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ORIGINAL ARTICLE

# Associations Between Avid Action and Real-Time Strategy Game Play and Cognitive Performance: a Pilot Study

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**Abstract** Over the past 15 years, numerous studies have demonstrated that action video game players outperform non-gamers on a variety of cognitive measures. However, few researchers have examined the potential beneficial effects of playing real-time strategy games or the effect of playing multiple game genres. As such, the purpose of the current study was to (a) replicate the existing findings that show cognitive differences between action gamers (AVGPs) and non-gamers (NVGPs), (b) examine whether real-time strategy gamers (SVGPs) also differ from NVGPs on various cognitive tasks, and (c) examine how multi-genre video game players ("Tweeners") compare to both AVGPs and NVGPs. We created a large task battery that tapped into various aspects of cognition (i.e., reaction time, selective attention, memory, executive control, and fluid intelligence) in order to examine the tasks that differed between our three gamer groups and non-gamers. Our results largely replicated the majority of the findings to date, such that AVGPs outperformed NVGPs on a wide variety of cognitive tasks, but the two groups do not differ in memory performance or fluid intelligence. We also demonstrated that SVGPs had numerically faster response times on several tasks as compared to the NVGPs. This pattern of results was similar to what was found with the AVGPs, although in the case of the SVGPs not all of the results reached the level of statistical significance. Lastly, we demonstrated that Tweeners perform similarly to genre-pure gamers in that their performance on several cognitive tasks was numerically better than for NVGPs, although the performance of the Tweeners was numerically lower than for both the AVGPs and the SVGPs. Overall, these findings have several implications for game studies, particularly with respect to how SVGPs and Tweeners are considered going forward.

**Keywords** Action video games · Real-time strategy video games · Cognition · Attention · Reaction time

## Introduction

Over the past several decades, there has been a great deal of interest in examining the extent to which playing video games is associated with positive changes in a variety of perceptual, motor, attentional, and cognitive functions (Bavelier et al. 2012; Greenfield 2014). Indeed, nearly as soon as video games rose to prominence in society, research started to accumulate, suggesting that practice with certain video games produced enhancements in performance on standard (i.e., non-game) laboratory tests of a variety of core cognitive functions (e.g., Dorval and Pepin 1986; Greenfield et al. 1994a, b; Griffith et al. 1983; Okagaki and Frensch 1994; Subrahmanyam and Greenfield 1994). However, while this early work strongly indicated that video games were potentially quite powerful tools for enhancing cognitive performance, the research did not always draw clear distinctions between various types of games. Instead, investigators tended to either focus on the impact of a single game (e.g., Greenfield et al. 1994a), or else aggregated all games together into an extremely broad "video game" category (e.g., Griffith et al. 1983).

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More recent work has focused on the relationship between certain genres of games and the associated cognitive impact. This is critical, as video games from a given genre tend to share a set of core features, including dynamics, mechanics/user interactions, and content (Apperley 2006; Hull et al. 2013; King et al. 2010; Wood et al. 2004). In other words, games from a given genre tend to share exactly those aspects that together determine the overall cognitive demands placed upon the user (Adams and Mayer 2012), and thus the likely influence of the games on cognitive function.

Of particular interest to the field has been one specific genre, known as the "action video game" genre. This genre encompasses a set of especially fast-paced video games that require participants to attend to multiple locations across a vast visual field, rapidly and accurately extract relevant information from the environment, and then promptly respond to that information. Action video games require the use of a number of key cognitive processes, such as visuospatial attention, motor coordination, object tracking, executive control, and cognitive flexibility (e.g., Bavelier et al. 2012; Colzato et al. 2013a, b; Green and Bavelier 2015; Spence and Feng 2010; Strobach et al. 2012).

A significant body of research now exists documenting the positive effects associated with playing such action video games. For instance, cross-sectional work has shown that avid action video game players (AVGPs) significantly outperform non-action video game players (NVGPs) on various measures of processing speed, temporal attention, visual search, multiple-object tracking, task-switching, multi-tasking, peripheral vision, visual crowding, contrast sensitivity, mental rotation, and visual short-term memory, among other abilities (e.g., Boot et al. 2008; Castel et al. 2005; Colzato et al. 2010, 2013a, b; Feng et al. 2007; Green and Bavelier 2003, 2006, 2007; Green et al. 2012; but see Appelbaum et al. 2013). Critically, a causal relationship between the act of playing action games and enhanced cognitive abilities has also been established via well-controlled intervention studies (e.g., Dye et al. 2009a; Gagnon 1985; Green and Bavelier 2003, 2006; Green et al. 2012; Oei and Patterson 2013; Strobach et al. 2012; but see Boot et al. 2008).

Interestingly, while it is the case that in the late 1990s action games were one of the only styles of video game that required strong visuo-spatial abilities, fast processing speeds, and good motor coordination in order to succeed, this is increasingly no longer true. Instead, there are a number of genres that were decidedly "non-action" 15 years ago, but now contain a significant number of these same demands. For example, games from the strategy video game genre did not typically include these fast-paced components in the late 1990s. In fact, this genre was often referred to as the "turn-based" strategy genre because it utilized what are known as turn-based mechanics. In turn-based games, the player is allowed as much time as he or she wishes to take an action. After the action is selected and the outcome(s) of the action takes place, the player must then wait for his/her opponent to select an action. Given the lack of time constraints, this style of gameplay focused more on strategy than on rapid processing.

Over the past decade, however, many game genres have undergone substantial evolution. Today, many (if not most) strategy video games contain complex action components that require the player to rapidly filter relevant from irrelevant information, quickly decide on a course of action, and then execute that action in real-time in a manner similar to action video games. These games are now usually referred to as "real-time strategy games" to distinguish them from the older "turn-based" strategy games. Furthermore, an offshoot of the real-time strategy genres, known as the Multiplayer Online Battle Arena (or MOBA) genre, explicitly combines strategy with action components (in fact, MOBA games are sometimes labeled as "action real-time strategy" games (ARTS)). This genre has become so popular that tournaments have been set up where players from all over the world, many of whom play games as a career, compete for millions of dollars in prize money.

Perhaps not surprisingly, given the literature on action games and the overlap in cognitive processes between action games and real-time strategy games, a set of recent studies has demonstrated that playing real-time strategy video games may lead to improvements in cognitive performance similar to what has previously been shown with action video games. For example, Glass et al. (2013) trained participants on either the real-time strategy video game *StarCraft II*, or on a control video game—the simulation game, *The Sims.* After training, only those participants trained on the real-time strategy game showed improvements in cognitive flexibility. Similarly, Basak et al. (2008) demonstrated that older adults who trained for 24 h on the real-time strategy game *Rise of Nations* outperformed controls on measures of working memory, task-switching, VSTM, and mental rotation following training. Unfortunately, despite these two positive intervention studies utilizing single exemplar games from these broader genres, gamers from this genre are still largely underrepresented in the literature and, aside from this handful of studies, little is known about whether playing real-time strategy games is associated with differences in cognitive function.

Furthermore, in addition to the rise in new genres (such as the real-time strategy and MOBA genres) that contain substantive action components, there is also an increasing tendency for gamers to fall in-between the categories that have often been utilized to classify individuals in the existing literature (e.g., individuals who do not play enough action games to qualify as AVGPs but play too much to qualify as NVGPs, or individuals who play too many non-action games in addition to action games to qualify as AVGPs). As gamers typically prefer a certain style of gameplay (e.g., some prefer fast-paced action, whereas others prefer the more cerebral style of a turn-based strategy game), it previously would have been rarer for gamers to play either multi-genre games or games across genres, as these genres were so distinct and unique. However, now that many games contain components and mechanics of several previously distinct genres, there is a broader appeal to these games. For example, gamers who disliked the former turn-based mechanics of the earlier *Final Fantasy* games may now be drawn to them given that they now use a real-time action mechanic. Similarly, strategy gamers might be more willing to try out games from the new action-strategy hybrid genre.

In addition, the rise of online streaming services such as *Twitch* allows gamers to watch others play a large assortment of games. As such, players are becoming more familiar with a larger variety of games than ever before, which may in turn lead to them experimenting with new genres. Such in-between gamers (which we refer to as "Tweeners" in our own laboratory) are either usually excluded from studies, or else (and perhaps worse) may be inadvertently mis-categorized as either AVGP or NVGP individuals (as these individuals' self-reported gaming can change, even between when they are first recruited and when they participate in a study).

Here, we examined the two main issues identified above—the rise of new genres with components that at least partially overlap those of traditional action games, and the increase in individuals who do not fit into the traditional categorization scheme. First, we sought to replicate some of the existing literature on differences between AVGPs and NVGPs. Specifically, we used a task battery including both tasks where clear differences between AVGPs and NVGPs have been reported (e.g., processing speed, selective attention, executive control), as well as tasks where the results have generally been either null or equivocal (e.g., verbal memory, fluid intelligence). Such a successful replication would suggest that the tasks are valid measures to address our second goal, which is to examine whether avid real-time strategy video game players (SVGPs) perform similarly to AVGPs on these same cognitive tasks. Given the overlap between many action and strategy games, and the few existing studies in the literature, we anticipate that the SVGPs will tend to differ from the NVGPs, particularly on measures of speed of processing. Lastly, we will examine how Tweeners perform in comparison to both genre-pure action gamers, as well as NVGPs, as this Tweener group is largely understudied. We anticipate that the performance of Tweener gamers will tend to fall in-between that of AVGPs and NVGPs.

## Methods

### Participants

A total of 57 University of Wisconsin-Madison undergraduate students (50 males, 6 females, 1 unspecified) ranging in age from 18 to 45 years ($M = 21.07$, $SD = 4.8$) were recruited for participation in this study. All participants provided informed consent and received either $60 or course credit for their participation. This study was approved by the University of Wisconsin-Madison Institutional Review Board (IRB).

### Gamer Selection and Procedure

Participants were recruited for this study based on how they responded to an online video game survey. Roughly half of the eventual participants completed this survey as part of a large test battery given at the beginning of the semester to individuals wishing to take part in the Introductory Psychology Research Participation Pool ($N = 30$). The other half were provided with the survey link after responding to a posted advertisement for the study ($N = 27$). The survey is designed to assess how often (i.e., how many hours per week on average) participants play video games from a variety of genres (action/shooter, role-playing, real-time strategy, turn-based strategy, music, and other) both over the past year, and before the past 12 months.

Based on their survey answers, qualifying participants were classified into one of four gamer categories: action video game players (AVGP; $N = 15$), real-time strategy video game players (SVGP; $N = 11$), gamers who play multiple genres (Tweeners; $N = 16$), or non-video game players (NVGP; $N = 15$). AVGPs and SVGPs were those who played at least 5 h per week of games from their respective genre, but no more than 3 h per week of any other genre in the current year. NVGPs were classified as those who reported playing zero action or real-time strategy games, and no more than a total of 3 h of other games per week in the current year. The Tweener category consisted of individuals who did not fit into any of these three categories. In practice, these were individuals who either (1) responded positively to poster advertisements looking for AVGP, SVGP, or NVGP participants, but who, upon completing the gaming questionnaire at the end of the task battery (see below), did not report gaming that qualified for one of the categories, or (2) reported gaming activity that qualified for AVGP, SVGP, or NVGP classification in an initial survey, but who, upon completing the gaming questionnaire at the end of the task battery (see below), did not report gaming that qualified for one of the categories.

All of the Tweeners played at least 5+ hours of video games per week and played an average of four different genres (note that it is not possible to determine the average number of games that were played from each genre as participants were asked to list no more than two games that they play for each genre). Given that these individuals arose from all possible routes identified above, it is not possible to separate them further given a total N of only 16 (e.g., it is not possible to examine only those individuals who responded to posters looking for NVGPs, but then who played too many games to qualify). However, because all 16 individuals fit squarely in-between the standard classifications, they should nonetheless provide interesting comparisons to the individuals who did fit within the classifications. Although this is expounded upon further in the discussion, we note that because this is a purely correlational study, the results cannot be used to speak to a causal relationship between gaming experience and differences in cognitive task performance. We therefore caution the reader to take care to interpret our findings as correlational throughout this paper.

Participants were required to complete 11 different cognitive tasks over the course of two 90-min sessions that were scheduled no more than 7 days apart. In the first session, participants completed seven computerized tasks in the following order: task-switching, N-back, useful field of view (UFOV), multiple-object tracking (MOT), attentional blink (AB), digit span (DSPAN), and a simple RT task. In the second session, participants completed four tasks in the following order: tests of variables of attention (TOVA), operation span (OSPAN), discrimination RT, and the Raven's Advanced Progressive Matrices (RAPM). These particular tasks were chosen to represent a mixture of tasks where previous research had indicated that a significant difference between AVGPs and NVGPs was either expected or was not expected (e.g., there were clear a priori predictions for each task). At the end of the second session, the video game survey was readministered to participants to ensure that they did in fact qualify for membership in their respective category (i.e., it was the participants' responses to this survey that determined their final categorization). A description of each task is provided below.

### Apparatus

Eight of the computerized tasks in this study were created and presented using MATLAB and the Psychophysics Toolbox (PTB-3; Brainard 1997; Kleiner et al. 2007; Pelli 1997). The remaining three tasks were programmed using the HTML5 canvas element and JavaScript, and participant data was saved in a MySQL database (Yung et al. 2015). All of the tasks were performed in a dimly lit testing room on a Dell OptiPlex 780 computer with a 23-in. flat screen monitor. Participants had an unrestrained viewing distance of approximately 60 cm. All responses were made via manual button press on the keyboard or mouse.

### Stimuli and Design

**Simple RT** At the beginning of each trial, a 5° × 5° black framed square was presented in the center of the screen. Shortly after this presentation, an 800-Hz warning tone was sounded for 500 ms. Following the warning tone, there was a variable delay of 1–2 s, after which the framed square suddenly changed into a black filled square. Participants were instructed to press the space bar as soon as the square changed. After each trial, participants were provided with visual feedback on their performance (their RT in milliseconds), and participants who responded too slowly were given instruction to increase their speed. In total, there were 6 practice trials, followed by 50 experimental trials. Performance was calculated by averaging RTs across all experimental trials.

