methods used to capture the data processed and analysed in this manuscript, please see Toth et al., (2021).

Data Processing

The FPS Flick Training software used in the previous study by Toth and colleagues (2021) allowed for the recording of the 3D location of both the targets and the participant's avatar at 60Hz. Therefore, the change in the avatar's yaw, pitch and roll position relative to targets could be calculated as could the overall aiming error (degrees error) over the course of the presentation and destruction of each target.

Targets were first segregated according to whether they were destroyed on each participant's first or second shot attempt (Ammo to Destroy). Each target in these groupings was then categorised into one of nine 'bins' based on its eccentricity in the avatar's field of view one frame following its appearance (the standardised horizontal field of view in the software was 90 degrees). Bins included 0-5, 5-10, 10-15, 15-20, 20-25, 25-30, 30-35, 35-40, 40-45 degrees. Targets in each bin were then further categorised as left or right based on the difference between the participant's avatar's yaw values one frame after target presentation and one frame prior to target destruction. Where this difference was positive, a rightward mouse movement was required to acquire and destroy targets (Right Target), whereas a negative difference required a leftward movement of the mouse and cursor to acquire and destroy targets (Left Target). Targets that were destroyed (time to destroy; TTD) in less than 0.1s or more than 3 seconds were excluded from further analyses. This preprocessing was implemented in Python (version 3.9) using Numpy and Pandas libraries.

A custom LabVIEW program was then used to filter the position data for each target using a 2nd order lowpass Butterworth filter with a 5Hz cut-off as a fast fourier transform of the signal showed that the true signal frequency content was predominantly below 5Hz. Position data were then differentiated to produce velocity profiles for each target. From the position and velocity data, we identified three component phases of movement in line with previous empirical work on pointing/reaching/ target acquisition (Recognition Phase, Movement Response Phase, Verification Phase) (Thompson et al., 2007; Walker, Meyer & Smelcer, 1993). The recognition phase (REC) was defined as the time between target appearance and the cursor position changing by more than 2 standard deviations from the average resting baseline cursor position during the first 5% of data after target appearance (Figure 1A). The first 5% of position data were chosen to represent the resting baseline average as the exploration of position data across individual targets showed no rapid change in cursor position occurred before this cut-off. The verification phase (V) for each target was determined by reversing the velocity profile and determining from target destruction the point at which the cursor velocity increased by more than 5% of the peak velocity (Figure 1B). This threshold is higher than the 2% value used by Thompson (2007) due to the peak velocities observed in our study being more than 2x greater than those observed in their study. The resulting time between the end of the recognition phase and start of the verification phase was the movement response phase (MR). In addition to these metrics, we also captured the Time to Destroy (TTD) for each target (time between target appearance and target destruction) and the Peak Velocity (PV) achieved during the destruction of each target.

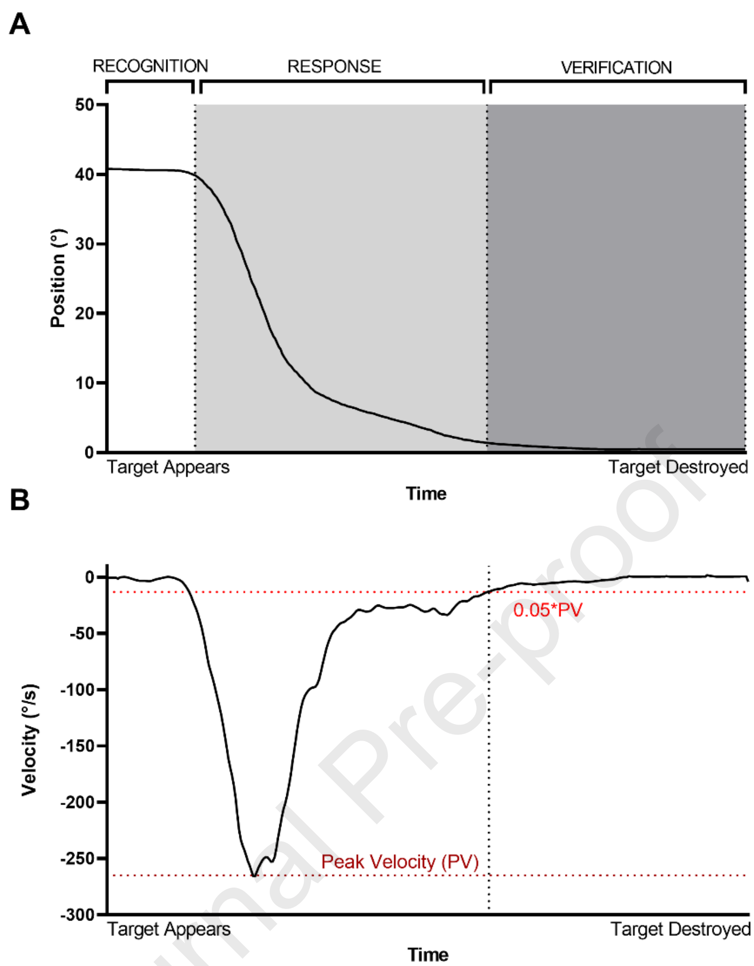

Figure 1: Example cursor position (A) and velocity (B) data for a target approximately 40 degrees eccentric to the participant's initial aim. The time windows corresponding to the recognition (REC), movement response (MR), and verification (V) phases are indicated, as is the peak velocity (PV).

Analyses

Analyses were conducted using SPSS v28 software. Means and standard errors are reported throughout unless otherwise indicated. Data were assessed for normality by evaluating the W statistic from Shapiro-Wilk tests and visualisation of histogram plots. Where data were deemed not normally distributed, outlier data exceeded 1.5 times the interquartile range of the dataset (1.5*IQR) were removed before re-averaging.

Expertise Comparisons

T-tests were conducted to test whether performance on each dependent variable significantly differed between target directions (L or R). Where target direction was not significant, 2-way ANOVAs (Expertise x Ammo to Destroy) were conducted to establish the effect of Expertise, Ammo to Destroy, and the interaction between these factors on day 1 dependent variables (TTD1, REC1, MR1, V1, PV1). Where the effect of target direction was significant, 3-way ANOVAs (Expertise x Ammo to Destroy x Target Direction) were conducted to establish the effect of Expertise, the number of shots required to destroy targets, target direction, and the interactions between these factors. Where multiple post hoc comparisons were examined, Sidak adjustments to alpha levels were conducted to account for increases in type I error rates.

Training Day Comparisons

To establish the effect of training on performance within each expertise group, two-way (TTD, REC, MR) (Training Day (1 – 5) x Stimulation Group (NoSTIM and SHAM only)) and three-way (V, PV) (Direction (L and R) x Training Day (1 – 5) x Training Group (NoSTIM and SHAM only)) ANOVAs were conducted with T1-T2, T1-T3, T1-T4 and T1-T5 a priori comparisons for training data.

