Behavioural and neuro-electrical correlates of cognitive performance in young mobile gamers of endless runner and match three genres

Sekhar Jiwal¹ / Preeti Jain² / Ajay Kumar Jain³

Abstract:
Video game players have been shown to significantly outperform non-video game players on a wide range of cognitive tasks. Exposure to specific genres of video games may also have a significant bearing on impacting certain task-specific domains of cognition. However, there is limited availability of scientific literature exploring the role of mobile game sub-genres on the cognitive abilities of an individual. The present study was therefore conducted to assess and compare the impact of playing either endless running video games (ERGs) or match three video games (MTGs) on behavioral and neuro-electrical correlates of cognitive performance in young adults, by using reaction time (RT) and P300, respectively. The ERG group included 45 male:female (M:F) ratio = 38:7 and the MTG group included 39 (M:F = 21:18) subjects who played ≥5 h/week of each respective video game genre in past 6 months. The ERG group had better behavioral performance in comparison to the MTG group, as indexed by their significantly faster visual reaction time (VRT). The ERG subjects also had significantly lower P300 amplitudes as compared to MTG subjects. However, no difference in either auditory reaction time (ART) or P300 latency could be ascertained between the two groups. These results suggest that not only were ERG players able to make faster decisions and performed better in visuo-motor tasks but, also had better optimization of neural resources in them as compared to the MTG players. The current data supports the notion that not only exposure to video games but also the nature (i.e. genre) of mobile game play determines the extent to which neural processes concerned with attentional orientation, information processing and cognitive control are influenced.

Keywords: P300, endless running video game, match three video game, mobile game genre, reaction time

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Introduction
Video gaming has become one of the most common recreational activities worldwide. Survey-based studies in various countries from across the globe have found that on average, more than 50% of population play video games regularly [1]. The last two decades have witnessed an evolution of gaming devices from consoles/personal computers (PCs) to handheld mobile devices. India has recently emerged as one of the top five gaming countries with over 250 million mobile gamers. Factors such as, increased availability of the Internet and low-cost smart-phones have contributed to a phenomenal growth of mobile gaming in this part of sub-continent [2]. There are myriad commercially available video games which are categorized into different genres (action, non-action, strategy, etc.) based on their inherent game mechanics, in-game tasks and rules. Rapid technological advances in the mobile industry has also led to the development of new hybrid genres of games such as action-adventure, action-role play, puzzle-role play, etc., that are especially suited for playing on mobile phones and smartphones. These games have been created by not only introducing new game features but also by merging the dynamics of multiple pre-existing genres. Endless runner, match three and racing games are amongst the most popular sub-genres played on mobile phones.

The endless runner video game (ERG) is a type of running-jumping game with plenty of built in action components. It is usually classified as action-adventure genre of a mobile game in which, the player controlled character is continuously moving forward through a usually procedurally-generated, theoretically endless game.
world. The player controlled character jumps, attacks or performs special actions. The object of these games is to get as far as possible before the character dies. The more a player progresses, the more difficult it gets. In order to survive, a fast response time is needed from the players, thereby, emphasizing first and foremost on peripheral processing of information [3]. ERGs have found particular success on mobile platforms as they are well-suited to the small set of controls these games require, often limited to a single screen tap for jumping. Temple Run and Subway Surfers are two highly popular games of this sub-genre in the Indian sub-population. On the other hand, match three video games (MTGs) are non-action games that have evolved from the puzzle genre. These games involve some level of abstraction, problem-solving skills and pattern recognition making use of colors, shapes or numbers [4]. Players may have unlimited time or infinite attempts to solve a level. Candy Crush and Bejeweled are MTGs, where the core gameplay is based on swapping two adjacent candies/jewels among several on the game-board so as to make a row or column of at least three matching-colored candies/jewels. A player scores points for these matches and gains progressively more points for chain reactions. The game is split among many levels, which must be completed in sequence. As the player progresses, levels become more difficult, convoluted and new contraptions are introduced which alter the game play.