**Discrimination RT** The discrimination RT task began with an 800-Hz warning tone that lasted for 500 ms, and after a variable delay of 1–2 s, a single black arrow measuring 5° in width and 1° in height was presented in the center of the screen. The arrow pointed to either the left or the right of the screen, and participants were instructed to indicate the direction of the arrow as quickly as possible by using the corresponding arrow keys on the keyboard. As with the simple RT task, participants received feedback on their performance at the end of each trial and were administered a warning if they responded too slowly, or if they responded incorrectly. There were a total of 6 practice trials and 60 experimental trials (30 left, 30 right). Performance was measured by taking the average RT for correct trials (conditionalized).

**Test of Variables of Attention (TOVA)** At the beginning of each trial, a fixation cross was presented in the center of the screen, and an 800-Hz warning tone was sounded for 500 ms. After a variable delay of 1–3 s, a green square measuring 2° × 2° was presented in either the top or the bottom half of the screen. If the square was presented in the top half, participants were instructed to press the up arrow key on the keyboard as quickly as possible (i.e., a Go trial), but if it was presented in the bottom half of the screen, they were instructed to withhold responding (i.e., a No Go trial). On Go trials, the square would disappear either immediately after the participant responded or, if they failed to respond, after 2 s. On No Go trials, the square would remain for 2 s and then disappear. Participants completed 6 practice trials, and then 160 experimental trials. The first 80 experimental trials primarily consisted of Go trials (80%; referred to as the "impulsivity" phase), whereas the last 80 trials primarily consisted of No Go trials (80%; referred to as the "sustained" phase). Performance was calculated by measuring RTs on correct Go trials and accuracy for No Go trials for the two halves of the task, thus providing an index of impulsivity and sustained RT and accuracy. This task was adapted from Greenberg et al. (1994).

**Attentional Blink (AB)** This task was a variation on the classic Raymond et al. (1992) AB task. Each trial began with a 1000 ms delay period, after which 200 × 200 pixel images of illustrated (Pokémon) characters were presented on the screen one at a time for 96 ms each with an ISI of 64 ms. Between 11 and 25 items (randomized) were presented on a given trial (drawn from a pool of 25 unique images), but participants were instructed to attend to just two of the items in the stream (i.e., the targets). The first target (T1) was an image of a "Vulpix" (a multi-tailed fox) that was facing either left (50%) or right (50%). Participants were instructed to attend to the direction in which it was facing. The second target (T2) was an image of a Venomoth (a moth-like character) that was oriented either upright (50%) or inverted (50%). Participants were instructed to attend to the orientation of this item. T1 was presented in various stream positions (6–12) to prevent participants from identifying T1 based on positional information alone. Critically, T2 was separated from T1 by a lag of between one and six items. At the end of each trial, participants were prompted to indicate the direction of T1, and the orientation of T2, by selecting the corresponding image on the screen. Each combination of T1 direction, T2 orientation, and lag was repeated four times for a total of 96 trials (divided into 4 blocks of 24 trials each). To measure performance, we first calculated T2 accuracy (conditionalized on T1 correct) for each lag. Then, an AB magnitude measure was calculated by subtracting mean long lag (5, 6) accuracy from mean short lag (2) accuracy. Lastly, we calculated AB recovery by determining the lag at which T2 accuracy reached 90% (i.e., the point at which the AB ended).

**Useful Field of View (UFOV)** At the beginning of each trial a blank gray screen was presented for a variable duration of 16–1440 ms. A three-part display was then presented which consisted of distractor shapes, a central fixation target, and a peripheral target. The distractors were empty squares (subtending 1°) presented along eight lines radiating from a center fixation point at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315° around a circle. There were 23 distractors in total which were located 3°, 5°, and 7° away from the central fixation point. Participants were instructed to ignore these distractors. The central fixation target was a smiley face (subtending 1°) that had either long (50% of trials) or short (50% of trials) hair. At the end of each trial, participants were instructed to indicate whether the central target had long ("D" key) or short ("S" key) hair by pressing the corresponding letter on the keyboard. Lastly, the peripheral target was a star (subtending 1°) that was simultaneously presented with the central target and distractors. This peripheral target was always presented at the furthest eccentricity from the central fixation at one of eight possible locations. Participants were instructed to use their mouse to click one of the eight lines on which they thought the target had appeared. Participants were also told that the target would always appear at the furthest eccentricity from the center. Participants received immediate feedback on their performance after each trial (indicated by a green check mark for correct answers, and a red "X" for incorrect answers). The display initially remained on the screen for 15 frames (assuming a 60-Hz refresh rate), but as the experiment progressed the presentation duration was altered based on participant performance using an adaptive three-down, one-up staircase procedure. After either eight reversals, or ten consecutive trials at one frame (ceiling), the task ended; thus, participants could complete a maximum of 72 trials (participants also completed a brief tutorial prior to attempting the full task to ensure that they understood the task requirements). Performance was calculated by averaging the final ten trials in order to obtain a detection threshold, which represents the minimum presentation time needed in order to achieve 79% accuracy for detecting the peripheral target. This task was adapted from Ball and Owsley (1993).

**Multiple Object Tracking (MOT)** At the beginning of each trial, a display of 16 circles (0.8° in diameter) was presented on the screen. The circles randomly moved within a gray circular field at a rate of 5°/s (10° in diameter). Most of the circles were yellow happy faces (i.e., the distractors), but a subset of circles were blue sad faces (i.e., target faces). The number of target faces ranged from 1 to 5, and participants were instructed to track the target faces as they moved throughout the display. The target faces remained blue for 2 s, after which they changed into yellow happy faces (i.e., indistinguishable from distractors) for 4 s. Participants were instructed to continue to track the target faces that had formerly been blue. At the end of each trial, the circles stopped moving and one of the circles changed into a white circle with a question mark (i.e., the probe). Participants were instructed to indicate whether the probe was one of the circles that they had previously been tracking by pressing the "S" key for yes (50%) and the "H key for no (50%). Participants received feedback on their performance at the end of each trial. The single target face condition was presented five times, and the 2–5 target conditions were presented ten times each, for a total of 45 trials (randomly intermixed). Participants also completed six practice trials with the one- and two-target conditions prior to completing the full task. Performance was calculated by taking the mean accuracy for each set size.

**Operation Span (OSPAN)** At the beginning of each trial, a 3-kHz warning tone was sounded, after which a simple mathematical operation with either a correct (50%) or incorrect (50%) answer was presented in black 32pt New Courier font in the center of the screen (e.g., "6 ÷ 2 + 5 = 7"). Participants were instructed to indicate whether the answer was correct or incorrect by hitting the left and right arrow keys, respectively. The operation remained on the screen for 5 s, regardless of whether or not the participant responded, and was then replaced by a single letter drawn from all possible letters of the alphabet (except "I," "N," "O," "X," or "Y"). The letter was presented for 1000 ms in black 32pt New Courier font in the center of the screen, and participants were instructed to remember the letter. After a variable number of operation/letter combinations had been presented (set sizes of 1, 3, 5, or 7), participants were prompted to write down all of the letters that they saw in the order in which they appeared. There were 6 practice trials, followed by 32 experimental trials (each set size presented eight times, randomly intermixed). An OSPAN score was calculated in two ways: a “harsh” measure of the total number of letters correctly recalled in order, and a “lenient” measure of the total number of letters recalled regardless of order. In both cases, only trials on which the operation task was correctly completed were included. The final OSPAN score was the average of the harsh and lenient measures. This task was adapted from Turner and Engle (1989).

**Digit Span (DSPAN)** Each trial began with 1000 ms delay, after which a 3.5-kHz warning tone sounded for 100 ms. Shortly after, a variable number of digits (between 1 and 12) were individually presented in black 32pt New Courier font in the center of the screen. Each digit appeared for 1000 ms, and there was a 1000 ms delay between each digit. At the end of each trial, participants were prompted to write down all of the digits that they saw in the order in which they appeared. Each set size was presented four times (randomly intermixed) for a total of eight trials. Mean accuracy for each set size was measured, and a threshold estimate was calculated for each participant.

**N-Back** In this variation on the N-back task, participants were first instructed to imagine that the screen was divided into 7 columns and 21 rows. The columns corresponded to the number of items back to which the participants were to respond, and the number of columns used in each trial were indicated at the beginning of each trial (e.g., a one-column condition is equivalent to a 1-back memory task, a five-column condition is equivalent to a 5-back task, etc.). The task began with the simplest one-column (1-back) condition, and increased in difficulty up to the seven-column (7-back) condition. For the purposes of explanation, we will first describe a two-column (2-back) condition. In the 2-back condition, each trial began with a 1000 ms delay, after which a single digit (1–9) was presented in the first row of the first column. The digit remained on the screen for 1000 ms, after which it was replaced by a second digit that was presented in the same row, but in the second column. Again, the digit remained for 1000 ms. The next digit was then presented in the first column, but this time in the *second* row. Participants were instructed to indicate whether this digit was the same (50%) or different (50%) from the digit that had previously been presented in the row above it in that same column by pressing the arrow keys (left arrow for same and right arrow for different). The digit remained on the screen until the participant responded, after which the next digit would be presented in the second column, but in the second row. Again, participants would indicate whether this digit was the same or different from the digit previously presented in this column, but in the row above. The trial would then proceed in this same fashion, wherein participants would indicate whether a presented digit was the same or different from the one previously presented in that same column, but in the row above, until 20 responses had been made. The other column conditions were conducted in the same way, but using a different number of columns. Each column condition (1–7) was presented four times, for a total of 28 trials. Performance was calculated by taking the mean accuracy for each column condition. This task was adapted from the standard N-back working memory task (Kirchner 1958).

**Task Switching** Each trial began with a 1000 ms wait, after which either a blue or a yellow square measuring 4° × 4° was presented in the center of the screen. A single digit (1–9, excluding 5) was then presented in 32pt New Courier font in the center of the square. On half of the trials, participants were instructed to classify the digit as higher or lower than 5 (“Z” and “X” keys for high/low, respectively), and on half, they were instructed to classify the digit as odd or even (“>” and “?” for odd/even, respectively). The classification criteria that was to be used on each trial was presented at the bottom of the square in 32pt New Courier Font, and the square color itself cued the participant as to which classification scheme to use (blue squares indicated high/low trials, and yellow squares indicated odd/even trials). The stimuli remained on the screen until a response was made. Importantly, the classification criteria would switch after two trials; thus, participants would complete two high/low trials followed by two odd/even trials, and so on. There were 10 practice trials and 400 experimental trials (100 each of high/low/odd/even). Performance was measured by separately calculating the mean RT for correct switch and no-switch trials, as well as the difference in RT for these two trial types (i.e., switch costs).

**Raven’s Advanced Progressive Matrices (RAPM)** This task utilized only the even-numbered items (18 in total) from the RAPM task (Raven 2000). On each trial, participants were presented with a pattern that had one piece missing. They were instructed to select one of eight options that they felt best matched the pattern by pressing the corresponding number key on the keyboard. The display remained on the screen until the participant made a response. There were 18 trials in total, and participants were given 10 min to complete the task. A countdown was presented at the top of the screen to inform participants of how much time they had remaining, and participants were encouraged to avoid random guessing. Performance was calculated by taking the sum of the correctly answered items for a maximum possible score of 18.

## Results

For each task, our primary questions of interest were always related to one of several possible pairwise comparisons. Specifically, for each task we first asked whether we had replicated the typical AVGP/NVGP differences. Some of these results were expected to be significant, such as for our RT tasks and the UFOV, and some were expected to be null, such as for the OSPAN and the DSPAN tasks. Note that although we did have strong a priori predictions for all tasks, we nonetheless utilized two-tailed *p* values in all cases for consistency with previous literature. After addressing this question, we then asked whether the same pattern of results was seen in the SVGP/NVGP comparison (see Supplemental Information for SVGP/AVGP comparisons, for which we did not have strong a priori predictions and thus treat with caution). Finally, we examined the performance of the Tweener group (comparing Tweeners against both AVGPs and NVGPs).

Note that for each comparison, we report the relevant effect size, and for null results, we report the Bayes factor (Morey and Rouder 2011; Rouder et al. 2009). The Bayes factor (denoted here as $BF_{10}$) is an increasingly common metric used to quantify the probability that the null hypothesis is true relative to the alternative hypothesis. In this metric, a value less than one indicates that the null hypothesis is more likely to be true than the alternative hypothesis, a value of exactly one indicates that the null and alternative hypotheses are equally likely to be true, and a value greater than 1 indicates that the alternative hypothesis is more likely to be true (e.g., a Bayes factor of 4 indicates that the alternative hypothesis is four times more likely than the null; see Jarosz and Wiley 2014 for details on interpretation). For interaction terms, we report the BF for the main effect model divided by the BF for the interaction model, which is interpreted as the likelihood of the main effects model relative to the interaction model (where a large number suggests that a main effects model better explains the data, and a low number suggests that an interaction model is favored). All Bayes factors were calculated using either a JZS Bayes factor *t*-test or a JZS Bayes factor ANOVA with default prior scales in JASP (Love et al. 2015).

### Simple RT

The mean RT across all participant groups ranged from 0.24 to 0.34 s ($M = 0.25$, $SD = 0.03$; see Fig. 1a for group means). Overall accuracy was extremely close to ceiling and did not differ significantly amongst the different gamer groups (see Table 1 for overall and individual group accuracy).

**AVGP vs NVGP** Based upon previous research, we expected to find a significant difference between the groups, with AVGPs responding more quickly than NVGPs. Consistent with this prediction, there was a significant difference between the AVGPs and the NVGPs, $F(1, 28) = 6.22$, $p = .02$, $\eta^2 = 0.22$, with the AVGPs responding on average 28 ms faster than the NVGPs.

