**INTRODUCTION**

Video games have become increasingly popular in the United States, with recent reports estimating that 91% of children aged 2-17 play video games (NPD Group, 2011), and that 97% of adolescents play for at least one hour per day (Granic, Lobel, & Engels, 2014). Video games have grown into a profitable industry forecasted to reach just under 100 billion dollars in 2018 (DFC Intelligence, 2014). The popularity and prevalence of video games is no longer uncertain, and many researchers have found evidence that they have benefits beyond entertainment. Green and Bavelier (2003) were among the first to suggest that video game play could result in attentional benefits for players, and others have furthered their work in exploring the cognitive and attentional benefits concomitant with expert video game skill and performance (Boot et al., 2008; Cain et al., 2012; Castel et al., 2005; Dye et al., 2009; & Glass et al., 2013). Although the generalizability of these cognitive and attentional benefits have been contested (Irons et al., 2011; Sims & Mayer, 2002), video games have been implicated with benefits in other domains, such as improving surgeon skill (Rosser et al., 2007; Schlickum et al., 2009), organizational security training (Cone et al., 2006), and military flight training (Lintern & Kennedy, 1984). Lewis and colleagues (2011) have suggested that expert performance in real-time strategy games could be relevant and transferable to real-world domains such as military strategy, air traffic control, and disaster management.

At their core, many video games could be considered complex perceptual and cognitive testing grounds which challenge the abilities of players. Given the ubiquity of video games in everyday life and the potential transferable benefits video game play has for players, a better understanding of the factors that influence game performance merits scientific investigation.

The present study investigated a computer-based video game, StarCraft II (SC2; Blizzard Entertainment, 2010), which is a fast-paced, cognitively demanding Real-Time Strategy game (RTS). Like chess, this game is played in a one-versus-one format, but requires the management of multiple tasks simultaneously. Each player assumes full control of an economy with structures, units, and resources which must be developed into an army that can destroy an opponent’s army. Integral to expert performance is the management of two major tasks – macromanagement and micromanagement. Players must manage their economy from a broad standpoint while also attending to small-scale skirmishes and battles between armies. With the exception of resource collection, nothing is automated. Triumphing over one’s opponent requires extensive physical and cognitive effort from the player. Not only must players execute rapid and efficient mouse and keyboard commands, they must generally be faster than their opponent, more cunning, and better at managing their military units and economy to be successful. Thompson and colleagues (2013) have discovered several in-game performance metrics (such as actions-per-minute) that determine whether or not someone will win a match in SC2. We argue that playing SC2 engages diverse aspects of cognition, and we believe that studying it offers a unique opportunity to better understand factors that influence performance in complex tasks. The purpose of the present study is to expand on prior work and investigate other variables which may influence game performance, such as usability, ergonomics, and individual differences.

**Multitasking**

Multitasking can be defined as the maintenance of multiple tasks simultaneously. This act is a result of a variety of cognitive functions, such as executive function, attentional control, and working memory (Morgan et al., 2013; Sanbonmatsu et al., 2013). Humans have a very limited ability to multitask, but can still rapidly switch between tasks to attempt concurrent completion of multiple actions (Lien et al., 2006; Wickens, 2002). Ophir and colleagues (2009) developed an individual difference measure of multitasking that identifies those who are high or low media multitaskers. This serves as the standard measure of everyday multitasking (Alzahabi & Becker, 2013; Sanbonmatsu et al., 2013). Recent findings have indicated this measure to be related to increased multi-tasking ability (Hambrick et al., 2010). However, researchers have found those that engage in general media multitasking tend to have lower working memory capacity (Sanbonmatsu et al., 2013; Ophir et al., 2009). In light of these opposing findings, we aimed to evaluate the relationship between media multitasking and SC2 performance metrics, due to the multitask nature of the game.
**Personality**

Regarding the Five Factor Model (McCrae & Costa, 1987), many researchers have found evidence that extraversion is related to cognitive task performance in many ways. Extraverts tend to show decrements for sustained attention (Matthews, 1997), but show advantages for multitasking ability (Lieberman & Rosenthal, 2001; Szymura & Necka, 1998), faster response times (Szalma, 2008), and short term memory performance (Matthews, 1997; Szalma, 2008). Because SC2 performance incorporates many of these aspects of cognition, we believe it is important to examine how extraversion may relate to game performance.

Some work has also identified a link between cognitive tasks and neuroticism (e.g., Neurotics tend to become stressed when coping with task difficulty), although many of the results depend on characteristics of the task, such as difficulty or stimulus type (Szalma, 2008). Because of the cognitively demanding nature of SC2, we included a measure of personality to assess the degree to which personality traits relate to game performance.

**Usability**

Another aspect we hypothesized to be related to game performance is usability. Kortum and Peres (2014) suggest a relationship could exist between subjective assessment of usability and performance. Nielsen and Norman (2015) affirmed this assertion and suggested that usability is correlated with performance. Specifically, increased performance was related to increased usability satisfaction. Logically, one might also expect usability problems to therefore hinder performance.