Stimulation Condition Comparisons

2-way (TTD, REC, MR) (Training Day (2 – 5) x Stimulation Group (NoSTIM, SHAM, and STIM)) and 3-way (V, PV) (Direction (L and R) x Training Day (2 – 5) x Stimulation Group (NoSTIM, SHAM, and STIM)) ANCOVAs were conducted for each of Non-Gamers, Low Skill Gamers, and Elite Gamers to test whether participants who received tDCS improved in their performance more than those who received sham tDCS or no tDCS. Day 1 scores were incorporated as covariates in the model to account for variation in baseline performance. Post hoc comparisons were restricted to investigating the difference between STIM scores and both NoSTIM and SHAM scores to determine if tDCS altered performance.

Results

Expertise Comparisons

A main effect for Ammo to Destroy (Shots) was found for Time to Destroy (TTD; $F(2,1765)= 534.47$, $p<0.001$, $\eta2=0.337$), Recognition (REC; $F(2,2271)= 10.685$, $p<0.001$, $\eta2=0.009$), Movement Response (MR; $F(2,2273)= 86.506$, $p<0.001$, $\eta2=0.071$) and Verification (V; $F(2,2264)=444.653$, $p<0.001$, $\eta2=0.282$) variables. Post hoc comparisons unsurprisingly revealed that participants in all groups took significantly longer to destroy targets with two shots as compared to targets destroyed with one shot (TTD). Moreover, they also revealed that all phases comprising the time to destroy (REC, MR, V) were significantly longer in duration for targets destroyed with 2 shots compared to targets destroyed with 1 shot, with the verification phase showing the largest effect. No significant main effect was found for Peak Velocity (PV; ($F(2,2264)= 0.357$, $p=0.700$, $\eta2=0.000$).

A main effect was also found for Expertise for all variables (TTD; $F(2,1765)= 211.995$, $p<0.001$, $\eta2=0.194$)(REC; $F(2,2271)= 29.492$, $p<0.001$, $\eta2=0.025$)(MR; $F(2,2273)= 464.025$, $p<0.001$, $\eta2=0.290$)(V; $F(2,2264)=51.501$, $p<0.001$, $\eta2=0.044$)(PV; ($F(2,2264)= 122.07$, $p<0.001$, $\eta2=0.097$). Post hoc comparisons revealed that all groups were significantly different from one another for all variables, except REC, where Low Skill and Elite CS:GO gamers did not differ from each other, but showed significantly shorter REC times compared to Non-Gamers. Overall, as expertise increased, the time taken to destroy targets (TTD; Figure 2A) decreased, the peak velocity with which participant's moved their cursor increased, and the time taken within each phase of the movement decreased (Figure 2B).

Finally, a main effect of direction was found for both verification (V; $F(1,2264)= 5.784$, $p=0.016$, $\eta2=0.003$) and peak velocity (PV; $F(1,2264)= 50.242$, $p<0.001$, $\eta2=0.022$) variables, whereby participants took longer during the verification phase and displayed faster peak velocities for left compared to right targets. No significant interaction effects were found.

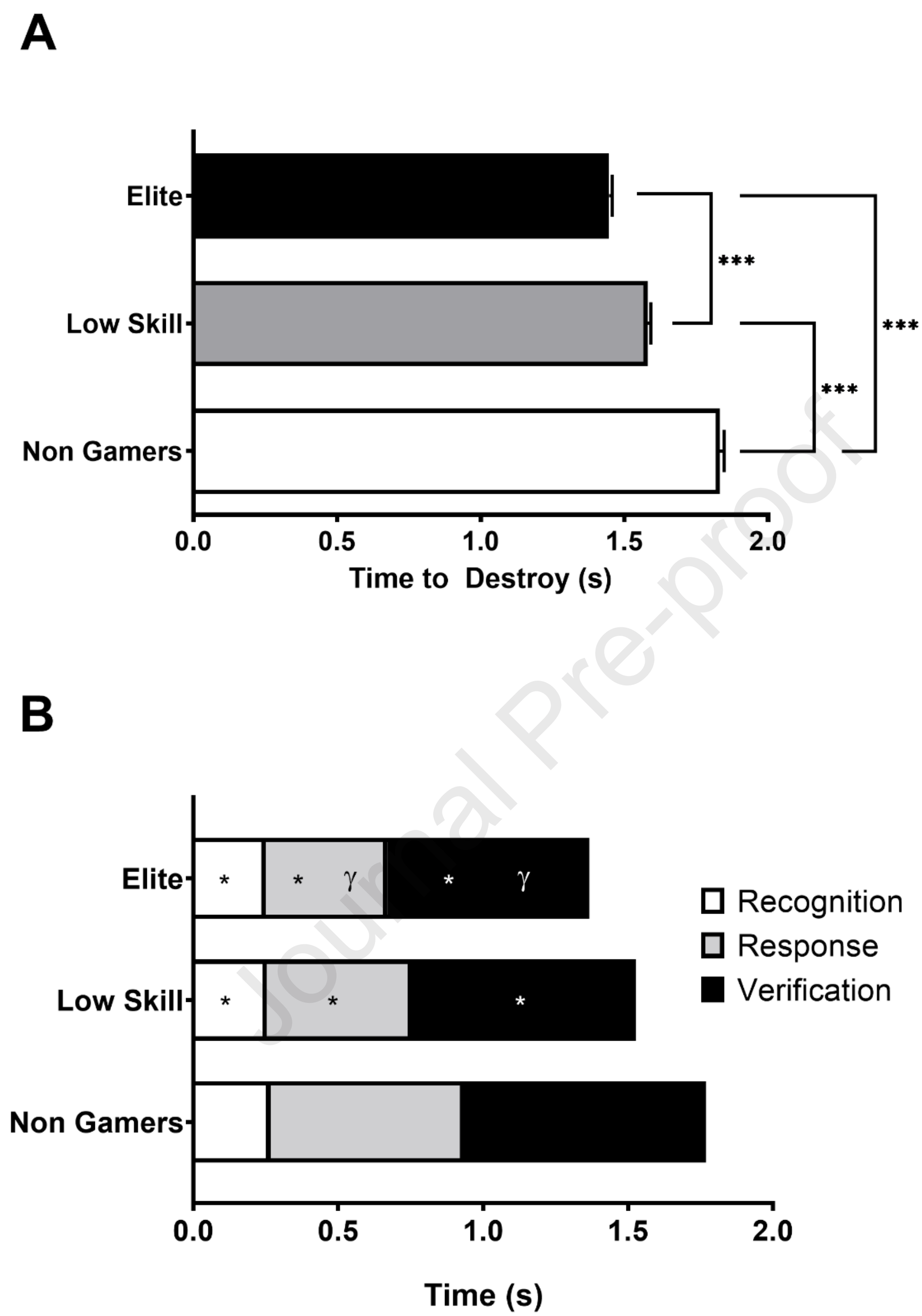

Figure 2: A: Average (± SE) Time (seconds) to destroy performance by Elite gamers, Low Skill gamers, and Non-Gamers on the target acquisition task on day 1. *** represents significance between groups at an alpha level of 0.001. B: Recognition, Movement Response, and Verification phases for Elite gamers, Low Skill gamers, and Non-gamers on the target

acquisition task on day 1. * and γ represent a significant difference from Non-Gamers and Low Skill Gamers, respectively, at an alpha level of 0.001.

Training Effects

The following results pertaining to the effects of training across NoSTIM and SHAM stimulation conditions are presented only for targets requiring 1 shot to destroy. Results for targets destroyed in 2 shots can be found in supplementary file 1.