**SVGP vs NVGP** Like the AVGPs, the SVGPs were predicted to respond more quickly than the NVGPs. However, while the SVGPs showed a clear numerical advantage in the predicted direction (13 ms), this effect did not reach significance, $F(1, 24) = 1.50$, $p = .23$, $\eta^2 = 0.06$ ($BF_{10} = 0.630$).

**Tweeners** Given that the Tweeners' game playing habits sat in-between that of the AVGPs and the NVGPs, their RTs were similarly predicted to fall in-between these two groups. This is indeed what was observed, with the Tweeners responding approximately 18 ms slower than the AVGPs and 11 ms faster than the NVGPs, although neither effect reached significance (Tweeners vs AVGPs, $F(1, 29) = 2.90$, $p = .10$, $\eta^2 = 0.11$, $BF_{10} = 1.003$); Tweeners vs NVGPs, $F(1, 29) = 1.04$, $p = .32$, $\eta^2 = 0.05$, $BF_{10} = 0.505$).

### Discrimination RT

The mean overall RT across all participant groups ranged from 0.32 to 0.68 s ($M = 0.43$, $SD = 0.07$; see Fig. 1b for group means). Overall accuracy was near ceiling and did not differ significantly among the different gamer groups (see Table 1 for overall and individual group accuracy).

**AVGP vs NVGP** As with the simple RT task, we expected that AVGPs would have significantly faster RTs than the NVGPs on this task. As anticipated, there was indeed a significant difference between the AVGPs and the NVGPs, $F(1, 28) = 8.64$, $p = .007$, $\eta^2 = 0.31$, such that the AVGPs were 82 ms faster than the NVGPs.

**SVGP vs NVGP** Like the AVGPs, we anticipated that the SVGPs would also respond faster on this task than the NVGPs. Consistent with this hypothesis, the SVGPs significantly differed from the NVGPs on this task, $F(1, 23) = 6.75$, $p = .02$, $\eta^2 = 0.29$, such that the SVGPs were approximately 74 ms faster.

**Tweeners** Lastly, the Tweeners were expected to perform slower than the AVGPs, but faster than the NVGPs. As predicted, the Tweeners significantly differed from the AVGPs, $F(1, 29) = 6.03$, $p = .02$, $\eta^2 = 0.20$, such that the AVGPs were approximately 49 ms faster on the task. The Tweeners did not, however, significantly differ from the NVGPs, $F(1, 29) = 1.60$, $p = .22$, $\eta^2 = 0.05$ ($BF_{10} = 0.623$), although they were approximately 32 ms faster than the NVGPs.

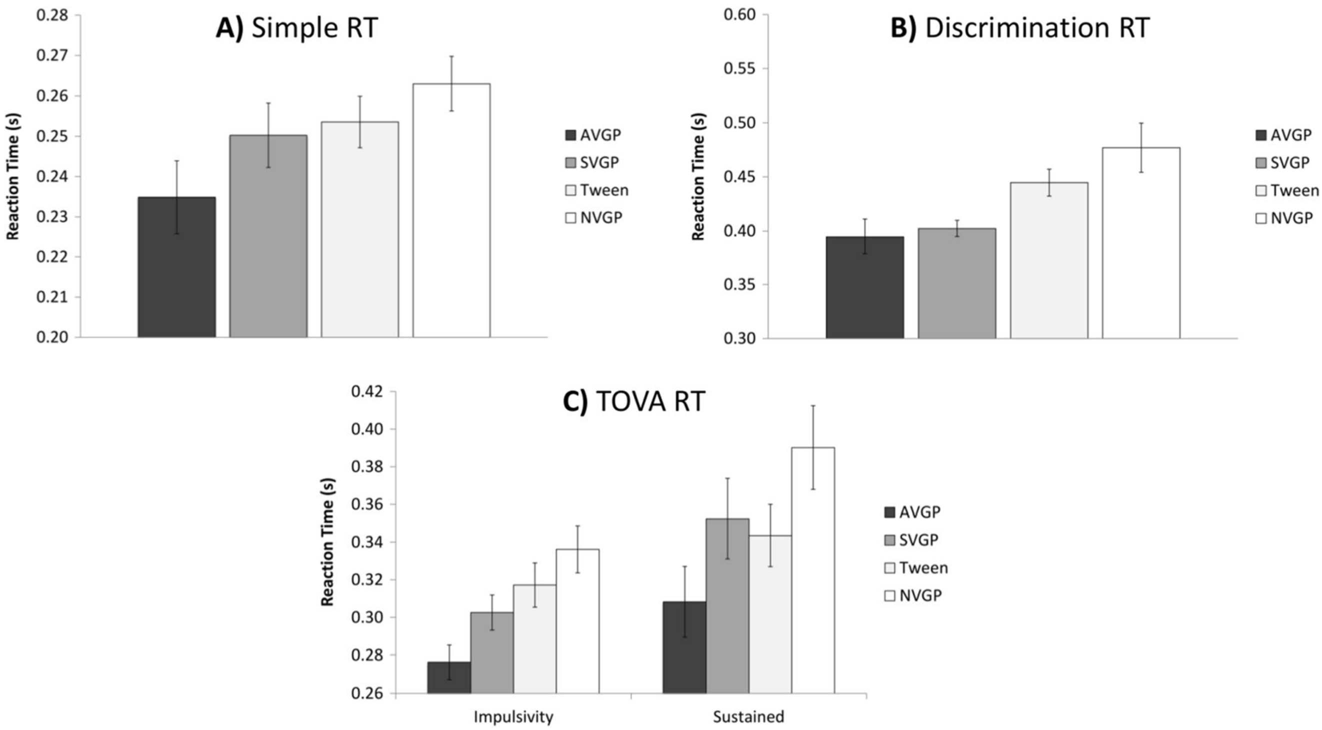


**Fig. 1** Mean reaction time in seconds as a function of gamer group on **a** the simple RT task, **b** the discrimination RT task, and **c** the impulsivity (*left*) and sustained (*right*) blocks of the TOVA task (*AVGP* action video game player, *SVGP* strategy video game player, *Tween* multi-genre player, *NVGP* non-video game player). *Bars* represent the standard error for each group mean

**TOVA**

There was an overall effect of block on RT with all groups combined, $F(1, 53) = 40.1$, $p < .001$, $\eta_p^2 = 0.42$, such that participants were generally faster on the impulsivity block than on the sustained block, as is typical (see Fig. 1c for group means). Accuracy did not differ across block, or amongst the different gamer groups (see Table 1 for overall and individual group accuracy).

**AVGP vs NVGP** We first examined the differences between the AVGPs and the NVGPs on this task. Given that past research has shown that AVGPs typically have faster response times than NVGPs, we anticipated a similar result here. Consistent with our hypothesis, there was a significant main effect of block, $F(1, 28) = 21.60$, $p < .001$, $\eta_p^2 = 0.44$, and of gamer group, $F(1, 28) = 10.96$, $p = .003$, $\eta_p^2 = 0.28$, wherein the AVGPs were 32 ms faster on the impulsivity block, and 54 ms faster on the sustained block, as compared to NVGPs. There was, however, no interaction between gamer group and block, $F(1, 28) = 1.43$, $p = .24$, $\eta_p^2 = 0.05$ ($BF_{10MainEffects}$/$BF_{10Interaction} = 1.95$), suggesting that the AVGPs were simply faster on the task overall, regardless of block.

**SVGP vs NVGP** Next, we examined whether the SVGPs would also differ from the NVGPs, as previous research has suggested that the SVGPs should have faster response times than NVGPs. There was a main effect of block, $F(1, 24) = 27.70$, $p < .001$, $\eta_p^2 = 0.54$, but no main effect of gamer group, $F(1, 24) = 2.32$, $p = .14$, $\eta_p^2 = 0.09$ ($BF_{10} = 0.903$),

**Table 1** Mean overall and group accuracy for RT tasks

| Measure | Overall *M* (*SD*) | AVGP *M* (*SD*) | SVGP *M* (*SD*) | Tweener *M* (*SD*) | NVGP *M* (*SD*) |
|---|---|---|---|---|---|
| Simple RT | 0.97 (0.03) | 0.96 (0.05) | 0.98 (0.01) | 0.97 (0.03) | 0.97 (0.02) |
| Discrimination RT | 0.93 (0.04) | 0.94 (0.04) | 0.94 (0.03) | 0.92 (0.04) | 0.93 (0.o4) |
| TOVA-sustained | 1.00 (0.01) | 1.00 (0.01) | 1.00 (0.01) | 1.00 (0.00) | 1.00 (0.00) |
| TOVA-impulsivity | 1.00 (0.01) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.02) |
| Switch | 0.97 (0.03 | 0.98 (0.02) | 0.98 (0.01) | 0.96 (0.04) | 0.97 (0.02) |
| No-switch | 0.97 (0.02) | 0.98 (0.02) | 0.98 (0.01) | 0.97 (0.03) | 0.97 (0.02) |

despite the SVGPs performing 34 and 36 ms faster than the NVGPs on the impulsivity and sustained blocks, respectively. There was also no interaction between SVGP/NVGP and block, $F(1, 24) = 0.45$, $p = .83$, $\eta_p^2 = 0.002$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.749$).

**Tweeners** Lastly, we examined the relationship between the Tweeners and both the AVGPs and the NVGPs. We anticipated that the Tweeners would not respond as quickly as the AVGPs, but would respond faster than the NVGPs. For the Tweener/AVGP comparison, there was a significant main effect of block, $F(1, 29) = 13.21$, $p = .001$, $\eta_p^2 = 0.31$, and a marginally significant main effect of gamer group, $F(1, 29) = 4.03$, $p = .05$, $\eta_p^2 = 0.12$, wherein the AVGPs were 42 ms faster on the impulsivity block, and 35 ms faster on the sustained block, as compared to the Tweeners. There was, however, no interaction between gamer group and block, $F(1, 29) = 0.13$, $p = .73$, $\eta_p^2 = 0.004$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.966$), suggesting that the AVGPs were simply faster on the task overall, regardless of block. For the Tweener/NVGP comparison, there was a significant main effect of block, $F(1, 29) = 27.79$, $p < .001$, $\eta_p^2 = 0.49$, but no main effect of gamer group, $F(1, 29) = 2.31$, $p = .14$, $\eta_p^2 = 0.07$ ($BF_{10} = 0.897$), and no interaction between gamer group and block, $F(1, 29) = 3.33$, $p = .08$, $\eta_p^2 = 0.10$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.098$), although the Tweeners were 19 ms faster than the NVGPs on the impulsivity block, and 47 ms faster on the sustained block.

### Attentional Blink

An overall repeated-measures ANOVA with all groups combined showed a significant main effect of lag, $F(5, 225) = 46.82$, $p < .01$, $\eta_p^2 = 0.51$, such that T2 accuracy conditionalized on T1 correct was lower for the short as compared to the long lags, as is typical (see Fig. 2a for group means).

**AVGP vs NVGP** We first examined the differences between the AVGPs and the NVGPs. Previous research has shown that AVGPs are less susceptible to the AB effect than NVGPs and are faster to recover from a blink (e.g., Green and Bavelier 2003); thus, we anticipated a similar result here. In contrast to our hypothesis, while there was a significant main effect of lag, $F(5, 125) = 48.46$, $p < .001$, $\eta_p^2 = 0.66$, there was no main effect of gamer group, $F(1, 25) = 0.47$, $p = .50$, $\eta_p^2 = 0.02$ ($BF_{10} = .286$), and no interaction between gamer group and lag, $F(5, 125) = 1.11$, $p = .36$, $\eta_p^2 = 0.04$ ($BF_{10MainEffects}/BF_{10Interaction} = 5.06$), although all effects were in the predicted direction. A one-way ANOVA also showed no differences between AVGPs and NVGPs on either AB magnitude, $F(1, 26) = 0.06$, $p = .80$, $\eta^2 = 0.004$ ($BF_{10} = 0.363$), or AB recovery, $F(1, 26) = 0.83$, $p = .37$, $\eta^2 = 0.03$ ($BF_{10} = 0.482$), although again, all effects were in the predicted direction.

**SVGP vs NVGP** Similar to the AVGPs, we predicted that the SVGPs would have smaller ABs, and faster recovery, as compared to the NVGPs. While there was a significant main effect of lag, $F(5, 105) = 37.44$, $p < .001$, $\eta_p^2 = 0.64$, there was no main effect of gamer group, $F(1, 21) = 0.17$, $p = .69$, $\eta_p^2 = 0.01$ ($BF_{10} = 0.247$), and no interaction between gamer group and lag, $F(5, 105) = 0.49$, $p = .78$, $\eta_p^2 = 0.02$ ($BF_{10MainEffects}/BF_{10Interaction} = 10.737$). A one-way ANOVA also showed no differences between SVGPs and NVGPs on either AB magnitude, $F(1, 22) = 0.16$, $p = .70$, $\eta^2 = 0.01$ ($BF_{10} = 0.396$), or AB recovery, $F(1, 22) = 0.57$, $p = .50$, $\eta^2 = 0.03$ ($BF_{10} = 0.460$).

**Tweeners** Lastly, we examined the differences between the Tweeners and both the AVGPs and the NVGPs. We expected that the Tweeners might perform slightly worse on the AB task (i.e., larger ABs and slower recovery) than the AVGPs, but slightly better than the NVGPs. However, neither hypothesis was supported. For the Tweener/AVGP comparison, there was a significant main effect of lag, $F(5, 130) = 33.67$, $p < .001$, $\eta_p^2 = 0.56$, but no main effect of gamer group, $F(1, 26) = 1.41$, $p = .25$, $\eta_p^2 = 0.05$ ($BF_{10} = 0.338$), or interaction between gamer group and lag, $F(5, 130) = 1.73$, $p = .13$, $\eta_p^2 = 0.06$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.967$). Similarly, for the Tweener/NVGP comparison, there was a significant main effect of lag, $F(5, 115) = 29.28$, $p < .001$, $\eta_p^2 = 0.56$, but no main effect of gamer group, $F(1, 23) = 0.22$, $p = .64$, $\eta_p^2 = 0.01$ ($BF_{10} = 0.257$), or interaction between gamer group and lag, $F(5, 115) = 0.88$, $p = .50$, $\eta_p^2 = 0.04$ ($BF_{10MainEffects}/BF_{10Interaction} = 6.636$). A series of one-way ANOVAs also showed no differences between Tweeners and AVGPs for AB magnitude, $F(1, 26) = 0.01$, $p = .94$, $\eta^2 < 0.001$ ($BF_{10} = 0.355$), or AB recovery, $F(1, 26) < 0.01$, $p = .99$, $\eta^2 < 0.001$ ($BF_{10} = 0.354$). There was also no difference between Tweeners and NVGPs for both AB magnitude, $F(1, 24) = 0.03$, $p = .87$, $\eta^2 < 0.001$ ($BF_{10} = 0.366$), and AB recovery, $F(1, 24) = 0.94$, $p = .34$, $\eta^2 = 0.04$ ($BF_{10} = 0.513$).