Several multidisciplinary studies have reported that playing video games has beneficial effects on the cognitive skills of a gamer [5], [6]. Action video game (AVG) players have been shown to perform significantly better than non-action video game players and non-video gamers on a wide range of cognitive domains including attentional control [7], perception, visuo-spatial skills, tracking of multiple objects [8], working memory, information processing [3] and executive functions [9]. Moreover, some cognitive abilities have also been shown to improve following training in either AVG [10], [11] or non-AVG [12], [13]. However, this is not a universal finding and evidence from a small number of studies demonstrates that video game experience may also be negatively related to poorer attention [14] or cognitive control [15]. These findings demonstrate that not all video games are likely to affect the cognitive system equally, nor are all the effects likely to be positive [6].

The extent to which a given experience alters behavioral outcomes depends strongly on both the exposition and nature of experience as well as the extent of neuronal plasticity of processes underlying the measured behavior [16]. Playing different kinds of video games requires different categories of skill and does not place an equivalent load on all cognitive abilities [17]. Theoretically, therefore, specific genres of video game play may have a significant bearing in impacting certain task-specific domains of cognition. Despite these probabilities, there is still limited availability of scientific literature in which cognitive effects of different genres of video games have been compared within the same study [9], [13]. Moreover, the impact of different mobile game sub-genres on cognitive abilities of an individual mostly remains an underexplored field.

Neural underpinnings of the cognitive effects of playing video games are now being explored by some researchers using neuroimaging techniques such as electroencephalography (EEG) [18] and event related potential (ERP) [19]. During wakefulness, the P300 component of ERP provides an electro-physiological correlate of assessing alterations in higher cerebral functions which are related to arousal level as well as, to selective attention, concentration, working memory, decision-making and information processing [20]. Although research in this field is still in its incipient stage, preliminary evidence does seem to show a link between video game experience and neuro-electrophysiological correlates of cognition [18]. Few studies have reported decrements in ERP amplitudes with increasing cognitive workload related to attention and working memory demands [21]. Contrary findings have also been put forth with increments in P300 amplitude being reported following short-term exposure to violent action video games as compared with exposure to neutral video games [22]. Lacunae still exists as to how the morphology of P300 would change as a function of the genre of video game played.

In order to address the topic of specific video game genre, we have designed and conducted this study with the aim to assess and compare the impact of playing either endless running or match three genre of video games on behavioral and neuro-electrical correlates of cognitive performance in young adults, by using reaction time (RT) and P300, respectively.

Materials and methods

This observational study was conducted in the Department of Physiology, Maulana Azad Medical College, New Delhi, after obtaining approval of the Institutional Ethical Committee.

Subjects

Eighty-four subjects (out of 233 respondents) were recruited via a gaming questionnaire administered as part of a department-level screening exercise. The study protocol was fully explained to the participants and informed
signed consent was taken. Based on our recruitment criteria, these subjects were categorized into one of the two groups: ERG players and MTG player groups.

- ERG players were required to have played ≥5 h/week of endless running type of action games in past 6 months and ≤2 h/week of MTG during the same time frame on mobile. They should have also rated their expertise on ERG as >1 and for MTG as <1 on a Likert scale.

- MTG players were required to have played ≥5 h/week of ’match three’ type of puzzle games in past 6 months and ≤2 h/week of ERG during the same time frame on a mobile device. They should have also rated their expertise on MTG as >1 and for ERG as <1 on a Likert scale.

Those who did not play either of the genre of digital video games under consideration or, played other genres of video games such as adventure, first person shooter, real-time strategy, role-playing, racing and multiplayer online battle arena for ≥2 h/week were not included in the study. Those students who did not play on a mobile device or were on any medication that could affect the test results were also excluded from the study. Subjects did not have any neurological, musculo-skeletal, auditory or visual impairment, sleep-related or psychological disorder at the time of inclusion and duration of the study. The final sample included 45 subjects in the ERG group and 39 subjects in the MTG group.