Non-Gamers

Time to Destroy (TTD)

2-way (Training Day x Stimulation Condition) repeated measures ANOVAs revealed a significant main effect of Training Day ($F(3.324,465.321) = 13.301$, $p<0.001$, $\eta 2=0.087$) and a significant interaction effect ($F(3.324,465.321) = 3.993$, $p=0.006$, $\eta 2=0.028$). No main effect of Stimulation Condition (NoSTIM vs. SHAM) was found. A priori comparisons showed that day 1 TTD times were significantly higher compared to day 3 ($p<0.001$), 4 ($p<0.001$), and 5 ($p=0.05$) times for the NoSTIM condition, and were significantly higher than days 4 ($p=0.009$) and 5 ($p<0.001$) for the SHAM condition (Figure 3A).

Recognition Phase (REC)

Main effects were found for both Training Day ($F(4,652) = 17.680$, $p<0.001$, $\eta 2=0.098$) and Stimulation Condition ($F(1,163) = 4.352$, $p=0.039$, $\eta 2=0.026$) in addition to the presence of a significant interaction effect ($F(4,652) = 17.150$, $p<0.001$, $\eta 2=0.089$). A priori comparisons showed that day 1 REC times were significantly higher compared to day 3 ($p=0.040$), 4 ($p<0.001$) and 5 ($p=0.006$) times for the NoSTIM condition and significantly higher than day 2 ($p=0.027$), 3 ($p=0.001$), 4 ($p<0.001$) and 5 ($p<0.001$) times for the SHAM condition (Figure 3B).

Movement Response Phase (MR)

Main effects were found for both Training Day ($F(3.663,644.638) = 18.835$, $p<0.001$, $\eta 2=0.097$) and Stimulation Condition ($F(1,176) = 31.240$, $p<0.001$, $\eta 2=0.151$) in addition to the presence of a significant interaction effect ($F(3.663,644.638) = 4.942$, $p<0.001$, $\eta 2=0.027$). A priori comparisons showed that day 1 MR times were significantly higher compared to day 3 ($p=0.025$), 4 ($p<0.001$) and 5 ($p<0.001$) times for the NoSTIM condition and significantly higher than day 4 ($p<0.001$) times for the SHAM condition (Figure 3C).

Peak Velocity (PV)

A main effect was found for Training Day ($F(3.725,655.550)= 14.564$, $p<0.001$, $\eta 2=0.076$) with a priori comparisons showing that day 1 MR times were significantly faster compared to day 2 ($p=0.001$), 3 ($p=0.004$), 4 ($p=0.007$) and 5 ($p<0.001$) times. No main effect of Stimulation Condition ($F(1,176)= 0.810$, $p=0.369$, $\eta 2=0.005$) or interaction effect ($F(3.725,655.550)= 1.874$, $p=0.118$, $\eta 2=0.011$) was found.

Verification Phase (V)

An interaction effect was found between Training Day and Stimulation Condition ($F(4,704)= 3.096$, $p=0.015$, $\eta 2=0.017$) with no significant main effects for Training Day ($F(4,704)= 1.797$, $p=0.128$, $\eta 2=0.010$) or Stimulation Condition ($F(1,176)= .954$, $p=0.330$, $\eta 2=0.005$). A priori comparisons showed that day 1 V times were significantly higher compared to day 3 ($p=0.041$) times for the NoSTIM condition while for the SHAM condition, day 1 times did not significantly differ from verification times on subsequent days (Figure 3D).

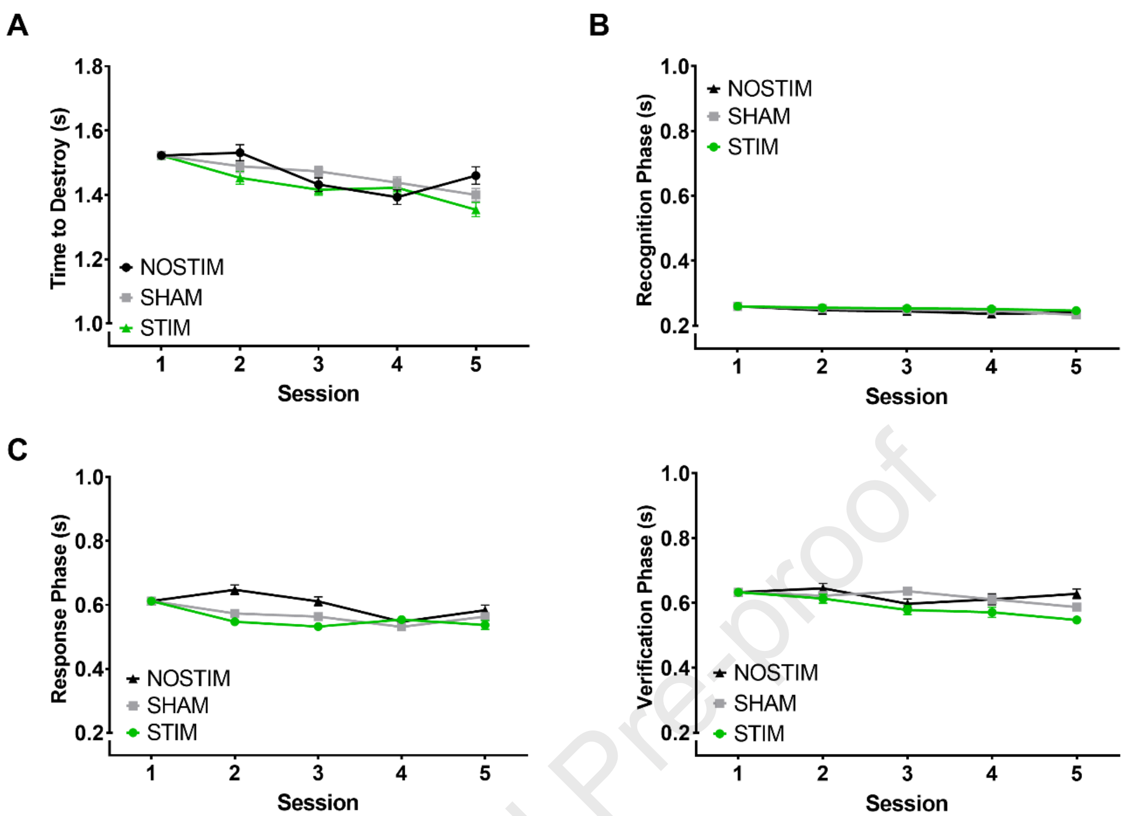

Figure 3: Time to destroy (TTD; A), recognition (REC; B), movement response (MR; C), and verification (V; D) times in seconds (mean ± SE) across training sessions and between stimulation (green), sham (grey) and no stimulation (black) groups for Non-Gamers.

Low Skilled Gamers

Time to Destroy (TTD)

A significant main effect of Training Day ($F(3.707,670.995)= 17.366$, $p<0.001$, $\eta2=0.088$) and Stimulation Condition ($F(1,181)= 6.301$, $p=0.013$, $\eta2=0.034$) was found while the interaction effect was not significant ($F(3.707,670.995)= 1.339$, $p=0.256$, $\eta2=0.007$). A priori comparisons showed that day 1 TTD times were significantly higher compared to day 3 ($p=0.024$), 4 ($p<0.001$) and 5 ($p<0.001$) times (Figure 4A).