### UFOV

There were large individual differences in UFOV threshold, with scores ranging from 18.3 to 163.3 ms ($M = 65.48$, $SD = 30.87$; see Fig. 2b for group means).

**AVGP vs NVGP** Based on previous research, we anticipated that the AVGPs would have lower UFOV thresholds than the NVGPs. Consistent with this hypothesis, there was a significant difference between the AVGPs and the NVGPs, $F(1, 28) = 4.93$, $p = .04$, $\eta^2 = 0.18$, such that the detection threshold for the AVGPs was about 17.5 ms lower than for the NVGPs.

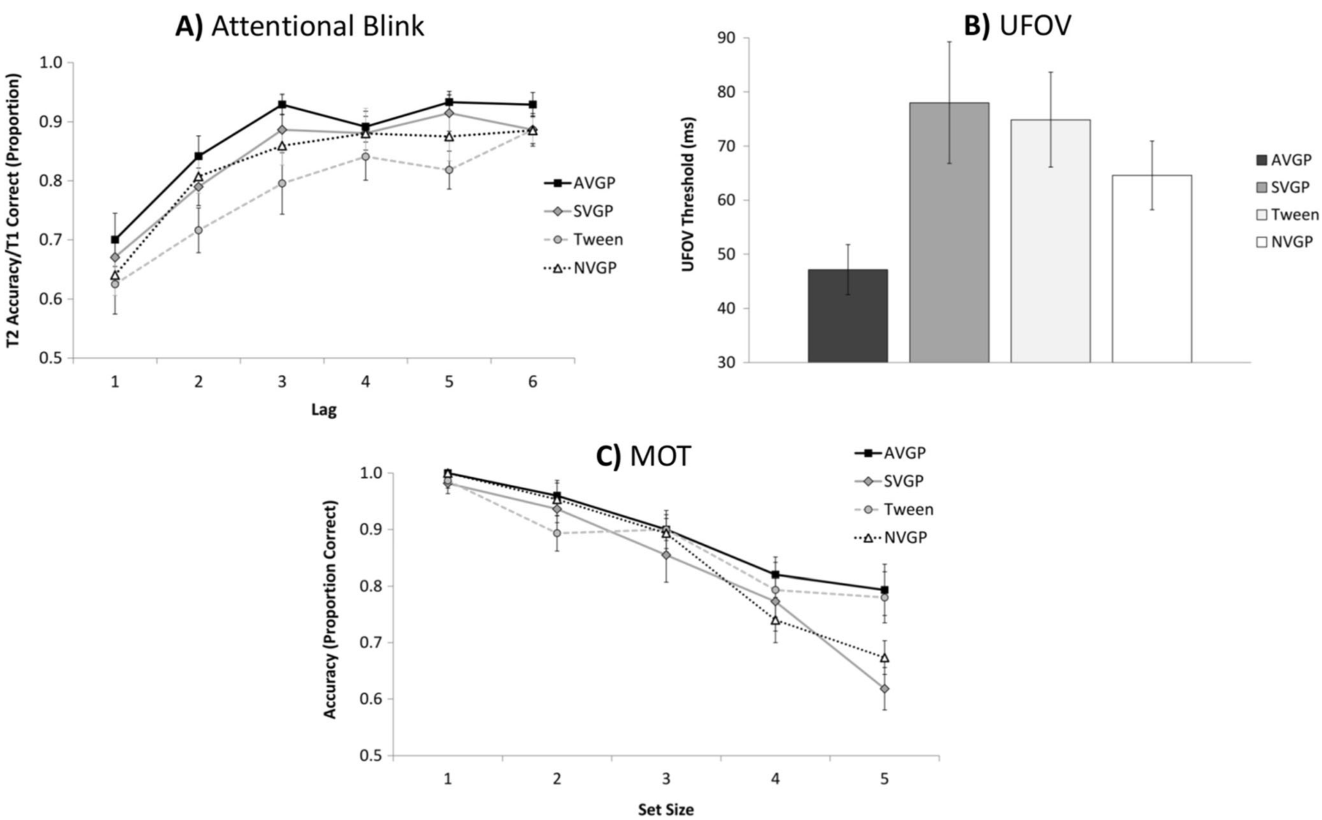


**Fig. 2** **a** Mean T2 accuracy conditionalized on T1 correct on the AB task as a function of gamer group. **b** Mean threshold in milliseconds on the UFOV task as a function of gamer group. **c** Accuracy for each set size (1–5) on the MOT task as a function of gamer group. *Bars* represent the standard error of each mean

**SVGP vs NVGP** We also anticipated that the SVGPs would have lower UFOV thresholds than the NVGPs. However, the SVGPs did not significantly differ from the NVGPs on this task, $F(1, 24) = 1.23$, $p = .28$, $\eta^2 = 0.05$ ($BF_{10} = 0.573$) and in fact, were numerically worse (see "Discussion").

**Tweeners** Lastly, we hypothesized that the Tweeners would have higher UFOV thresholds than the AVGPs, but lower thresholds than the NVGPs. Consistent with this hypothesis, we found that the Tweeners significantly differed from the AVGPs, $F(1, 29) = 7.55$, $p = .10$, $\eta^2 = 0.26$, such that the threshold for the AVGPs was approximately 28 ms lower than for the Tweeners. The Tweeners did not, however, significantly differ from the NVGPs, $F(1, 29) = 0.88$, $p = .36$, $\eta^2 = 0.03$ ($BF_{10} = 0.476$).

## MOT

An overall repeated-measures ANOVA with all groups combined showed a significant main effect of set size, $F(4, 208) = 49.70$, $p < .01$, $\eta_p^2 = 0.49$, such that accuracy decreased as set size increased, as is typical (see Fig. 2c for group means).

**AVGP vs NVGP** Based on previous research, we expected that the AVGPs would outperform the NVGPs on this task, particularly at the larger (more difficult) set sizes. There was a significant main effect of set size, $F(4, 112) = 31.28$, $p < .001$, $\eta_p^2 = 0.53$, but no main effect of gamer group, $F(1, 28) = 3.36$, $p = .08$, $\eta_p^2 = 0.11$ ($BF_{10} = 0.468$), or interaction between gamer group and set size, $F(4, 112) = 1.78$, $p = .14$, $\eta_p^2 = 0.06$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.75$). However, because many of the set sizes were near ceiling (and thus were not useful in discriminating between groups), we then conducted a series of one-way ANOVAs to examine whether the two groups differed at the most difficult (4 and 5) set sizes. For set size 4, there was no difference between the AVGPs and NVGPs, $F(1, 28) = 2.49$, $p = .13$, $\eta^2 = 0.09$ ($BF_{10} = 0.868$), but the groups did significantly differ at set size 5, $F(1, 28) = 4.89$, $p = .04$, $\eta^2 = 0.17$, such that the AVGPs were 12% more accurate than the NVGPs. This was in accordance with our hypothesis that the AVGPs would be more accurate at the more difficult set sizes.

**SVGP vs NVGP** Similar to the AVGPs, we expected that the SVGPs would perform better than the NVGPs at the most difficult set sizes. There was a significant main effect of set size, $F(4, 96) = 34.67$, $p < .001$, $\eta_p^2 = 0.59$, but no significant main effect of gamer group, $F(1, 24) = 0.83$, $p = .37$, $\eta_p^2 = 0.03$ ($BF_{10} = 0.272$), or interaction between gamer group and set size, $F(4, 96) = 0.48$, $p = .75$, $\eta_p^2 = 0.02$ ($BF_{10MainEffects}/BF_{10Interaction} = 8.565$). We then conducted a series of one-way ANOVAs to examine whether the two groups differed at the most difficult (4 and 5) set sizes. In contrast to our hypothesis, there was no difference between the SVGPs and the NVGPs for either set size 4, $F(1, 24) = 0.26$, $p = .62$, $\eta^2 = 0.01$ ($BF_{10} = 0.402$), or set size 5, $F(1, 24) = 1.34$, $p = .26$, $\eta^2 = 0.05$ ($BF_{10} = 0.596$).

**Tweeners** Lastly, we anticipated that the Tweeners might perform slightly worse than the AVGPs, but slightly better than the NVGPs, at the most difficult set sizes. For the Tweener/AVGP comparison, there was a significant main effect of set size, $F(4, 112) = 16.29$, $p < .001$, $\eta_p^2 = 0.37$, but no significant main effect of gamer group, $F(1, 28) = 0.81$, $p = .39$, $\eta_p^2 = 0.03$ ($BF_{10} = 0.307$), or interaction between gamer group and set size, $F(4, 112) = 0.36$, $p = .83$, $\eta_p^2 = 0.01$ ($BF_{10MainEffects}/BF_{10Interaction} = 11.326$). Similarly, for the Tweener/NVGP comparison, there was a significant main effect of set size, $F(4, 112) = 24.32$, $p < .001$, $\eta_p^2 = 0.47$, but no significant main effect of gamer group, $F(1, 28) = 0.80$, $p = .38$, $\eta_p^2 = 0.03$ ($BF_{10} = 0.250$), or interaction between gamer group and set size, $F(4, 112) = 2.00$, $p = .10$, $\eta_p^2 = 0.07$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.199$). We then conducted a series of one-way ANOVAs to examine whether the groups differed at the most difficult (4 and 5) set sizes. For the Tweener/AVGP comparison, there was no difference for either set size 4, $F(1, 28) = 0.22$, $p = .65$, $\eta^2 = 0.01$ ($BF_{10} = 0.374$), or set size 5, $F(1, 28) = 0.04$, $p = .84$, $\eta^2 = 0.001$ ($BF_{10} = 0.350$), contrary to our hypothesis. Similarly, for the Tweener/NVGP comparison, there was no difference for set size 4, $F(1, 28) = 0.72$, $p = .40$, $\eta^2 = 0.03$ ($BF_{10} = 0.453$), although the difference at set size 5 approached significance, $F(1, 28) = 3.90$, $p = .06$, $\eta^2 = 0.14$ ($BF_{10} = 1.435$).

### OSPAN

Scores on the OSPAN ranged widely from 12.5 to 94.5 ($M = 50.53$, $SD = 19.68$; see Fig. 3a for group means).

**AVGP vs NVGP** Based on past research, we did not anticipate that the AVGPs would perform differently than the NVGPs on this memory task. Consistent with this prediction, we found no significant differences between the AVGPs and the NVGPs, $F(1, 26) = 0.23$, $p = .63$, $\eta^2 = 0.008$ ($BF_{10} = 0.386$).

**SVGP vs NVGP** As with the AVGPs, we did not expect any differences between the SVGPs and the NVGPs. As anticipated, the SVGPs and NVGPs did not significantly differ on this task, $F(1, 22) = 0.42$, $p = .97$, $\eta^2 < 0.001$ ($BF_{10} = 0.374$).

**Tweeners** Lastly, there were also no differences between the Tweeners and both the AVGPs, $F(1, 29) = 2.48$, $p = .13$, $\eta^2 = 0.09$ ($BF_{10} = 0.861$), and the NVGPs, $F(1, 27) = 1.35$, $p = .26$, $\eta^2 = 0.05$ ($BF_{10} = 0.580$), as anticipated.

### DSPAN

DSPAN thresholds ranged from 0.51 to 0.96 ($M = 0.77$, $SD = 0.12$; see Fig. 3b for group means).

**AVGP vs NVGP** As with the OSPAN, we anticipated no differences between the AVGPs and SVGPs. As expected, no such differences were found between these two groups, $F(1, 20) = 0.08$, $p = .78$, $\eta^2 = 0.004$ ($BF_{10} = 0.347$a).

**SVGP vs NVGP** Again, we expected no differences between the SVGPs and NVGPs on this task, and found that they did not significantly differ in their DSPAN performance, $F(1, 20) = 0.78$, $p = .39$, $\eta^2 = 0.04$ ($BF_{10} = 0.598$).

**Tweeners** Lastly, we expected no differences between the Tweeners and the AVGPs/NVGPs on this task. While there were no significant differences between the Tweeners and both the AVGPs, $F(1, 25) = 3.43$, $p = .08$, $\eta^2 = 0.14$ ($BF_{10} = 1.110$), and the NVGPs, $F(1, 25) = 3.50$, $p = .07$, $\eta^2 = 0.14$ ($BF_{10} = 2.354$) on this task, both relationships did approach significance.

### N-Back Accuracy

An overall repeated-measures ANOVA on N-back accuracy with all groups combined showed a significant main effect of set size, $F(6, 318) = 163.10$, $p < .01$, $\eta_p^2 = 0.76$, such that accuracy decreased as a function of N (i.e., the number of items back), as is typical (see left panel of Fig. 3c for group means).