**Gaming questionnaire**

The questionnaire was completed twice, once as part of department-level screening exercise that was used for recruitment and once, at the time of experimental session. This self-report video gaming experiences questionnaire included five questions:

The first question asked subjects to respond as yes/no to whether they played video games. If the subjects responded “yes” to the first question, they were then required to respond as yes/no to whether they played the following genres, namely, ERG (Temple Run, Subway Surfer), MTG (Candy Crush, Bejeweled) or others (adventure, real-time strategy, role-playing, racing and a multiplayer online battle arena). In the next question, subjects had to rate their perceived level of expertise on each of the games mentioned above via a 4-point Likert scale expertise ratings (0 = have never played, 1 = novice, 2 = intermediate, 3 = expert). The fourth question pertained to the platform used for gaming purposes. On the basis of these four questions, subjects were grouped into the two study groups. The fifth and final question pertained to the gaming behavior of subjects and asked them to indicate the total number of hours spent playing each genre of video games (to which they had responded as yes in previous questions) in a week.

**Study protocol**

Subjects reported to the laboratory between 1 and 2 p.m. during their lunch break. The experimental session comprised recording of auditory and visual reaction times (ART and VRT, respectively) and a P300 component of the ERP. In order to alleviate anxiety and apprehension associated with testing, they were familiarized with the procedure and apparatus to be used. Ambient laboratory temperature on different days varied between 22 °C and 25 °C.

**Reaction time**

RT [23] denotes the time lapse between presentation of a sensory stimulus and subsequent behavioural response (which could be typically a button press or some other observable behavior). It is an index of the proficiency of information processing system being related to the alertness and attentional orientation of an individual [24].

ART and VRT were recorded in a standard audiometric, soundproof room, using an Audio-visual Reaction Timer (Recorders & Medicare Systems Pvt Ltd., Chandigarh, India). Before testing, each subject was familiarized with the instrument and given 10 trial sessions to practice. Each subject was asked to first identify the stimulus, i.e. tone/light and press the response button (using their right index finger) to stop the electronic timer as fast as possible on hearing the sound or seeing the light for recording ART and VRT, respectively. The time taken by the subject to turn off the sound/light is called the RT and that is displayed on an electronic timer in milliseconds. Sound signals were a continuous beep of 1 KHz on the speaker. The light signal was a red or green LED light. Three readings for each parameter were noted and their respective average calculated. The interval between the three test stimuli for each parameter was randomly varied from 10 to 30 s.
**P300 component of ERP [25]**

ERP refers to patterns of voltage change that occur in ongoing neural activity in response to, or in preparation for a stimulus or response. An amplitude of P300 reflects allocation of attentional resources during stimulus engagement with greater amplitude reflecting greater resource allocation [26]. The latency of P300 is believed to index stimulus classification and evaluation speed with increased latency reflecting a longer processing time [27].

The P300 was recorded in a calm and quiet soundproof room at an ambient temperature of 22–25 °C using an E.B. Neuro Machine (evoked potential measuring system; Galileo NT, Firenze, Italy) as per the guidelines of the International Federation of Clinical Neuro-physiologists. Subjects were familiarized with the stimuli and recording procedure. They were instructed to wash their hair before coming for the test in order to minimize electrode impedance. Linked earlobe referenced electroencephalograms were measured from Fz, Cz and Pz sites of international 10–20 sites using Ag/AgCl disk electrodes and neuropep skin jelly. Fpz served as the ground electrode. Skin electrode contact impedance was kept below 5 ohms. In order to avoid artifacts due to eye movements and improve their concentration to target stimulus, subjects were instructed to fixate their eyes on a particular spot on the ceiling during recording. P300 was recorded using an “oddball acoustic paradigm” in which two different tones were used, namely, the rare or target and the frequent or non-target tones. These tones were presented randomly and binaurally in phase by means of headphones. A total of 200 stimuli were randomly presented to the subject out of which 40 (20%) tones were of 2 KHz frequency and constituted the target stimuli and rest 160 (80%) tones were of 1 KHz frequency and comprised non-target stimuli. The auditory stimuli had a rise/fall time of 10 ms, a plateau of 100 ms, and an intensity of 60 dB above the normal hearing threshold. The subjects were asked to count the target stimuli non-verbally. At the end, each subject’s count was compared with the actual number of target tones given to assess the accuracy of the task performance. The error rate was <5% for all the subjects. A total of 40 target stimuli were averaged simultaneously, excluding the rejection errors, in the Galileo NT setting with a band pass of 0.1–50 Hz. P300 was defined as the largest peak after the N-100-P200-N200 complex within a latency window between 230 and 380 ms. The amplitude of P300 was measured as a change score from the pre-stimulus baseline and latency of P300 as the time point corresponding to the maximum amplitude.