Recognition Phase (REC)

A significant main effect for Training Day ($F(4,816)= 10.743$, $p<0.001$, $\eta 2=0.050$) and a significant interaction effect ($F(4,816)= 3.358$, $p=0.010$, $\eta 2=0.016$) were found. The effect of Stimulation Condition was not significant ($F(1,204)= 0.000$, $p=0.983$, $\eta 2=0.000$). A priori comparisons showed that day 1 REC times were significantly higher compared to day 4 ($p<0.001$) times for the NoSTIM condition and significantly higher than day 3 ($p=0.004$) and 4 ($p<0.001$) times for the SHAM condition (Figure 4B).

Movement Response Phase (MR)

A significant main effect for Training Day ($F(3.787,772.534)= 4.555$, $p=0.001$, $\eta 2=0.022$) and a significant interaction effect ($F(3.787,772.534)= 2.425$, $p=0.050$, $\eta 2=0.012$) were found. The effect of Stimulation Condition was not significant ($F(1,204)= 0.356$, $p=0.551$, $\eta 2=0.002$). A priori comparisons showed that day 1 MR times were significantly higher compared to day 5 ($p=0.005$) times for the NoSTIM condition and significantly higher than day 3 ($p=0.005$), 4 ($p=0.007$) and 5 ($p=0.017$) times for the SHAM condition (Figure 4C).

Peak Velocity (PV)

A significant main effect for Training Day ($F(3.837,782.670)= 6.742$, $p<0.001$, $\eta 2=0.032$) and a significant interaction effect ($F(3.837,782.670)= 2.867$, $p=0.024$, $\eta 2=0.014$) were found. The effect of Stimulation Condition was not significant ($F(1,204)= 0.322$, $p=0.571$, $\eta 2=0.002$). A priori comparisons showed that day 1 peak velocities were significantly slower compared to day 4 ($p=0.006$) velocities for the NoSTIM condition and significantly slower than day 5 ($p=0.006$) velocities for the SHAM condition.

Verification Phase (V)

A significant main effect of Training Day ($F(3.690,752.711)= 12.158$, $p<0.001$, $\eta 2=0.056$) and Stimulation Condition ($F(1,204)= 20.679$, $p<0.001$, $\eta 2=0.092$) was found while the interaction effect was not significant ($F(3.690,752.711)= 2.368$, $p=0.056$, $\eta 2=0.011$). A priori comparisons showed that day 1 V times were significantly higher compared to day 3 ($p=0.012$), 4 ($p<0.001$) and 5 ($p<0.001$) times (Figure 4D).

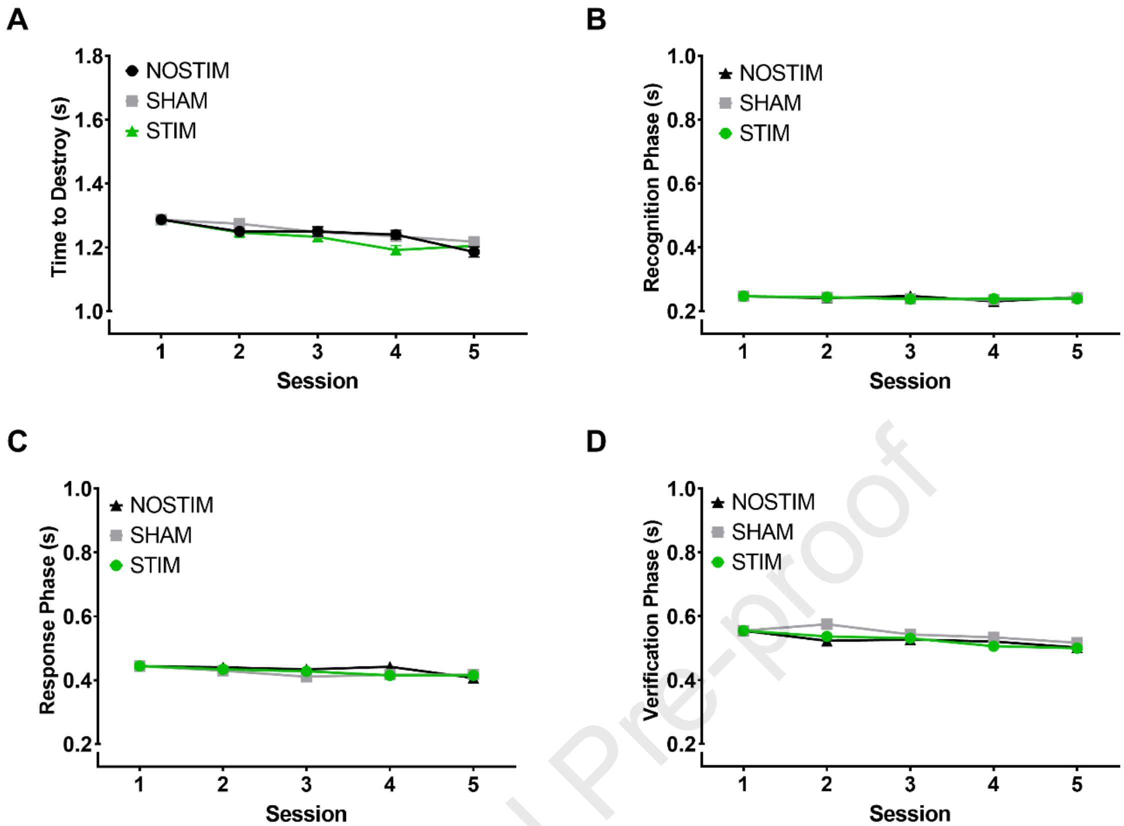

Figure 4: Time to destroy (TTD; A), recognition (REC; B), movement response (MR; C), and verification (V; D) times in seconds (mean ± SE) across training sessions and between stimulation (green), sham (grey) and no stimulation (black) groups for Low Skill Gamers.

Elite Gamers

Time to Destroy (TTD)

A significant main effect for Training Day ($F(4,620)= 3.997$, $p=0.003$, $\eta2=0.025$) and a significant interaction effect ($F(4,620)= 4.980$, $p<0.001$, $\eta2=0.031$) were found. The effect of Stimulation Condition was not significant ($F(1,155)= 0.155$, $p=0.694$, $\eta2=0.001$). A priori comparisons showed that day 1 TTD times were significantly slower compared to day 4 ($p=0.018$) times for the NoSTIM condition and significantly faster than day 3 ($p=0.017$) times for the SHAM condition.

Recognition Phase (REC)

No significant main effects or interaction effects were found (Training Day; $F(3.689,704.512)= .192$, $p=0.932$, $\eta2=0.001$)(Stimulation Condition; $F(1,191)= 0.775$, $p=0.380$, $\eta2=0.004$)(Interaction; $F(3.689,704.512)= 1.035$, $p=0.385$, $\eta2=0.005$).