**AVGP vs NVGP** In accordance with past research, we did not expect the AVGPs and NVGPs to differ on this task. There was a significant main effect of number of columns, $F(6, 168) = 92.87$, $p < .001$, $\eta_p^2 = 0.77$, but no main effect of gamer group, $F(1, 28) = 0.06$, $p = .81$, $\eta_p^2 = 0.002$ ($BF_{10} = 0.220$). The interaction between gamer group and N, however, approached significance, $F(6, 168) = 2.10$, $p = .06$, $\eta_p^2 = 0.07$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.14$). We then conducted a series of one-way ANOVAs to examine whether the two groups differed for the most difficult (6 and 7) column conditions. There were no differences between the AVGPs and the NVGPs for either the six-column condition, $F(1, 28) = 1.80$, $p = .19$, $\eta^2 = 0.07$ ($BF_{10} = 0.676$), or the seven-column condition, $F(1, 28) = 0.04$, $p = .84$, $\eta^2 < 0.001$($BF_{10} = 0.350$).

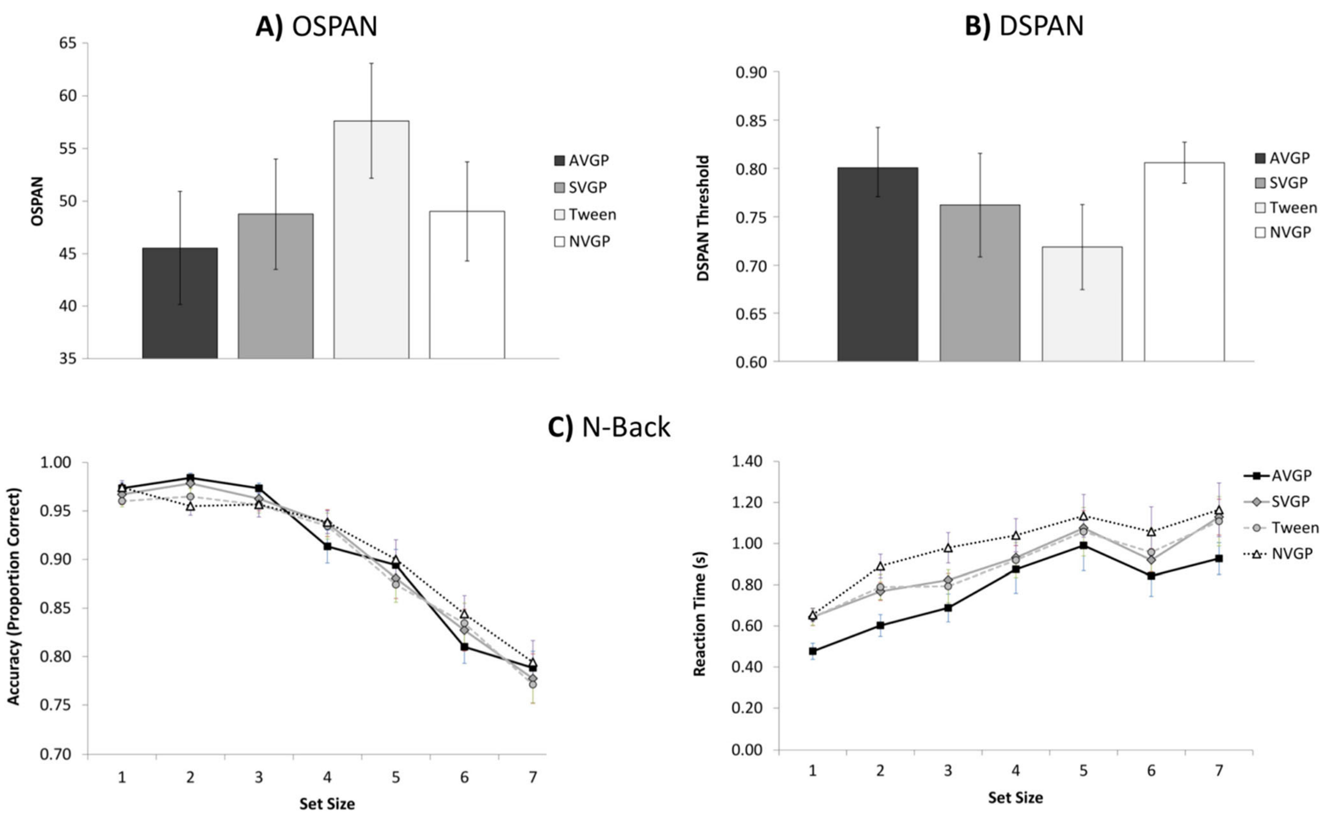


**Fig. 3** **a** Scores on the OSPAN task as a function of gamer group. **b** DSPAN thresholds as a function of gamer group. **c** *Left panel* shows accuracy on the N-back task as a function of both set size (i.e., number of columns or number of items back), and gamer group. *Right panel* shows RT in seconds on the N-back task as a function of both set size (i.e., number of columns or number of items back), and gamer group. *Bars* represent the standard error of each mean

**SVGP vs NVGP** Similar to the AVGP/NVGP comparison, we anticipated that the SVGPs would not differ from the NVGPs on this task. Consistent with this hypothesis, we found a significant main effect of number of columns, $F(6, 144) = 66.04$, $p < .001$, $\eta_p^2 = 0.73$, but no main effect of gamer group, $F(1, 24) = .08$, $p = .79$, $\eta_p^2 < 0.003$ ($BF_{10} = 0.253$), or an interaction, $F(6144) = 0.75$, $p = .61$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 10.722$). We next conducted a series of one-way ANOVAs to examine whether the two groups differed for the most difficult (6 and 7) column conditions. There were no differences between the SVGPs and the NVGPs for either the six-column condition, $F(1, 24) = 0.35$, $p = .56$, $\eta^2 = 0.02$ ($BF_{10} = 0.416$), or the seven-column condition, $F(1, 24) = 0.25$, $p = .62$, $\eta^2 = 0.01$ ($BF_{10} = 0.401$).

**Tweeners** Lastly, we examined whether the Tweeners differed from both the AVGPs and the NVGPs. As with the other comparisons, we did not expect any differences amongst the groups. For the Tweener/AVGP comparison, there was a significant main effect of number of columns, $F(6, 174) = 101.23$, $p < .001$, $\eta_p^2 = 0.78$, but no main effect of gamer group, $F(1, 29) = 0.19$, $p = .67$, $\eta_p^2 < 0.01$ ($BF_{10} = 0.220$), or an interaction, $F(6174) = 1.66$, $p = .13$, $\eta_p^2 = 0.05$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.617$). Similarly, for the Tweener/NVGP comparison, there was a significant main effect of number of columns, $F(6, 174) = 88.11$, $p < .001$, $\eta_p^2 = 0.75$, but no main effect of gamer group, $F(1, 29) = 0.36$, $p = .55$, $\eta_p^2 < 0.01$ ($BF_{10} = 0.260$), or an interaction, $F(6174) = 0.70$, $p = .65$, $\eta_p^2 = 0.02$ ($BF_{10MainEffects}/BF_{10Interaction} = 14.074$). We then conducted a series of one-way ANOVAs to examine whether the two groups differed for the most difficult (6 and 7) column conditions. There were no differences between the Tweeners and the AVGPs for either the six-column condition, $F(1, 29) = 0.82$, $p = .37$, $\eta^2 = 0.03$ ($BF_{10} = 0.464$), or the seven-column condition, $F(1, 29) = 0.45$, $p = .51$, $\eta^2 = 0.01$ ($BF_{10} = 0.405$). Similarly, when we compared the Tweeners to the NVGPs, there were no differences for either the six-column condition, $F(1, 29) = 0.12$, $p = .73$, $\eta^2 = 0.01$ ($BF_{10} = 0.357$), or the seven-column condition, $F(1, 29) = 0.63$, $p = .44$, $\eta^2 = 0.02$ ($BF_{10} = 0.432$).

### N-Back-Reaction Time

An overall repeated-measures ANOVA on N-back reaction time with all groups combined showed a significant main effect of set size, $F(6, 318) = 52.20$, $p < .01$, $\eta_p^2 = 0.50$, such that RT generally increased as a function of N (i.e., the number of columns; see right panel of Fig. 3c for group means).

**AVGP vs NVGP** Given that numerous studies have demonstrated that AVGPs have faster response times than NVGPs, we anticipated that the AVGPs would outperform the NVGPs, particularly at the easiest set sizes (1 and 2). There was a significant main effect of number of columns, $F(6, 168) = 26.42$, $p < .001$, $\eta_p^2 = 0.49$, and a marginally significant main effect of gamer group, $F(1, 28) = 3.96$, $p = .06$, $\eta_p^2 = 0.12$. The interaction between gamer group and number of columns, however, was not significant, $F(6, 168) = 0.72$, $p = .64$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 13.629$). We then conducted a series of one-way ANOVAs to examine whether the two groups differed for the two easiest (1 and 2), and the most difficult (6 and 7), column conditions. As hypothesized, the AVGPs were significantly faster than the NVGPs in both the one-column condition $F(1, 28) = 11.89$, $p = .002$, $\eta^2 = 0.43$, and in the two-column condition, $F(1, 28) = 13.44$, $p = .001$, $\eta^2 = 0.48$ (~180 and ~289 ms faster in the one- and two-column conditions, respectively). However, there were no differences between the AVGPs and the NVGPs for either the six-column condition, $F(1, 28) = 1.89$, $p = .18$, $\eta^2 = 0.07$ ($BF_{10} = 0.697$) or the seven-column condition, $F(1, 28) = 2.43$, $p = .13$, $\eta^2 = 0.09$ ($BF_{10} = 0.851$).

**SVGP vs NVGP** For the SVGP/NVGP comparison, we also anticipated that the SVGPs would perform significantly faster than the NVGPs, particularly at the easiest set sizes. There was a significant main effect of number of columns, $F(6, 144) = 24.89$, $p < .001$, $\eta_p^2 = 0.51$, but no main effect of gamer group, $F(1, 24) = 0.79$, $p = .38$, $\eta_p^2 = 0.03$ ($BF_{10} = 0.506$). The interaction between gamer group and number of columns was also not significant, $F(6, 144) = 0.66$, $p = .68$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 11.792$). We then conducted a series of one-way ANOVAs to examine whether the two groups differed for the two easiest (1 and 2), and the most difficult (6 and 7), column conditions. Contrary to our expectations, the SVGPs did not significantly differ from the NVGPs in the one-column condition, $F(1, 24) = 0.04$, $p = .84$, $\eta^2 = 0.002$ ($BF_{10} = 0.371$), or the two-column condition, $F(1, 24) = 2.53$, $p = .13$, $\eta^2 = 0.11$ ($BF_{10} = 0.909$). The two groups also did not differ in either the 6-column condition, $F(1, 24) = 0.86$, $p = .36$, $\eta^2 = 0.04$ ($BF_{10} = 0.501$), or the seven-column condition, $F(1, 24) = 0.04$, $p = .84$, $\eta^2 = 0.002$ ($BF_{10} = 0.372$).

**Tweeners** Lastly, we expected that the Tweeners would be slower than the AVGPs on this task, but faster than the NVGPs, particularly at the easiest set sizes. For the Tweener/AVGP comparison, there was a significant main effect of number of columns, $F(6, 174) = 28.46$, $p < .001$, $\eta_p^2 = 0.50$, but no main effect of gamer group, $F(1, 29) = 1.21$, $p = .28$, $\eta_p^2 = 0.04$ ($BF_{10} = 0.619$), or an interaction between gamer group and number of columns, $F(6, 174) = 0.75$, $p = .61$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 13.064$). For the Tweener/NVGP comparison, there was a significant main effect of number of columns, $F(6, 174) = 27.01$, $p < .001$, $\eta_p^2 = 0.48$, but no main effect of gamer group, $F(1, 29) = 0.64$, $p = .43$, $\eta_p^2 = 0.02$ ($BF_{10} = 0.516$), or an interaction between gamer group and number of columns, $F(6, 174) = 0.73$, $p = .63$, $\eta_p^2 = 0.02$ ($BF_{10MainEffects}/BF_{10Interaction} = 14.045$).

We then conducted a series of one-way ANOVAs to examine whether the groups differed for the two easiest (1 and 2), and the two most difficult (6 and 7), column conditions. In accordance with our predictions, the Tweeners significantly differed from the AVGPs in both the one-column condition, $F(1, 29) = 8.66$, $p = .01$, $\eta^2 = 0.30$, and the two-column condition, $F(1, 29) = 5.29$, $p = .03$, $\eta^2 = 0.18$, such that the AVGPs were 166 and 187 ms faster than the Tweeners at the one- and two-column conditions, respectively. The two groups, however, did not differ in either the six-column condition, $F(1, 29) = 0.57$, $p = .46$, $\eta^2 = 0.02$ ($BF_{10} = 0.423$), or the seven-column condition, $F(1, 29) = 1.56$, $p = .22$, $\eta^2 = 0.05$ ($BF_{10} = 0.613$). For the Tweener/NVGP comparison, there was no difference between the groups for either the one-column condition, $F(1, 29) = 0.05$, $p = .83$, $\eta^2 = 0.001$ ($BF_{10} = 0.346$), or the two-column condition, $F(1, 29) = 1.46$, $p = .24$, $\eta^2 = 0.05$ ($BF_{10} = 0.592$). The two groups also did not differ in either the six-column condition, $F(1, 29) = 0.36$, $p = .55$, $\eta^2 = 0.01$ ($BF_{10} = 0.391$), or the seven-column condition, $F(1, 29) = 0.10$, $p = .76$, $\eta^2 = 0.003$ ($BF_{10} = 0.353$).

### Task Switching

The mean RT on switch trials across all groups was 1147.1 ms (*SD* = 290.89), whereas the mean RT on no-switch trials was 713.6 ms (*SD* = 158.22). There was an overall significant main effect of trial type with all groups combined, $F(1, 53) = 360.79$, $p < .01$, $\eta_p^2 = 0.87$, such that no-switch RTs were faster, as expected (see Fig. 4 for group means). Accuracy did not differ across block or among the different gamer groups (see Table 1 for overall and individual group accuracy).