**Statistical evaluation**

Data collected was analyzed using SPSS version 20. The Gaussian fit of data was checked using Lilliefors corrected Kolmogorov-Smirnov test. Test-retest reliability analysis of the gaming questionnaire was done using Pearson’s correlation. Group-wise descriptive statistics of continuous data was done as mean ± standard deviation (SD). Categorical data was expressed as frequency and percent. The chi-square ($\chi^2$) test was used to measure association between categorical variables. Inter-group statistical comparisons for continuous data were done using the Mann-Whitney U test. A value of $p < 0.05$ was considered significant for all tests.

**Results**

The mean age of subjects was comparable in ERG (18.82 ± 0.83 years) and MTG (19.18 ± 1.07 years) groups. The $\chi^2$ test revealed that there was a significant difference in the distribution of male and female subjects in the two study groups $\chi^2 = 12.70$, $p < 0.001$. The test-retest reliability analysis of gaming questionnaire was acceptable ($r = 0.76$).

There was no statistical difference in the mean number of hours spent by subjects in gaming per week between the ERG and MTG groups (8.20 ± 2.71 and 8.46 ± 3.20 h, respectively; $p > 0.05$).

The mean VRT of subjects in the ERG (347.33 ± 50.96 ms) group was significantly lower ($p < 0.05$) as compared to that of subjects in MTG (374.62 ± 65.57 ms) group. No significant difference in the mean ART was observed between the two study groups (253.56 ± 41.95 and 267.95 ± 56.47 ms; $p > 0.05$ for ERG and MTG groups, respectively).

The mean P300 amplitudes at all the three electrode sites were significantly less (Fz-$p < 0.05$; Cz and Pz-$p < 0.001$) in the ERG as compared to the MTG group. However, no significant difference ($p > 0.05$) between the two study groups could be ascertained at any of the three recording sites for P300 latency (Table 1 and Figure 1).

**Table 1:** P300 amplitude and latency of the subjects in ERG and MTG groups.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>ERG (n = 45)</th>
<th>MTG (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P300 amp (μV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fz</td>
<td>7.46 ± 3.19</td>
<td>9.51 ± 4.62</td>
</tr>
<tr>
<td>Cz</td>
<td>7.10 ± 3.69</td>
<td>10.97 ± 5.91</td>
</tr>
<tr>
<td>Pz</td>
<td>5.63 ± 2.15</td>
<td>8.09 ± 3.80</td>
</tr>
<tr>
<td>P300 lat (ms)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fz</td>
<td>299.53 ± 30.61</td>
<td>298.26 ± 27.22</td>
</tr>
<tr>
<td>Cz</td>
<td>298.07 ± 32.82</td>
<td>288.46 ± 17.83</td>
</tr>
<tr>
<td>dPz</td>
<td>298.06 ± 32.73</td>
<td>297.92 ± 25.01</td>
</tr>
</tbody>
</table>

Values are mean ± SD; a p < 0.05; b p < 0.001 as compared to ERG respectively. ms, milliseconds; μV, microvolt. ERG, endless running video game group; MTG, match three video game group.

Figure 1: Grand average P300 waveforms at the three midline recording sites in the endless runner gamer (ERG: black lines) and match three gamer (MTG: blue lines) groups.
The marker depicts the P300 latencies at the three sites. Each division on the x-axis corresponds to 100 ms and on the y-axis to 5 mV. The block arrow on the left-hand corner represents the zero time.