Movement Response Phase (MR)

A significant main effect for Training Day ($F(3.748,715.995)= 3.828$, $p=0.005$, $\eta2=0.020$) was found, while the main effect for Stimulation Condition ($F(1,191)= 0.503$, $p=0.479$, $\eta2=0.003$) and the interaction effect ($F(3.748,715.995)= 2.197$, $p=0.072$, $\eta2=0.011$) were each not significant. A priori comparisons showed that day 1 MR times were significantly lower compared to day 3 ($p=0.006$) times.

Peak Velocity (PV)

A significant main effect for Training Day ($F(3.478,664.332)= 13.047$, $p<0.001$, $\eta2=0.064$) was found while the main effect of Stimulation Condition ($F(1,191)= 0.363$, $p=0.548$, $\eta2=0.002$) and the interaction effect ($F(3.478,664.332)= 0.207$, $p=0.915$, $\eta2=0.001$) were each not significant. A priori comparisons showed that day 1 peak velocities were significantly slower compared to day 3 ($p<0.001$), 4 ($p<0.001$) and 5 ($p<0.001$) velocities.

Verification Phase (V)

A significant main effect for Training Day ($F(3.784,722.710)= 8.446$, $p<0.001$, $\eta2=0.042$) was found while the main effect of Stimulation Condition ($F(1,191)= 3.086$, $p=0.081$, $\eta2=0.016$) and the interaction effect ($F(3.784,722.710)= 1.897$, $p=0.113$, $\eta2=0.010$) were not significant. A priori comparisons showed that day 1 V times were significantly slower compared to day 4 ($p<0.001$) and 5 ($p=0.004$) times.

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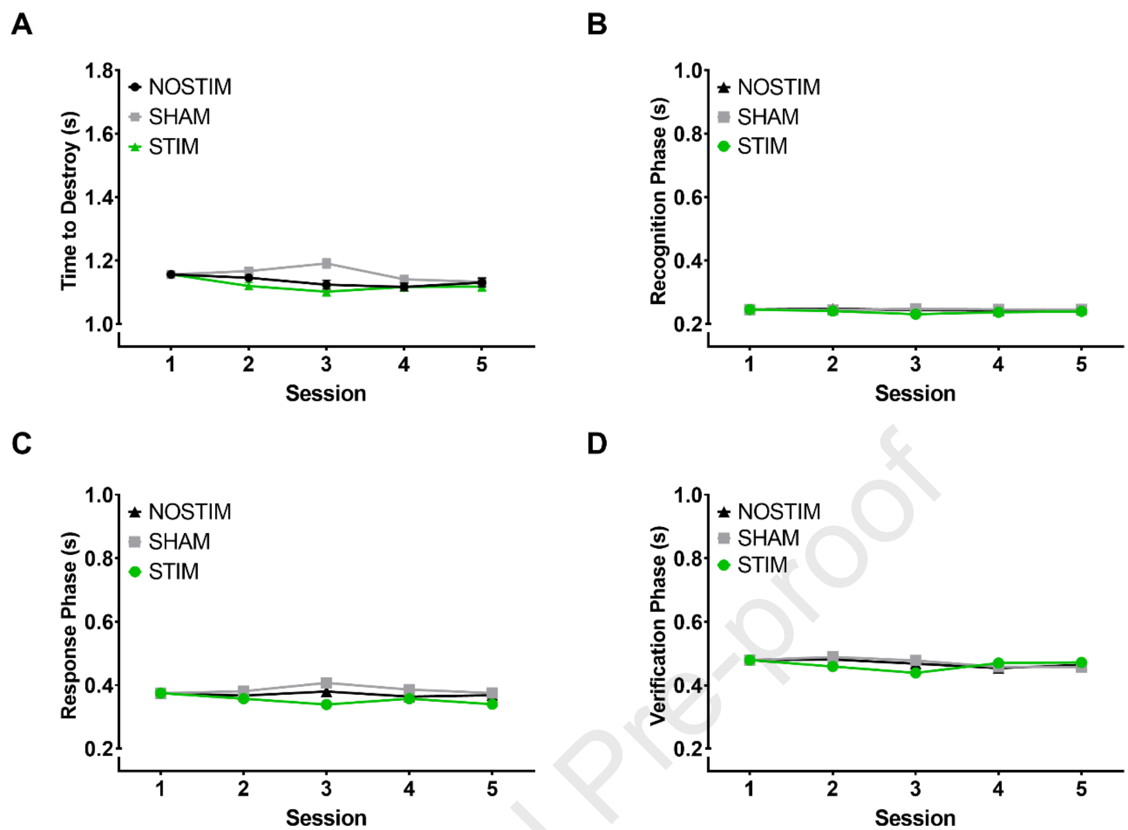

Figure 5: Time to destroy (TTD; A), recognition (REC; B), movement response (MR; C), and verification (V; D) times in seconds (mean ± SE) across training sessions and between stimulation (green), sham (grey) and no stimulation (black) groups for Elite Gamers.

Neurostimulation Effect

The following results from ANCOVA analyses testing the effect of Stimulation Condition across Training Days are presented for targets requiring 1 shot to destroy only. Results for targets destroyed in 2 shots can be found in Supplementary File 1.

Non-Gamers

Time to Destroy (TTD)

2-way (Training Day x Stimulation Condition) repeated measures ANCOVAs, controlling for day 1 scores, revealed a significant interaction effect between Training Day and Stimulation

Condition ($F(5.425,594.086)= 4.078$, $p<0.001$, $\eta2=0.036$). The main effects of Training Day ($F(2.713,594.086)= 0.652$, $p=0.566$, $\eta2=0.003$) and Stimulation Condition ($F(2,219)= 2.392$, $p=0.094$, $\eta2=0.021$) were not significant. Post hoc comparisons revealed that STIM TTD times were significantly lower than NoSTIM times at day 2 ($p=0.016$) and 5 ($p=0.003$), and significantly lower than SHAM times at day 3 ($p=0.016$) (Figure 3A).

Recognition Phase (REC)

The interaction effect between Training Day and Stimulation Condition ($F(5.739,748.914)= 2.668$, $p=0.016$, $\eta2=0.020$) as well as the main effects of both Training Day ($F(2.869,748.914)= 4.443$, $p=0.005$, $\eta2=0.017$) and Stimulation Condition ($F(2,261)= 6.352$, $p=0.002$, $\eta2=0.046$) were all significant. Post hoc comparisons revealed that STIM REC times were significantly higher than NoSTIM times at day 3 ($p=0.009$) and 4 ($p<0.001$), and significantly higher than SHAM times at day 5 ($p<0.001$) (Figure 3B).

Movement Response Phase (MR)

The interaction effect between Training Day and Stimulation Condition ($F(5.806,757.697)= 6.452$, $p<0.001$, $\eta2=0.047$) and the main effect of Stimulation Condition ($F(2,261)= 6.447$, $p=0.002$, $\eta2=0.047$) were both significant. The main effect of Training Day was not significant ($F(2.903,757.697)= 0.766$, $p=0.509$, $\eta2=0.003$). Post hoc comparisons revealed that STIM MR times were significantly lower than NoSTIM times at days 2 ($p<0.001$), 3 ($p<0.001$) and 5 ($p=0.035$) (Figure 3C).