**AVGP vs NVGP** Based on previous research, we expected that the AVGPs would not only perform faster than the NVGPs on both the switch and no-switch blocks, but that the AVGPs would also have fewer switch costs than the NVGPs. Consistent with this prediction, we found a significant main effect of trial type, $F(1, 28) = 157.19$, $p = <.001$, $\eta_p^2 = 0.85$, and a significant effect of gamer group, $F(1, 28) = 8.87$, $p = .01$, $\eta_p^2 = 0.24$, such that the AVGPs were 335 ms faster on switch trials, and 159 ms faster on the

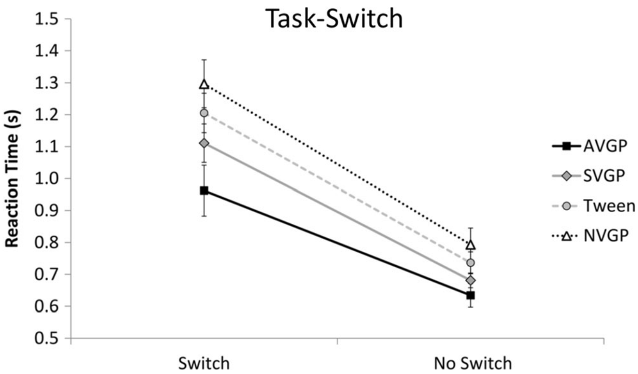


**Fig. 4** Reaction time in seconds for switch and no-switch trials on the task-switching paradigm as a function of gamer group. *Bars* represent the standard error of each mean

no-switch trials, as compared to NVGPs. There was also an interaction between gamer group and trial type, $F(1, 28) = 6.99$, $p = .01$, $\eta_p^2 = 0.20$, such that the AVGPs were less susceptible to switch costs (328 ms of cost for the AVGPs vs 504 ms of cost for the NVGPs).

**SVGP vs NVGP** We anticipated that the SVGPs might perform similarly on this task to the AVGPs, such that they would respond faster than the NVGPs on both trial types, and would have fewer switch costs. However, while there was a significant main effect of trial type, $F(1, 24) = 188.33$, $p = <.001$, $\eta_p^2 = 0.89$, the effect of gamer group only approached significance, $F(1, 24) = 3.70$, $p = .07$, $\eta_p^2 = 0.13$ ($BF_{10} = 0.705$), and there was no interaction between gamer group and trial type, $F(1, 24) = 1.17$, $p = .29$, $\eta_p^2 = 0.05$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.847$).

**Tweeners** Lastly, we expected that the Tweeners might respond slower/have greater costs than the AVGPs but would respond faster/have fewer costs when compared to the NVGPs. For the Tweener/AVGP comparison, there was a significant main effect of trial type, $F(1, 29) = 171.97$, $p = <.001$, $\eta_p^2 = 0.86$, and a significant effect of gamer group, $F(1, 29) = 5.56$, $p = .03$, $\eta_p^2 = 0.16$, such that the AVGPs were 243 ms faster on switch trials, and 102 ms faster on the no-switch trials, as compared to the Tweeners. In support of our hypothesis, there was also an interaction between gamer group and trial type, $F(1, 29) = 5.34$, $p = .03$, $\eta_p^2 = 0.16$, such that the AVGPs were less susceptible to switch costs than the Tweeners (328 ms of cost for the AVGPs vs 469 ms of cost for the Tweeners). For the Tweener/NVGP comparison, however, there was a significant main effect of trial type, $F(1, 29) = 287.61$, $p = <.001$, $\eta_p^2 = 0.91$, but no significant effect of gamer group, $F(1, 29) = 0.96$, $p = .34$, $\eta_p^2 = 0.03$ ($BF_{10} = 0.380$), and no interaction between gamer group and trial type, $F(1, 29) = 0.36$, $p = .56$, $\eta_p^2 = 0.01$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.488$).

## Fluid Intelligence

Scores on the RAPM ranged from 3 to 14 with a mean score of 9.05 (*SD* = 2.58; see Fig. 5 for group means).

**AVGP vs NVGP** We did not anticipate any differences between AVGPs and NVGPs on this task and indeed found no significant differences between the groups, $F(1, 28) = 0.97$, $p = .33$, $\eta^2 = 0.03$ ($BF_{10} = 0.496$).

**SVGP vs NVGP** Similar to the AVGPs, we expected no differences between the SVGPs and the NVGPs on this task, and found no significant differences between the two groups, $F(1, 24) = 1.14$, $p = .30$, $\eta^2 = 0.05$ ($BF_{10} = 0.555$).

**Tweeners** As with the other comparisons, we did not anticipate any differences between the Tweeners and the other groups. In accordance with this hypothesis, there were no differences between the Tweeners and either the AVGPs, $F(1, 29) = .12$, $p = .73$, $\eta^2 = 0.004$ ($BF_{10} = 0.356$), or the NVGPs, $F(1, 29) = 0.46$, $p = .51$, $\eta^2 = 0.02$ ($BF_{10} = 0.405$).

## Effect of Recruitment Strategy

Although it was not a main goal of the study, the fact that some of our participants were recruited overtly (i.e., they were recruited via posters specifically mentioning video game playing and thus they could assume that the purpose of the study was related to their gaming habits), while some of our participants were recruited covertly (i.e., they had filled out a questionnaire at the beginning of the semester related to their gaming, alongside hundreds of other non-gaming-related questions, and thus, although their responses to this questionnaire were used by the research team to invite them to participate, they had no reason to suspect that the study they were participating in was related to that initial questionnaire), allowed us to examine the effect of these different recruitment strategies on eventual performance. Indeed, several authors have expressed concerns that overt recruitment strategies

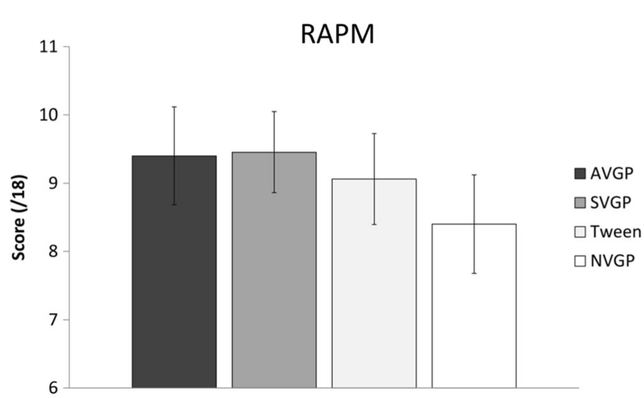


**Fig. 5** RAPM score out of 18 as a function of gamer group. *Bars* represent the standard error of each mean

may induce differences in performance due to expectation effects (i.e., AVGPs may believe they are expected to perform better and thus alter their performance in an attempt to match this expectation, while NVGPs may believe and thus do the opposite; e.g., Boot et al. 2011, 2013). While all participants were unaware of our specific hypotheses, 6 of 15 AVGPs and 7 of 15 NVGPs were overtly recruited, whereas the remaining 9 AVGPs and 8 NVGPs were under the impression that they had randomly been selected to participate. We ran a series of ANOVAs to examine whether the overt and covert AVGPs and NVGPs differed from each other on any of the tasks (see Table 2 for group means and SDs).

**Simple RT** For this task, a one-way ANOVA showed that there was no effect of overt/covert recruitment for the AVGPs, $F(1, 13) = 0.001$, $p = .98$, $\eta_2 < 0.001$ ($BF_{10} = 0.442$), but there was a marginally significant difference between the overtly and covertly recruited NVGPs, $F(1, 13) = 1.63$, $p = .051$, $\eta_2 = 0.19$ ($BF_{10} = 1.751$), such that the overtly recruited NVGPs were approximately 26 ms faster on the task.

**Discrimination Reaction Time** There was no effect of recruitment for either the AVGPs, $F(1, 13) = 0.10$, $p = .76$, $\eta_2 < 0.001$ ($BF_{10} = 0.457$), or the NVGPs, $F(1, 13) = 1.73$, $p = .21$, $\eta_2 = 0.14$ ($BF_{10} = 0.763$).

**TOVA** There was no main effect of overt/covert recruitment for the AVGPs, $F(1, 13) = 0.22$, $p = .65$, $\eta_p^2 = 0.02$ ($BF_{10} = 0.657$), nor an interaction between recruitment type and trial type, $F(1, 13) = 0.37$, $p = .55$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.244$). Similarly, for the NVGPs there was no main effect of overt/covert recruitment, $F(1, 13) = 0.50$, $p = .49$, $\eta_p^2 = 0.04$ ($BF_{10} = 0.754$), nor an interaction between recruitment type and trial type, $F(1, 13) = 0.10$, $p = .76$, $\eta_p^2 = 0.01$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.042$).

**AB** There was no significant main effect of covert/overt for the AVGPs, $F(1, 13) = 1.87$, $p = .19$, $\eta_p^2 = 0.13$ ($BF_{10} = 0.471$), but there was a significant interaction between recruitment type and lag, $F(5, 65) = 2.30$, $p = .04$, $\eta_p^2 = 0.10$, such that the overtly recruited AVGPs performed slightly worse at the shorter lags than the covertly recruited AVGPs. The overtly/covertly AVGPs also differed in their AB magnitude, $F(1, 13) = 4.75$, $p = .05$, $\eta_2 = 0.36$, such that the overt AVGPs had slightly larger ABs, although they did not differ in AB recovery, $F(1, 13) = 2.94$, $p = .11$, $\eta_2 = 0.23$ ($BF_{10} = 1.099$). For the overt/covert NVGPs, there was no main effect of overt/covert, $F(1, 10) = 0.96$, $p = .35$, $\eta_p^2 = 0.09$ ($BF_{10} = 0.460$), nor an interaction between recruitment type and lag, $F(5, 50) = 1.04$, $p = .41$, $\eta_p^2 = 0.09$ ($BF_{10MainEffects}/BF_{10Interaction} = 3.023$). For the NVGPs, there was also no difference between overt/covert for either AB magnitude, $F(1, 11) = 0.15$, $p = .70$, $\eta_2 = 0.01$ ($BF_{10} = 0.480$), or AB recovery, $F(1, 11) < .001$, $p = 1.0$, $\eta_2 < 0.001$ ($BF_{10} = 0.457$).

**MOT** There was no significant main effect of covert/overt for the AVGPs, $F(1, 13) = 0.10$, $p = .76$, $\eta_p^2 = 0.01$ ($BF_{10} = 0.365$), nor an interaction between recruitment type and set size, $F(4, 52) = 0.73$, $p = .58$, $\eta_p^2 = 0.05$ ($BF_{10MainEffects}/BF_{10Interaction} = 4.138$). Similarly, for the overt/covert NVGPs, there was no main effect of overt/covert, $F(1, 13) = 0.16$, $p = .69$, $\eta_2 = 0.01$ ($BF_{10} = 0.310$), nor an interaction between recruitment type and set size, $F(4, 52) = 1.60$, $p = .19$, $\eta_2 = 0.11$ ($BF_{10MainEffects}/BF_{10Interaction} = 1.382$).

**UFOV** For the UFOV task, thresholds did not differ as a function of recruitment type for either the AVGPs, $F(1, 13) = 1.01$, $p = .33$, $\eta_2 = 0.08$ ($BF_{10} = 0.615$), or the NVGPs, $F(1, 13) = 0.44$, $p = .52$, $\eta_2 = 0.03$ ($BF_{10} = 0.506$).

**DSPAN** For the DPSAN task, thresholds did not differ as a function of recruitment type for either the AVGPs, $F(1, 13) = 0.01$, $p = .93$, $\eta_2 < 0.001$ ($BF_{10} = 0.443$), or the NVGPs, $F(1, 13) = 0.15$, $p = .70$, $\eta_2 = 0.01$ ($BF_{10} = 0.460$).

**OSPAN** Unlike with the DSPAN task, there was a significant difference between overt and covert OSPAN scores for both AVGPs, $F(1, 13) = 6.89$, $p = .02$, $\eta_2 = 0.53$, and NVGPs, $F(1, 11) = 5.09$, $p = .05$, $\eta_2 = 0.46$, such that overtly recruited participants had higher OSPAN scores than covertly recruited participants (24 points higher for overt AVGPs, and 18 points higher for overt NVGPs).