**Discussion**

The primary objective of our study was to ascertain the cognitive performance in players of different genres of mobile games. To address this topic, we designed a study in which subjects who played either endless runner or match three sub-genre of games were recruited. Both these games were specifically chosen as they are amongst the most popular games played on mobile phones. Moreover, their inherent gameplay mechanics places markedly different cognitive skills requirement on the players. Although, gaming on mobile phones is not a critical feature but still, it is noteworthy, as most of the previous data has primarily been gathered from participants who used different gaming consoles or PC systems for video game play [4], [28].

In a number of prior studies, participants who reported casual playing of various genres of non-AVG were grouped together with non-gamers in a single control group when compared with experienced AVG [10]. Since, the expertise levels in playing various genres of video games may have variable influence on cognitive performance of an individual [29], it is quite possible that the effects of playing non-action games may have been masked by the inclusion of non-gamers. In contrast, such grouping may have unfairly favored experienced AVG players and hence, conclusions drawn on the superiority of AVG players based on such selection criteria raises doubts. To ensure the homogeneity in our study groups, we recruited players of similar expertise levels (intermediate or expert gamers). Both our study groups were found to be comparable in terms of number of hours spent per week in gaming by the subjects. This could be attributed to the fact that, as they were all undergraduate medical students of the same institute pursuing a rather difficult course, they had almost equivalent time available for leisure activities.

Our RT data indicate a beneficial effect of playing ERGs on proficiency of information processing mechanisms as compared to playing MTGs. In the present study, subjects in the ERG group had significantly faster...
VR T as compared to those in the MTG group. However, no statistical difference in ART was ascertained between the two study groups. These observations in our study corroborate with earlier works examining the influence of video gaming on behavioral performance employing different populations and different experimental paradigms [7], [8], [30], [31]. For instance, in one of the cross-sectional studies it was shown that players of first-person shooter games had better selective attention as compared to players of role play games [31]. On the other hand, in another study it was reported that real-time strategy gamers had quicker overall RTs as compared to first-person shooter gamers [28]. In a multiple game training study in which non-gamers were trained for 20 h spread over 4 weeks in either action, memory, hidden-object, match three or agent-based life simulation game on mobile devices, researchers reported that participants who trained in AVG showed an improvement in not only the attentional blink task, but also outperformed participants trained in all other genres [13].

The mechanism underlying such enhancements in behavioural performance has been put forth in one of the recent studies which demonstrated that, the brains of video gamers were able to collect visual and auditory information more efficiently and that enabled them to make a faster decision as compared to non-gamers [3]. Moreover, the extent to which cognitive costs are incurred while performing a cognitive task also depends on the training strategy employed [32]. As, endless running games are predominantly timed, visuo-motor tasks, hence, exposure to these video games may have enabled the ERG group subjects in making faster decisions, which is a crucial function for optimal performance on RT task. Similarly, due to the inherent game-mechanics of MTGs wherein, players can proceed at their own pace without any time constraints, subjects in this group showed comparatively slower VRT.

In our study, we also assessed the impact of playing different genres of video games on neuro-electrical correlates of cognition, i.e. the P300 component of ERP. The amplitude of P300 reflects the extent to which allocation of neural resources concerned with working memory, cognitive control and selective attention has occurred, which in turn, depends on the level of cognitive demands of the environment [11]. ERG subjects had significantly smaller P300 amplitudes as compared to the MTG subjects. Moreover, significant differences in P300 amplitudes were observed globally across all three mid-line (i.e. Fz, Cz, Pz) recording electrode sites. However, there was no significant difference between the two groups for P300 latencies at any of recording electrode sites. Prior researchers have suggested that subjects who played prosocial video games for short terms required less attention or cognitive resources to differentiate violent words and therefore, had smaller P300 amplitudes as compared to short-term neutral video game players [33]. Moreover, in another study, smaller amplitudes of P300 have been associated with aggression and desensitization to violence following chronic exposure to violent video games [34]. As, ERG is not violent in nature, therefore, the desensitization theory does not apply here. Although, our P300 results do indicate that players of ERG and MTG respond differently in the way they deploy their neuronal resources.