Peak Velocities (PV)

An interaction effect was found between Training Day and stimulation condition ($F(5.642,727.847)= 8.166$, $p<0.001$, $\eta2=0.060$) with no significant main effects for Training Day ($F(2.821,727.847)= 0.973$, $p=0.401$, $\eta2=0.004$), Direction ($F(1,258)= 0.337$, $p=0.562$, $\eta2=0.001$) or Stimulation condition ($F(2,258)= 0.049$, $p=0.952$, $\eta2=0.000$). A priori comparisons showed that that STIM peak velocities were significantly lower than NoSTIM velocities at day 2 ($p=0.006$) and significantly higher than both NoSTIM ($p=0.044$) and SHAM ($p=0.003$) velocities at day 4.

Verification Phase (V)

The interaction effect between Training Day and Stimulation Condition ($F(6,774)= 2.954$, $p=0.007$, $\eta 2=0.022$) and the main effect of Stimulation Condition ($F(2,261)= 4.974$, $p=0.008$, $\eta 2=0.037$) were both significant. The main effect of Training Day ($F(3,774)= 1.692$, $p=0.167$, $\eta 2=0.007$) and Direction ($F(1,258)= 3.861$, $p=0.051$, $\eta 2=0.015$) were not significant. Post hoc comparisons revealed that STIM MR times were significantly lower than NoSTIM times at day 5 ($p<0.001$) and significantly lower than SHAM times at days 3 ($p=0.002$) and 5 ($p=0.029$) (Figure 3D).

Low Skilled Gamers

Time to Destroy (TTD)

A significant interaction effect between Training Day and Stimulation Condition was found ($F(6,792)= 2.195$, $p=0.042$, $\eta 2=0.016$) while the main effect of both Training Day ($F(3,792)= 0.261$, $p=0.853$, $\eta 2=0.001$) and Stimulation Condition ($F(2,264)= 1.241$, $p=0.291$, $\eta 2=0.009$) were not significant. Post hoc comparisons revealed that STIM TTD times were significantly lower than NoSTIM ($p=0.015$) and SHAM ($p=0.027$) times at day 4 (Figure 4A).

Recognition Phase (REC)

A significant interaction effect between Training Day and Stimulation Condition was found ($F(6,882)= 4.216$, $p<0.001$, $\eta 2=0.028$) while the main effect of both Training Day ($F(3,882)= 1.295$, $p=0.275$, $\eta 2=0.004$) and Stimulation Condition ($F(2,294)= 0.172$, $p=0.842$, $\eta 2=0.001$) were not significant. Post hoc comparisons revealed that STIM REC times were significantly lower than NoSTIM times at day 3 ($p=0.003$) and higher than NoSTIM times at day 4 ($p=0.032$) (Figure 4B).

Movement Response Phase (MR)

The interaction effect between Training Day and Stimulation Condition ($F(5.826,856.418)= 2.047$, $p=0.059$, $\eta 2=0.014$), the main effect of Stimulation Condition ($F(2,294)= 1.160$, $p=0.315$, $\eta 2=0.008$), and the main effect of Training Day ($F(2.913,856.418)= 1.658$, $p=0.176$, $\eta 2=0.006$) were all not significant (Figure 4C).

Peak Velocities (PV)

A significant interaction effect between Training Day and Stimulation Condition was found ($F(5.816,846.268)= 2.767$, $p=0.012$, $\eta2=0.019$) while the main effects of Training Day ($F(2.908,846.268)= 0.986$, $p=0.397$, $\eta2=0.003$), Stimulation Condition ($F(2,291)= 0.455$, $p=0.635$, $\eta2=0.003$) and Direction ($F(1,291)= 1.926$, $p=0.166$, $\eta2=0.007$) were all not significant. Post hoc comparisons showed that that STIM peak velocities were not significantly different compared to NoSTIM or SHAM velocities on any day.

Verification Phase (V)

The interaction effect between Training Day and Stimulation Condition ($F(6,873)= 1.941$, $p=0.072$, $\eta2=0.013$), the main effect of Stimulation Condition ($F(2,291)= 2.907$, $p=0.056$, $\eta2=0.020$), the main effect of Training Day ($F(3,873)= 0.771$, $p=0.510$, $\eta2=0.003$) and the main effect of Direction ($F(1,291)= 2.789$, $p=0.096$, $\eta2=0.009$) were all not significant (Figure 4D).

Elite Gamers

Time to Destroy (TTD)

The interaction effect between Training Day and Stimulation Condition ($F(5.651,655.531)= 2.850$, $p=0.011$, $\eta2=0.024$) and the main effect of Stimulation Condition ($F(2,232)= 5.500$, $p=0.005$, $\eta2=0.045$) were both significant. The main effect of Training Day ($F(2.826,655.531)= 2.134$, $p=0.099$, $\eta2=0.009$) was not significant. Post hoc comparisons revealed that STIM TTD times were significantly lower than SHAM times at days 2 ($p=0.003$) and 3 ($p<0.001$) (Figure 5A).

Recognition Phase (REC)

The interaction effect between Training Day and Stimulation Condition ($F(6,909)= 2.234$, $p=0.038$, $\eta2=0.015$) and the main effect of Stimulation Condition ($F(2,232)=6.310$, $p=0.002$, $\eta2=0.040$) were both significant. The main effect of Training Day ($F(3,909)= 0.853$, $p=0.465$, $\eta2=0.003$) was not significant. Post hoc comparisons revealed that STIM REC times were significantly lower than NoSTIM times at days 2 ($p=0.038$) and 3 ($p<0.001$), and significantly lower than SHAM times at days 3 ($p<0.001$) and 4 ($p=0.016$) (Figure 5B).

Movement Response Phase (MR)

The interaction effect between Training Day and Stimulation Condition ($F(5.707,864.641)= 3.075$, $p=0.006$, $\eta 2=0.020$), the main effect of Stimulation Condition ($F(2,303)= 12.331$, $p<0.001$, $\eta 2=0.075$), and the main effect of Training Day ($F(2.854,864.641)= 6.435$, $p<0.001$, $\eta 2=0.021$) were all significant. Post hoc comparisons revealed that STIM MR times were significantly lower than NoSTIM times at days 3 ($p<0.001$) and 5 ($p=0.022$), and significantly lower than SHAM times at days 2 ($p=0.010$), 3 ($p<0.001$), 4 ($p=0.006$) and 5 ($p=0.005$) (Figure 5C).

Peak Velocities (PV)

A significant interaction effect between Training Day and Stimulation Condition was found ($F(5.849,877.404)= 2.920$, $p=0.009$, $\eta 2=0.019$) while the main effects Training Day ($F(2.925,877.404)= 1.274$, $p=0.282$, $\eta 2=0.004$) Stimulation Condition ($F(2,300)= 0.121$, $p=0.886$, $\eta 2=0.001$) and Direction ($F(1,300)= 3.235$, $p=0.073$, $\eta 2=0.011$) were all not significant. Post hoc comparisons showed that that STIM peak velocities were not significantly different compared to NoSTIM and SHAM velocities on any day.