**N-Back** For accuracy on the N-back task, a repeated-measures ANOVA revealed no main effect of covert/overt recruitment for the AVGPs, $F(1, 13) = 2.25$, $p = .16$, $\eta_p^2 = 0.15$ ($BF_{10} = 0.420$), but there was a significant interaction between overt/covert and set size, $F(6, 78) = 2.68$, $p = .02$, $\eta_p^2 = 0.17$, such that accuracy differed between the two groups at some of the set sizes. A follow-up analysis showed that the differences between overtly and covertly recruited AVGPs were for set size 3, $F(1, 13) = 9.62$, $p = .01$, $\eta_2 = 0.75$, and set size 5, $F(1, 13) = 6.81$, $p = .02$, $\eta_2 = 0.53$, wherein overtly recruited AVGPs were 3% (set size 3) and 7% (set size 5) more accurate than covertly recruited AVGPs. For the NVGPs, a similar result emerged wherein there was no main effect of overt/covert recruitment, $F(1, 13) = 1.58$, $p = .23$, $\eta_p^2 = 0.11$ ($BF_{10} = 0.537$), but there was an interaction between recruitment type and set size, $F(6, 78) = 3.20$, $p = .01$, $\eta_p^2 = 0.15$. Although none of the individual set sizes significantly differed between the two groups for the NVGPs, the overtly

**Table 2** Means and SDs for covert/overt AVGPs and NVGPs

| Measure | AVGP-Covert *M* (*SD*) | AVGP-Overt *M* (*SD*) | NVGP-Covert *M* (*SD*) | NVGP-Overt *M* (*SD*) |
|---|---|---|---|---|
| Simple RT | 0.24 (0.05) | 0.24 (0.05) | 0.28 (0.03) | 0.25 (0.01) |
| Simple accuracy | 0.95 (0.06) | 0.98 (0.02) | 0.98 (0.02) | 0.95 (0.02) |
| Discrimination RT | 0.40 (0.08) | 0.39 (0.02) | 0.45 (0.07) | 0.51 (0.10) |
| Discrimination acc. | 0.94 (0.04) | 0.93 (0.05) | 0.95 (0.04) | 0.91 (0.04) |
| TOVA-sustained RT | 0.28 (0.04) | 0.27 (0.02) | 0.35 (0.04) | 0.32 (0.06) |
| TOVA-impulsive RT | 0.33 (0.09) | 0.28 (0.02) | 0.41 (0.07) | 0.36 (0.10) |
| TOVA-sustained acc. | 0.99 (0.02) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (.01) |
| TOVA-impulsive acc. | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.00) | 0.99 (0.02) |
| AB-lag 1 | 0.77 (0.18) | 0.64 (0.08) | 0.69 (0.13) | 0.71 (0.11) |
| AB-lag 2 | 0.93 (0.09) | 0.83 (0.08) | 0.86 (0.09) | 0.88 (0.08) |
| AB-lag 3 | 0.96 (0.05) | 0.96 (0.05) | 0.91 (0.11) | 0.86 (0.11) |
| AB-lag 4 | 0.93 (0.09) | 0.90 (0.08) | 0.97 (0.06) | 0.92 (0.10) |
| AB-lag 5 | 0.97 (0.03) | 0.99 (0.03) | 0.99 (0.03) | 0.95 (0.10) |
| AB-lag 6 | 0.99 (0.03) | 0.98 (0.03) | 0.94 (0.06) | 0.96 (0.05) |
| AB magnitude | 0.13 (0.12) | 0.25 (0.05) | 0.18 (0.11) | 0.16 (0.05) |
| AB recovery | 2.11 (1.27) | 3.17 (0.98) | 3.00 (1.55) | 3.00 (1.53) |
| MOT-set size 1 | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.00) | 1.00 (0.00) |
| MOT-set size 2 | 0.98 (0.04) | 0.93 (0.16) | 0.91 (0.15) | 1.00 (0.00) |
| MOT-set size 3 | 0.90 (0.17) | 0.90 (0.06) | 0.91 (0.10) | 0.87 (0.16) |
| MOT-set size 4 | 0.80 (0.10) | 0.85 (0.15) | 0.70 (0.16) | 0.79 (0.15) |
| MOT-set size 5 | 0.82 (0.14) | 0.75 (0.23) | 0.71 (0.11) | 0.63 (0.11) |
| UFOV threshold | 43.39 (21.74) | 52.83 (8.22) | 60.58 (30.93) | 69.17 (15.95) |
| OSPAN | 35.83 (17.70) | 60.08 (17.25) | 40.57 (15.30) | 58.92 (13.77) |
| DSPAN | 0.80 (0.15) | 0.81 (0.09) | 0.80 (0.07) | 0.82 (0.07) |
| N-back 1 RT | 0.43 (0.17) | 0.56 (0.10) | 0.65 (0.13) | 0.66 (0.13) |
| N-back 2 RT | 0.57 (0.25) | 0.66 (0.11) | 0.86 (0.25) | 0.92 (0.21) |
| N-back 3 RT | 0.68 (0.34) | 0.70 (0.12) | 0.93 (0.32) | 1.03 (0.25) |
| N-back 4 RT | 0.96 (0.56) | 0.75 (0.20) | 0.97 (0.37) | 1.13 (0.24) |
| N-back 5 RT | 1.10 (0.58) | 0.83 (0.23) | 1.10 (0.42) | 1.18 (0.41) |
| N-back 6 RT | 0.88 (0.48) | 0.79 (0.20) | 0.93 (0.43) | 1.21 (0.49) |
| N-back 7 RT | 0.93 (0.37) | 0.93 (0.18) | 1.11 (0.58) | 1.23 (0.44) |
| N-back 1 acc. | 0.98 (0.01) | 0.97 (0.03) | 0.99 (0.02) | 0.96 (0.03) |
| N-back 2 acc. | 0.99 (0.01) | 0.97 (0.03) | 0.95 (0.04) | 0.96 (0.03) |
| N-back 3 acc. | 0.96 (0.02) | 0.99 (0.01) | 0.95 (0.07) | 0.97 (0.01) |
| N-back 4 acc. | 0.89 (0.06) | 0.95 (0.05) | 0.93 (0.05) | 0.94 (0.04) |
| N-back 5 acc. | 0.87 (0.06) | 0.94 (0.05) | 0.87 (0.09) | 0.94 (0.04) |
| N-back 6 acc. | 0.80 (0.06) | 0.83 (0.08) | 0.82 (0.08) | 0.87 (0.06) |
| N-back 7 acc. | 0.78 (0.08) | 0.80 (0.05) | 0.76 (0.10) | 0.83 (0.05) |
| Switch RT | 0.93 (0.38) | 1.02 (0.16) | 1.25 (0.24) | 1.35 (0.35) |
| No-switch RT | 0.62 (0.18) | 0.65 (0.06) | 0.76 (0.18) | 0.83 (0.23) |
| Switch accuracy | 0.98 (0.03) | 0.98 (0.02) | 0.96 (0.03) | 0.99 (0.01) |
| No-switch accuracy | 0.98 (0.02) | 0.98 (0.01) | 0.96 (0.02) | 0.98 (0.01) |
| RAPM score | 9.78 (2.86) | 8.83 (2.79) | 8.13 (2.75) | 8.71 (3.04) |

recruited participants were 7% more accurate than the covertly recruited NVGPs for both set sizes 5 and 7.

For RT on the N-back task, there was no main effect of overt/covert recruitment for the AVGPs, $F(1, 13) = 0.08$, $p = .79$, $\eta_p^2 = 0.01$ ($BF_{10} = 0.481$), but there was a significant interaction between recruitment type and set size, $F(6, 78) = 2.30$, $p = .04$, $\eta_p^2 = 0.15$, wherein the overtly recruited AVGPs were slightly faster on the task than the covertly recruited AVGPs. For the NVGPs, there was no main effect of overt/covert recruitment, $F(1, 13) = 0.52$, $p = .48$, $\eta_p^2 = 0.04$ ($BF_{10} = 0.575$), nor an interaction between recruitment type and set size, $F(6, 78) = 0.78$, $p = .59$, $\eta_p^2 = 0.06$ ($BF_{10MainEffects}/BF_{10Interaction} = 5.985$).

**Task Switch** For the AVGPs, there was no main effect of overt/covert recruitment, $F(1, 13) = 0.22$, $p = .65$, $\eta_p^2 = 0.02$ ($BF_{10} = 0.480$), nor an interaction between recruitment type and trial type, $F(1, 13) = 0.37$, $p = .55$, $\eta_p^2 = 0.03$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.074$). Similarly, for the NVGPs there was no main effect of overt/covert recruitment, $F(1, 13) = 0.50$, $p = .49$, $\eta_p^2 = 0.04$ ($BF_{10} = 0.468$), nor an interaction between recruitment type and trial type, $F(1, 13) = 0.10$, $p = .76$, $\eta_p^2 = 0.01$ ($BF_{10MainEffects}/BF_{10Interaction} = 2.254$).

**RAPM** For this task, scores did not differ as a function of recruitment type for either the AVGPs, $F(1, 13) = 0.40$, $p = .54$, $\eta_2 = 0.03$ ($BF_{10} = 0.505$), or the NVGPs, $F(1, 13) = 0.10$, $p = .76$, $\eta_2 = 0.01$ ($BF_{10} = 0.461$).

## Discussion

### AVGPs vs NVGPs

Previous literature has demonstrated that individuals who play video games, particularly action video games, show superior performance to non-gamers on various measures of cognitive performance. Specifically, AVGPs have been reported to have faster processing speed (Castel et al. 2005; Dye et al. 2009a; Green and Bavelier 2008; Griffith et al. 1983), better spatial attention (Greenfield 2014; Subrahmanyam and Greenfield 1994), better performance on attention tasks like the TOVA (Dye et al. 2009b), UFOV (Feng et al. 2007; Green and Bavelier 2003, 2006), MOT (Boot et al. 2008; Green and Bavelier 2006), and AB (Green and Bavelier 2003), and better control over the deployment of attentional resources on a task-switching paradigm (Boot et al. 2008; Colzato et al. 2010, 2013a; Green et al. 2012). However, the literature for whether or not action gamers have better working memory, or fluid intelligence, is decidedly mixed, with some studies showing greater working memory capacity in action gamers as compared to non-gamers (Colzato et al. 2013b), whereas others show little-to-no differences in various measures of working memory (Boot et al. 2008; McDermott et al. 2014). Similarly, some recent studies have demonstrated that fluid intelligence, as measured by the RAPM, is susceptible to training (Jaeggi et al. 2008), whereas others have found no such effect (Redick et al. 2013). Our first goal was to both replicate previous findings, and to explore some of the discrepancies in the literature. We created a large task battery that tapped into various aspects of cognition (i.e., reaction time, selective attention, memory, executive control, and fluid intelligence) in order to allow us to systematically examine the tasks that differ (and do not differ) between action gamers and non-gamers.

On the whole, our findings closely matched those that have been reported in the past. AVGPs were significantly faster than NVGPs on not only the “pure” RT tasks, but also showed generally faster RTs on the N-back working memory task, the TOVA, and the task-switching paradigm. Given the importance of hand-eye coordination in playing fast-paced action games, this finding was expected, and was fully in line with that of several groups who have consistently shown that regularly playing AVGs is associated with faster processing speed (Castel et al. 2005; Dye et al. 2009a; Gagnon 1985; Green and Bavelier 2008; Griffith et al. 1983). This general effect can be seen in the Brinley plot (see Fig. 6), wherein AVGP RT in every RT task condition is plotted against NVGP RT for the same conditions. Consistent with findings by Dye et al. (2009a), there is a clear linear trend wherein AVGPs are faster by a proportional amount relative to NVGPs (Fig. 6).

In the attention domain, the results were mainly consistent with previous literature. First, AVGPs were significantly faster than NVGPs on both the impulsivity and the sustained blocks of the TOVA task but, critically, did not differ from NVGPs in their accuracy. This suggests that while AVGPs are faster on the task than NVGPs, they are not more impulsive, replicating the finding of Dye et al. (2009a). For the UFOV, we also found that AVGPs had significantly faster detection thresholds than NVGPs, indicating that AVGPs require less time to process a given display, and thus can more rapidly extract and process pertinent information from their environment. This replicates the findings of a number of researchers who have consistently shown that not only do AVGPs require shorter presentation durations than NVGPs on this task (Feng et al. 2007; Green and Bavelier 2003, 2006), but also that training non-gamers on AVGs can actually reduce UFOV thresholds (Green and Bavelier 2003, 2006).

For the MOT task, we expected that AVGPs would have significantly higher accuracy than NVGPs, particularly at the larger set sizes. While AVGPs were not more accurate than NVGPs overall, we did find significant differences between the two groups at the most difficult set size (5), suggesting that gamers are better able to track multiple moving objects across space and time than NVGPs. Given that most action games require participants to attend to a rapidly changing environment that contains critical information both centrally and in the periphery, it follows that avid gamers may have developed the ability to attend to, and track, multiple areas of a given space simultaneously. Again, this finding largely replicated what has previously been reported in the literature (Green and Bavelier 2006).

Contrary to our predictions, we were unable to find a difference between AVGPs and NVGPs in the actual magnitude

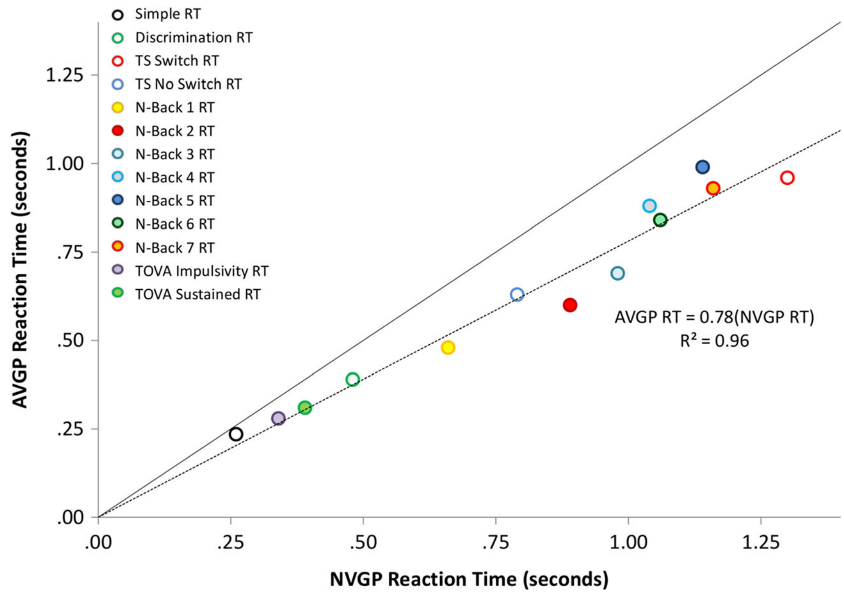


**Fig. 6** Brinley plot with mean reaction time (RT) in seconds of non-video game players (NVGPs) on the *X*-axis and action video game players (AVGPs) on the *Y*-axis for 13 different tasks/variables. For each experimental condition, the RTs of VGPs and NVGPs were retrieved and plotted as one separate data point. The *dashed line* represents the best fit using the equation AVGP RT = 0.78 * NVGP RT)

of the AB in the AB task, or on a measure of AB recovery. This finding is in contrast to that of Green and Bavelier (2003), who showed that while the actual AB itself was not attenuated in gamers, gamers showed a better recovery. This discrepancy between our results and previously published results may, in part, be due to the picture-based, 2-AFC task that we used here. The vast majority of our participants recovered relatively early from the AB, whereas there was more variation in recovery in Green and Bavelier (2003), possibly due to their use of the more traditional version of the AB task (Raymond et al. 1992). Indeed, the original intent underlying the design of this AB version was for it to be useful for both children and adults, but the desire to capture this broader range may have resulted in a restricted range of high performance in adults.