Previous studies have shown that ERP amplitudes tend to correlate negatively with cognitive workload in expert video gamers [11], [21]. While P200 and N200 have been found to have maximum amplitude in the fronto-parietal regions, P300 was reported to be larger in the parietal regions [21]. Moreover, habitual video game players showed less recruitment of fronto-parietal networks as compared to non-gamers suggesting better optimization of attentional resources in experienced gamers [11]. However, our results are in contradiction to studies in which either, expert gamers have been shown to exhibit significantly larger P300 components as compared to non-gamers under a high perceptual load [18], or exhibit a significant increase in P300 amplitude, and a decrease in P300 latency has been observed following training in video games [19]. Disparity in methodological factors relating to different video game genres, study design or subject selection (gamers versus non-gamers) may be potential sources for inconsistency in our findings with those of previous research.

Traditionally, a two-stream model for visuo-spatial processing has been conceptualized in which, a visual dorsal stream for spatial location and visual ventral stream for object recognition has been implicated. Both these paths depart from the visual cortex in the occipital lobe and reach the posterior parietal and inferior temporal cortices, respectively [35]. Prior neuroimaging studies have also shown that structural volumes of areas like the frontoparietal system, the anterior cingulate cortex and the dorsolateral prefrontal cortex correlate with video game performance over time [36]. Moreover, reward centers in the brain such as the ventral tegmental area and the nucleus basalis have been shown to be extremely active when individuals play action video games. Interestingly, these areas also play a large role in producing plastic changes in sensory areas.

ERG is a sub-genre of AVG which requires navigational and visuo-spatial skills with precise timing. Playing these games could have produced a reduction in the cognitive workload incurred and led to plastic changes in brain areas concerned with cognitive functions. These in turn, may have resulted in better optimization of neural resources in areas concerned with visuospatial processing, visuo-motor integration, decision-making and execution in them. This was reflected in not only alerting the effects of sensory inputs (visual stimuli), better tonic readiness for motor action and attention in ERG as compared to MTG subjects, but also the positive modulation of P300 morphology in them. On the other hand, MTG is a sub-genre of non-AVG that emphasizes more on problem-solving skills and pattern recognition and usually does not have any time limit. Slower RTs
and larger P300 amplitudes in these subjects suggest that subjects in the MTG group had comparatively lower cognitive performance. Our findings support the notion that not only exposure to video games (i.e. number of hours of game-play, expertise level) but also nature (i.e. genre) of video game play determines the extent to which neural processes concerned with cognition would be influenced.

The main limitation of our study was that we did not have a control group of non-video gamers. Hence, we could not comment as to whether exposure to either of these two genres of video games improved or had a negative impact on cognitive performance. Given that both behavioral and cognitive abilities underpin many areas of our lives, be it in occupation, social or educational settings, future efforts aimed at improving these critical abilities through specific genres of video game play can surely be explored.

Conclusion

In conclusion, our results illustrate that playing different genres of mobile games had a differential impact on behavioral and neuro-electro correlates of cognitive performance in young adults. Players of ERGs had a faster VRT and lower P300 amplitudes as compared to MTG players. These results indicate better selective attention, response-speed, cognitive control and information processing in ERG subjects as compared to MTG players. The current data is probably one of the preliminary studies linking exposure to a specific genre of mobile game with differential deployment of neuronal resources concerned with attentional orientation, information processing and cognitive control, using RT and P300. Understanding the cognitive domains that are modified by playing specific mobile games may have practical applications. It may prove to be particularly helpful for those researchers attempting to develop and utilize various mobile games for enhancements of specific aspects of cognition in both, healthy and diseased populations.

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Author contributions: Sekhar Jiwal: conceptualized the study, designed the task, data analysis and final drafting of the article; Preeti Jain: supervised the study, conceptualized the study, designed the task, analysis and interpretation of the data and final drafting of the article; Ajay Kumar Jain: co-supervised the study, conceptualized the study, designed the task, analysis and interpretation of the data and final drafting of the article.

References