Verification Phase (V)

The interaction effect between Training Day and Stimulation Condition ($F(5.265,789.757)= 5.227$, $p<0.001$, $\eta 2=0.034$), the main effect of Direction ($F(1,300)= 4.920$, $p=0.027$, $\eta 2=0.016$) and the main effect of Training Day ($F(2.633,789.757)= 3.112$, $p=0.032$, $\eta 2=0.010$) were all significant, while the main effect of Stimulation Condition ($F(2,300)= 1.005$, $p=0.367$, $\eta 2=0.007$) was not. Post hoc comparisons revealed that STIM V times were significantly lower than both NoSTIM and SHAM times on days 2 ($p=0.015$; $p=0.002$) and 3 ($p=0.009$; $p<0.001$) (Figure 5D).

Discussion

This study sought to determine how previously observed target acquisition performance differences (Toth et al., 2021) manifested between and among FPS players of varying levels of expertise, and whether neurostimulation could enhance performance improvements resulting from training. Our results showed that when considering differences between expertise groups, gamer participants recognised targets and/or developed motor programs more quickly, moved more rapidly, with potentially fewer sub-movements, and took less time verifying the accuracy of their movements compared to non-gamers. Elite gamers moved more quickly and took less time verifying the accuracy of their movements compared to lower-skilled gamers. When examining how training influenced the various components of target acquisition performance within each expertise group, we first saw that improvements in TTDs among non-gamers across days were largely dictated by improvement in REC and MR times for targets destroyed using both 1 and 2 shots. For Low Skill gamers, the reduction in TTDs across training days was more greatly dictated by reductions in both MR and V times. For Elite gamers, reductions in V times had the greatest influence on TTD reduction. Finally, we observed a larger effect of tDCS on accelerating the improvement of 2 shot TTDs compared to 1 shot TTDs among non-gamers, with the effect manifested in increased REC times and reduced V times with little effect on MR times. While there was little to no evidence that tDCS could facilitate TTD improvements among Low Skill Gamers for targets destroyed in either one or two shots, we observed weak evidence that tDCS could facilitate TTD improvements among Elite gamers for targets destroyed in 1 and 2 shots with the effect manifested in decreased REC and MR times.

Expertise

Previous work describing the various phases of pointing or target acquisition tasks (Keele & Posner 1968; Meyer, Abram, Kornblum, Wright & Smith, 1988; Thompson et al., 2007; Woodworth 1899) has led to the identification of 3 predominant phases of movement. The first phase (recognition) describes the recognition of a target and the neural planning of a motor program to move to acquire it. The second phase comprises the movement response toward the target and the use of visual and/or kinesthetic feedback during various sub-movements as one home in on the target. The final verification phase describes the time to verify that the target has been acquired before selecting it.

Turning to our findings, we observed a shorter REC phase by both Low Skill and Elite Gamers compared to non-gamers (Figure 2), suggesting that gamers of higher expertise may be better at visually identifying on-screen targets (visual search) and may show increased neural efficiency when developing a motor program to acquire a target. This is supported by previous work studying various tasks that have shown experts demonstrate more efficient task-specific gaze patterns (Gaveau et al., 2014; Law, Atkins, Kirkpatrick & Lomax, 2004; Ziv, 2016) and superior visual search ability (Burggraaf, van der Geest, Hooge & Frens, 2021; Wu, 2008) compared to novices. Moreover, work examining the neural correlates of expertise demonstrates that experts often have lower prefrontal and premotor activation during tasks, suggesting increased neural efficiency during the rapid development of motor programs (Carius, Hörnig, Ragert, & Kaminski, 2020; Luft & Buitrago, 2005).

The observation of significantly faster MR and V times among more skilled groups (Figure 2) suggests that as expertise develops, gamers are better able to process the visual and kinaesthetic information to update their sub-movements and home in on targets and develop the confidence to verify their accuracy more quickly before releasing a shot on target. Despite the appeal of the description that as motor expertise develops, movement control becomes more ‘open-loop’ or automatic, research has shown that a large component of motor skill development involves learning to use online afferent information more rapidly and effectively (Elliott, Helsen & Chua, 2001; Keele, 1968; Schmidt, 1976). This has been clearly demonstrated for aiming tasks by Proteau and colleagues (1987), whereby participants who had more practice and repetition with an aiming task showed greater errors when visual information was subsequently removed, suggesting that as expertise develops, participants become more rather than less, dependent on the relevant sensory feedback. Furthermore, Abrams and Pratt (1993) and Chua and Elliot (1993) respectively demonstrate that with the practice of target acquisition tasks, sub-movement times decreased, and fewer errors were made as participants spent more time in the deceleration phase of the movement. This suggests that skilled participants could more rapidly and efficiently use their movement feedback to alter sub-movement trajectories. The faster peak velocities of higher-skilled gamers may have afforded them the ability to acquire the relevant visual and kinaesthetic feedback earlier. This improved processing of visual information by more skilled gamers could also enhance confidence with ballistic and sub-movements, leading to lower verification times and faster decisions to attempt a shot at a target.

In addition to the motor advantages displayed by Elite gamers that help them achieve superior target acquisition performance, there may also be a cognitive contribution. The faster peak cursor velocities achieved by higher-skilled gamers means that the on-screen 3d movement of the environment would be greater and produce more motion blur. The ability to take in the relevant visual feedback under these conditions to acquire targets would arguably place greater demands on attention, as Brebner points out in their work (1968). More recent work has established the enhanced attentional abilities of habitual action video gamers (Kowal, Toth, Exton & Campbell, 2018; Toth, Kowal & Campbell, 2019) and thus, it could be that skilled gamers possess a cognitive advantage that allows them to better process the relevant sensory feedback to guide accurate movements during target acquisition.

Overall, we quantify here for the first time that target acquisition skill development involves improvement in both the organisation of initial ballistic responses and in the feedback error correction process, corroborating previous work by Kahn, Franks, and Goodman (1998).

Training

When examining how REC, MR, and V times change with training in each expertise group, we noticed that NGs recognised targets faster and, despite slower peak velocities displayed across training sessions, showed reduced MR times, suggesting that fewer sub-movements were required to acquire targets. The fact that NGs display faster REC times with training aligns with a plethora of work on motor skill learning, suggesting that as expertise develops, individuals show improved target selection (see Ferrante et al., 2018, for example) and develop less variable neural patterns in frontal and premotor areas, indicative of greater motor planning efficiency (Bacigalupo & Luck, 2019; Ma et al., 2010; Steele & Penhune, 2010). Previous work examining serial simple reaction time tasks suggests that reductions in response times are likely due to an increased ability to recognize and select the appropriate motor program to acquire a target (Shmuelof et al., 2012), whereas in motor tasks involving tracking, response time reductions are more greatly influenced by improvements in motor execution (Diedrichsen & Kornysheva, 2015; Hikosaka, Nakamura, Sakai & Nakahara, 2002). The serial nature of the target acquisition used task in this study (a new target appears immediately after the destruction of the previous target) suggests that novice participants are likely improving both the selection and execution phases of the task with training. With greater experience with, and thus a more formalized motor program in place for, the FPS target acquisition task in this study, we see little to no improvement in REC times among Low Skill and Elite CS:GO players. Instead, MR and V times show significant reductions across training days, demonstrating that as expertise develops, the rapid and accurate use of visual and kinesthetic feedback becomes the predominant factor underlying target acquisition performance. This conclusion is again supported by the work of Proteau and colleagues (Proteau, Marteniuk, Girouard & Dugas, 1987), who show that the dependence on relevant feedback for error correction increases as expertise develops with target acquisition tasks.