Lastly, we found large RT differences between AVGPs and NVGPs on both switch and no-switch trials for the task-switching paradigm, demonstrating the superior processing speed of AVGPs. Interestingly, though, we also showed that AVGPs had fewer switch costs than NVGPs, demonstrating that not only are AVGPs faster in general, but they are also better able to reset their cognitive template during a task switch, and were thus less susceptible than NVGPs to this switch. This, again, was in line with previous literature that has shown that avid gamers are better at task-switching than non-gamers (Colzato et al. 2010, 2013a; Green et al. 2012; Karle et al. 2010).

While AVGPs performed significantly better than NVGPs on the majority of the tasks, this was not true in all cases. Namely, there were virtually no differences between AVGPs and NVGPs on our three working memory tasks (except for RT in the N-back). This suggests that, at least on tasks of working memory, action gaming is not associated with better performance, replicating the findings of both Boot et al. (2008) and McDermott et al. (2014). Given that action games typically do not require gamers to store items in the working memory for any significant length of time, these types of games may not tax working memory thereby leading to no improvements in this process. In addition to working memory, scores on the RAPM did not differ between the two groups.

Overall, therefore, our findings were largely in compliance with the larger body of literature, such that AVGPs were shown to have better performance than NVGPs on a variety of measures, across a variety of processes, suggesting that regularly playing AVGs is associated with superior cognitive abilities and faster speed of processing.

### Real-Time Strategy Gamers

Given that our task battery produced results that replicated the existing literature comparing AVGPs with NVGPs, our next interest was in examining how real-time strategy gamers compared to NVGPs. While strategy gamers have typically been excluded completely, or erroneously lumped into the NVGP category, recent evidence has shown that individuals who were trained on SVGs receive cognitive benefits that are similar in size and scope to those seen with AVG training (Basak et al. 2008; Glass et al. 2013). Additionally, in the past decade, the AVG and SVG genres have become less distinguishable, such that a significant number of "action" elements are now incorporated into most SVG games (e.g., StarCraft II). As such, we were interested in examining how existing SVGPs compare to NVGPs.

In terms of reaction time, for the most part the SVGPs were numerically faster than the NVGPs, although these effects did not always reach the level of statistical significance. The SVGPs were likewise typically statistically indistinguishable from the AVGPs (see Supplemental Information), although their numerical performance was often slightly worse (slower) than the AVGPs. This particular pattern of results suggests that playing strategy games may also be associated with increased processing speed, but that this advantage was slightly smaller than is typically seen in AVGPs. Given that SVGs contain many of the same action components as AVGs, although to a slightly lesser extent, it is possible that exposure to fast-paced game content wherein the player must rapidly process and respond to incoming threats is associated with faster processing speed. However, given the reasonably small sample size (and the potentially associated fact that not all effects reached statistical significance), these results will need to be replicated in a larger sample. We did not find an advantage for SVGPs over NVGPs for several other tasks, however, including the AB, MOT, task-switching, and the UFOV, despite finding AVGP/NVGP differences on those same tasks.

Interestingly, on the UFOV task the SVGPs were significantly worse than the AVGPs, and numerically had the highest thresholds of all the groups (although this was not statistically significant). It is unclear why this group would have had the highest thresholds on this task, but it is possible that some aspect of playing strategy games trains a more narrowed focus of attention. For example, in *StarCraft II*, players have multiple items on which to focus, but generally tend to focus on one task at a time in a specific order, whereas in action games like *Call of Duty*, players must constantly scan their surroundings for enemies and avoid "tunnel vision," as this often leads to deaths in the game (i.e., people can sneak up on you, or attack from unexpected directions). This could naturally lead to SVGPs having difficulties with tasks that measure attentional breadth, while simultaneously showing superior performance on visual search paradigms, as has previously been reported (Glass et al. 2013).

In support for this hypothesis, we also found that SVGPs had numerically lower accuracy than all other groups at set size 5 on the MOT task. Given that the MOT requires that attention be divided across several areas, it would follow that if SVGPs have difficulty dividing or diffusing their attention that they should also perform poorly on this task. Our sample of pure SVGPs was rather small, and cross-sectional in nature, thus a larger sample, a dedicated training design, and a more detailed analysis of the mechanics of the strategy games played, would be necessary in order to conclude that playing SVGPs may have negative effects on attentional breadth (or, conversely, lead to an increase in focused attention), but the data do seem to support this hypothesis.

### Role of "Tweeners"

Lastly, we were interested in examining how "Tweeners"—individuals who fit in none of the three categories of gamers above—compared to those groups. Tweeners are typically excluded from video game research studies for a number of reasons, but they are particularly problematic because their game play experience is far less homogenous than pure-genre gamers, making it difficult to determine what is driving any differences in cognitive performance that we may see. For example, Tweeners tend to play different mixtures of games and genres for varying amounts of time and with varying skill, they are not consistently exposed to the same game mechanisms (i.e., some gamers may focus on action-type games across genres, whereas others may lean more toward strategy, puzzle, or role-playing games), and they may play multiple genres that have influences that "cancel" each other out. However, Tweeners are by far the most common, and most easily found, participants; thus, it is important to understand how this type of gamer compares to both genre-pure gamers and non-gamers. Given the numerous changes over the past decade to both the games that are on the market, and to the ways in which gamers now play, it is becoming increasingly difficult to find and recruit appropriate genre-pure gamers. As such, our final goal was to examine whether these "Tweeners" also show enhanced cognitive performance as compared to non-gamers, and whether these advantages, if they exist, are comparable to those seen with genre-pure gamers.

Ultimately, and perhaps not surprisingly, the performance of the Tweeners largely fell in-between that of the AVGPs and the NVGPs (tending to be slower/less accurate than AVGPs and faster/more accurate than NVGPs; often not significantly different from either). Studies with larger sample sizes, and that employ a causal (training) design, are definitely necessary in the future, but the data suggest that, at the very least, general video game play is associated with enhanced processing speed.

### Effect of Recruitment

While not a primary objective of the current study, we also examined whether there was an effect of recruitment on the results. Some authors have expressed concerns that overt recruitment strategies may produce differences in performance due to expectation effects (e.g., Boot et al. 2011, 2013). For example, AVGPs may believe that they are expected to perform better and may alter their performance in an attempt to match this expectation, while NVGPs may believe that they are expected to perform worse, and thus may not try as hard as they normally would. Given that we had an almost equal mix of overtly and covertly recruited AVGPs and NVGPs, we decided to examine this possibility.

In general, we did not find evidence that expectation effects played a role in our results, although there were some significant effects. For example, the overtly recruited NVGPs were slightly faster than covertly recruited NVGPs on the simple RT task (although this would run counter to the prediction of the authors cited above). We also found that overtly recruited AVGPs were slightly worse on the AB task than covertly recruited participants (again, in the opposite direction of the prediction given by previous critiques of the literature), and slightly faster than covertly recruited participants on the N-back task. Also, for both the AVGPs and the NVGPs, overtly recruited participants were slightly more accurate on the N-back task, and had higher OSPAN scores than their covertly recruited counterparts. In both cases, the effect was in the same direction and of similar magnitudes; thus, it likely did not influence the overall results (noting that performance on these tasks did not differ between AVGPs and NVGPs, regardless). As this was not a primary goal of the study, and given the small sample sizes, these effects (or lack thereof) should be interpreted with caution. This is particularly true given that a recent meta-analysis has shown that expectation effects may indeed influence the data to some extent, but the magnitude of these effects may make them difficult to detect in a single study (Bediou et al. under review). As such, we cannot rule out the possibility that expectation effects may have played a role in the differences seen here between gamers and non-gamers.

### Future Directions, Limitations, and Conclusions

To summarize, we have replicated the majority of the findings to date showing that AVGPs outperform NVGPs on a wide variety of cognitive tasks, although the two groups do not differ in their memory performance or their fluid intelligence. We have also demonstrated, for the first time, that SVGPs show an advantage over NVGPs on several of the same reaction time tasks as do AVGPs, although these findings did not always reach the level of statistical significance and the AVGPs, for the most part, still showed superior performance to all other gamer groups. Interestingly, not only did the SVGPs perform similarly to the NVGPs on most of the non-speeded tasks; numerically, the SVGPs actually showed the poorest performance of all groups on some measures of attentional breadth. This finding was somewhat unexpected and bears further investigation. Lastly, we demonstrated that multi-genre gamers perform similarly to genre-pure gamers (and better than NVGPs) on several reaction time tasks.

These findings have several implications for game studies going forward. First, given the similarity in performance between the AVGPs and SVGPs in some domains, particularly on tasks that required speeded responses, more research is needed on the effects of playing games from the strategy genre. In particular, we need to better understand how training on AVGPs and SVGPs can lead to both similar, and dissimilar, benefits/drawbacks, as this may help us understand the precise game mechanisms that lead to changes in cognitive performance in training studies. Given the cross-sectional nature of the current study, and the reasonably small sample, no firm conclusions can currently be drawn regarding whether dedicated game training can enhance (or impair) cognitive processing, but the evidence suggests that regular players of both genres show similar performance on RT tasks, but dissimilar performance on other cognitive measures such as tasks of attentional breadth and cognitive control/flexibility.

The similarities in performance between AVGPs and SVGPs on several (but not all) of our speeded tasks also suggest that we should reconsider our genre-based classifications of games. If AVGPs and SVGPs perform similarly on certain cognitive tasks while both differing from non-gamers, and the AVGP/SVGP games themselves show considerable overlap with respect to game mechanisms, then it may no longer be useful to separate gamers based on these traditional classification schemes. At the very least, researchers should be extremely cautious of inadvertently lumping SVGPs into the non-action gamer category, as these individuals clearly perform similarly to action gamers, and differently than non-gamers, on some cognitive tasks. An additional concern is with the recent emergence of the MOBA/ARTS genre. Because our current disposition is that these games have more in common with RTS games, we included the few individuals who played a MOBA in our SVGP category. However, these games share several similarities with action games as well. As such, additional research is needed in order to better understand where these MOBA gamers fit, especially given the proliferation of this genre in recent years with the introduction of popular games like *DotA* and *League of Legends*.

Lastly, the fact that the performance of the Tweeners on many of the tasks presented herein was somewhat numerically worse than the genre-pure gamers on certain tasks, and somewhat numerically better than the non-gamers on certain tasks, is of particular interest. Tweeners make up the vast majority of gamers in a given sample, yet they are generally discarded. Given that these gamers differ (albeit not statistically, in most cases) from non-gamers on some cognitive tasks, they should be studied further, particularly as this gamer category is far more representative of the general gamer population than the genre-pure gamers. While no firm conclusions can be drawn here given the cross-sectional nature of the current study, future researchers could create a training study that separates Tweeners based on their game-play style (e.g., majority action games, majority puzzle games, majority adventure games, etc.) to examine whether this is associated with their cognitive performance. Doing so will require better measures of game play habits than those that we currently have available. Indeed, one recent empirical investigation (Green et al. 2017) found that those individuals who reported playing multiple genres tended to overestimate the amount of time they spent playing video games overall. As a result of these issues, understanding the cognitive abilities of Tweeners, and the beneficial effects of multi-genre game play, may require more sophisticated methods to assess game play habits than simple questionnaires, such as daily journal entries or directly monitoring game play.

There were several limitations to this study that could have potentially influenced the results, beyond those related to classifying Tweeners discussed above. Of particular note, this study was cross-sectional in nature. As such, while we are able to study the differences in cognitive performance between our gamer groups, and whether gamers differ from non-gamers, we are unable to directly investigate the causal effects of playing video games. Indeed, only a dedicated training study in which non-gamers are trained on SVGs, or on multiple game genres, could definitively show whether playing SVGs, or games in general, can enhance cognitive processing. However, the findings in this study were largely consistent with several of the intervention studies that have been conducted to-date (e.g., Gagnon 1985; Green and Bavelier 2003, 2006; Green et al. 2012; Oei and Patterson 2013; Strobach et al. 2012). They thus suggest that there would be value in continued intervention studies examining the causal impact of playing strategy games (Glass et al. 2013; Basak et al. 2008).

Another significant limitation was the small sample sizes of our groups. This was largely due to our stringent classification criteria but was also due to the fact that the pool of university students who qualify as genre-pure gamers is extremely small. Furthermore, anecdotally, we have observed that this already-small pool of genre-pure gamers is shrinking over time, with more and more individuals instead meeting the classification of "Tweener" due to multi-genre game play. As such, it is becoming increasingly difficult to perform cross-sectional studies on genre-pure gamers. Future work may need to use either online recruitment strategies, or recruit across multiple institutions, in order to obtain larger samples of genre-pure gamers.

Finally, as is the case in all studies employing large batteries of tasks, we are not able to examine the impact of task order on performance (although we have no a priori reason to suspect that the task order that was chosen would favor/disfavor any of the groups at hand; and indeed, participants were given ample opportunity for breaks in between tasks to, at a minimum, reduce the potential impact of cognitive fatigue). Given the sheer number of unique orders, a fully-intermixed design will likely never be possible. However, future work could potentially utilize a smaller subset of orders (perhaps two—with tasks measuring similar constructs placed in discriminative positions within these two orders) to begin to address the issue.

Overall, this study was the first to systematically examine both SVGPs and Tweeners, and how the cognitive performance of these two gamer groups compares to that of both AVGPs and non-gamers. Our results show promise for future studies of gamers of other, often overlooked, genres, and provide a foundation for training studies that use a causal design. Our findings also suggest that future research should perhaps begin moving away from genre-based classifications. The AVGPs and SVGPs performed similarly on several tasks of processing speed, but differed on tasks of cognitive control and attentional breadth. Given the increasing overlap between the two categories of games, it seems likely that these two genres are no longer entirely distinct from one another, and thus may lead to similar benefits on certain cognitive tasks. As such, simply categorizing them as completely separate genres may not be as useful as once thought. Therefore, the field should attempt to begin moving toward understanding of the actual in-game mechanisms that may lead to differences in cognitive processing.

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