Neurostimulation

We found evidence among non-gamers that tDCS increased REC times and decreased V times across training days compared to groups who did not receive tDCS or received a sham tDCS. The fact that verification times decreased aligns with previous work examining the effect of tDCS on motor skill learning (Pixa & Pollok, 2018; Toth et al., 2021; Yamaguchi et al., 2020) and suggests an enhancement of feedback loops to guide sub-movements onto the target. However, the increase in REC times observed in the tDCS NG group was unexpected and may be due to a leakage of the stimulation to increase the excitability of neighboring premotor and supplementary motor areas. Given the evidence suggesting that activity decreases in these cortical areas as expertise develops (Ma et al., 2010; Ungerleider, Doyon & Karni, 2002), it may be that the anodal stimulation over these areas to excite the underlying neurons is hindering the feedforward process of selecting the appropriate motor program in a timely and efficient manner. Indeed, previous work has shown that tDCS over M1 can also influence the premotor cortex but does so with high variability compared to high definition tDCS specifically targeting the premotor cortex (Lefebvre et al., 2019). Moreover, previous work comparing the effect of anodal tDCS over M1 and the premotor cortex during learning of a finger tapping task showed that premotor stimulation did not enhance online learning and retention (Russo, Carneiro, Vallar & Bolognini, 2020). Finally, Greeley and colleagues (2020) actually saw a decrement in performance following stimulation of both the left and right prefrontal cortex, whereas performance on the same motor task improved with M1 stimulation. Overall, the effect of tDCS to further reduce TTDs over the course of training sessions in novices appears to result from its ability to reduce verification times due arguably to an enhanced plasticity of sensory-motor feedback loops.

Among Low Skill gamers, there was no discernable effect of tDCS on the various kinematic target acquisition parameters we analysed. As has been previously suggested, this may result from the fact that gamers of low skill have developed enough expertise to require more time with stimulation to notice a benefit (Sharma, Farahani, Bikson & Parra, 2022) and are still variable in their performance. However, we did notice that despite showing little effect for targets destroyed in 1 shot, tDCS further reduced TTDs compared to SHAM and STIM conditions among Elite gamers across training days for targets destroyed in 2 shots, facilitated by improvements in REC and V times (Supplementary File 1). The fact that tDCS did not significantly enhance performance for 1 shot targets aligns with our finding regarding the lack of effect of tDCS on FPS target acquisition performance in experts previously (Toth et al., 2021). However, when isolating targets that were missed initially and then destroyed after a subsequent adjustment and second shot attempt, we see evidence that tDCS reduced motor planning times and the sensory-motor processing times to correct the initial error (missed first shot). This contrasts with Toth and colleagues (2021), whereby tDCS was concluded to not impact Elite performance across training days but is likely due to our separation of targets destroyed with 1 and 2 shots in this study. The lack of an effect of neurostimulation for the large number of targets destroyed with 1 shot among Elite gamers may have masked the effect we are observing for targets destroyed with 2 shots in the study by Toth and colleagues (2021), where all targets were analysed together.

Overall, non-gamers appear to benefit from tDCS through its facilitatory effect on sensory-motor processing to arguably reduce sub-movement times, while Elites seem to confer this benefit specifically for targets where initial shots are missed. That tDCS appears to confer an advantage among Elite gamers during the selection and motor planning phase while at the same time conferring a disadvantage for non-gamers requires further work and a robust examination regarding the effect that stimulating various cortical regions has on the various components of the target acquisition performance. One area often neglected but potentially highly influential for this type of target acquisition task is the posterior parietal cortex. With a specialized contribution to the performance of reaching/pointing tasks (Battaglia-Mayer et al., 2000; Fernandez-Ruiz, Goltz, DeSouza, Vilis & Crawford, 2007; Rivera-Urbina, Molero-Chamizo & Nitsche, 2022; Snyder, Batista & Andersen, 1997), there is reason to believe that neurostimulation of this site may augment skill acquisition for a similar task in a video gaming environment.

Limitations

This paper is the first to analyse the various component phases of a target acquisition task in a video game performance environment. However, our analyses were limited in two important ways, which restricted the interpretation of some of our findings. Firstly, we did not specifically examine the number or time of any sub-movements employed by participants during the movement response phase. As indicated in previous work (Desmurget & Grafton, 2000; Philips & Triggs, 2001; Walker et al., 1993), after the initial ballistic movement to bring the hand and cursor in the vicinity of the target, sensory feedback is used to drive additional sub-movements to facilitate homing in on the target. The number and length of these sub-movements have been shown to reduce for more easily acquired targets or as skill progresses (Carlton, 1994; Tränkle & Deutchmann, 1991). Secondly, in our study, we dichotomized the MR and V phases by determining the point from the end of the movement at which the instantaneous velocity increased beyond 5% of the peak velocity recorded during the entire movement. This value differs slightly from the 2% value Thompson and colleagues (2007), and arguably, some sub-movements could be included within the verification phase. Thus, our interpretations above regarding the shortening of MR and V times are similar, in that reduced times in either phase indicate more rapid and efficient sensory processing to better control sub-movements as participants home in on the given target. Secondly, as we did not perform kinematic analysis of the hand and arm movements of the participants, we propose that future work examine the biomechanics of gamers more closely to better understand how movement strategies are altered to achieve the same cursor movements under different control display gains. Based on the analyses by Toth and colleagues (2021), given that Non Gamers tended to use a significantly higher cursor sensitivity, we can only assume that non-gamer participants' movement was largely confined to the wrist joint, whereas for Low Skill and Elite Gamer, a larger contribution from the upper and lower arm would be observed.

Conclusion

This paper showcased for the first time the differences in the component phases of target acquisition movements among first person shooter gamers of various expertise and non-gamers. It also investigated the effect that training and neurostimulation had on the improvement of these components across five 10-minute sessions of training. Overall, we saw that the inclusion of these components in a predictive model provided good predictability regarding whether a participant was a gamer and whether they were of lower or higher skill. We also determined that while non-gamers showed the greatest improvement in recognition and verification phases across training days, indicative of improvements in target recognition, motor planning, and sensory-motor processing, more skilled gamers saw their improvements in the movement response and verification phases, largely indicative of improved sensory motor processing. Finally, we showed that while tDCS differentially affected the recognition phase displayed by Non-Gamers and Elite gamers (for targets destroyed using 2 shots), it commonly reduced verification times among both groups, indicative of an accelerated improvement in sensory-motor processing to control the number and timing of sub-movements as participants homed in on their targets. Future work should look to examine more closely the sub-movements displayed by FPS gamers of various expertise and classify the biomechanical movement strategies that produce the phases of cursor movements observed here.

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Highlights

The kinematic phases of targeting movements are quantified among gamers.

High skill FPS players show superior motor planning and sensorimotor integration.

Training augments all phases of target acquisition movements.

tDCS improves performance on targets requiring sensorimotor adjustments.