We have also identified several usability issues in SC2. The game is designed such that it is played with one’s left hand on the keyboard and one’s right hand on the mouse. This works for most actions a player needs to execute in the game, but sometimes there are ergonomic problems. For example, gameplay in SC2 involves the use of “hotkeys,” or keys that must be pressed to perform certain actions in the game. The same kinds of commands can be initiated through mouse-clicks, but pressing hotkeys allows the user to execute actions much more efficiently. Many of these hotkeys are in reachable positions, but some keys are located across the keyboard, making some difficult to reach (e.g., “P” is far for the left hand to reach). Alternatively, mouse-clicking the same hotkeys on the screen may involve less movement of one hand but may actually be less efficient. Other factors that may affect usability and gameplay include ergonomic aspects of gameplay, such as the type of keyboard and mouse used. For example, gaming keyboards typically have quicker input rates and allow users to execute key commands more rapidly. The degree to which keyboard type (and other peripheral device usage) influences gameplay performance is a topic that has received some attention in social media (see Daskeyboard, 2014), but to date there is no scientific evidence to substantiate any effects on performance.

In order to assess whether or not usability affects performance in SC2, we adapted usability questionnaires to relate to SC2. Lund (2001) created a general usability questionnaire with questions worded broadly enough that they can be used for gaming as well as other domains. Another usability measure is Nielsen’s Heuristic Evaluation, which is similar in focus to Lund’s scale with phrases specifically geared to assess system usability (Nielsen, 1994).

**THE CURRENT RESEARCH**

The overarching goal of this study was to determine to what extent multitasking tendencies, individual differences and user preferences are related to in-game performance. By examining these factors with SC2 performance data, we can better understand how they influence game performance. Specifically, we hypothesized that people higher in media multitasking would show greater scores on performance metrics. Due to the complex nature of SC2 and the diversity of findings for personality and task performance, we hypothesized that extraversion and neuroticism would also be related to game performance. Additionally, because usability factors can influence game performance, we expected those who perceived the game as being less usable would show lower performance scores, whereas those who have taken the steps to improve the usability of the game for them (be it through in-game settings or use of peripheral input devices) would show greater performance scores.

**METHOD**

**Participants**

There were 104 adults from a variety of countries recruited for this study. Of the participants who started the study, 75 responded to every item of the survey. Of those who completed all items, 51 participants submitted a replay file. Participants ranged from 18-33 years old and were all experienced SC2 players. All but four participants were male, 55% were Caucasian, 10% were Asian, 6% were Hispanic, and 6% reported their ethnicity as “Other.” Participants also came from a wide variety of nations: 38% were from the United States, 10% were from Germany, 9% were from Sweden, 8% were from Canada, and 7% were from England, with the remaining participants from other countries in Europe, Asia, and South America. Sixty-five percent of participants reported that they used a laser mouse when playing (the other 35% reported using an optical mouse), 63% of participants said that they used a gaming keyboard, and 29% of participants said that they used sound-cancelling head-phones. On a scale from 1 to 7, mean extraversion and neuroticism scores were 3.42 ($SD=1.63$) and 1.95 ($SD=1.26$) respectively. There was no compensation for participation, and mean participation time was roughly 18 minutes.

**Materials**

*Personality.* The Ten-Item Personality Inventory (TIPI; Gosling et al., 2003) is a brief and reliable measure of personality aligned with the Five-Factor Model of personality. This measure was selected to reduce time needed for participation.

*Multitasking.* Participants also provided a self-report of their multitasking behavior with the Media Multitasking Index (MMI; Ophir et al., 2009). This measure consists of 24 items focused on media multitasking, which assess the extent to
which one engages in a specific type of media while concurrently engaging in other types of media. For example, someone who watches TV while listening to music and playing video games would be a high media multitasker. In essence, this scale provides a glimpse into the degree to which one is or is not a multitasker.

**Usability and ergonomics.** Participants were asked several questions about usability and ergonomics based on standardized usability scales and SC2 game settings. Nielsen’s (1994) usability heuristics and Lund’s (2001) usability self-report measure were adapted with minor modifications to be more relevant for SC2. Participants reported the degree to which they agreed or disagreed with several statements (e.g., “How frequently do you feel like there are too many things to remember while playing SC2?”). We then asked several questions based on game settings which users could select to improve the usability of SC2 (e.g., “How many custom hotkeys have you created?”). We also identified participants’ peripheral equipment choices (e.g., gaming keyboards, sound-cancelling headphones, laser mice) to assess the degree to which they have made ergonomic changes to their gameplay experience.

**Replay data.** In addition to answering the previous sets of questions, we requested participants to upload game replay files to be analyzed. These replay files are text-based records of a match between players which can be reconstructed in visual form or as a set of data. These files contain every user input and action committed during the game session.

**Procedure**

The participants were recruited through a variety of online sites and forums such as Reddit and Battle.net. Participants received a survey link to participate in the study. Once they provided consent, they were requested to upload a replay file of their strongest SC2 performance, and provide their SC2 account name so that it would be possible to match their replay file to their self-report responses. After uploading their replay the participants continued to the survey consisting of the aforementioned measures which were presented in the following order: TIP1, user preferences and settings questions, MM1, and finally, our modified usability perceptions questionnaire.

**RESULTS**

Replay files were analyzed with SC2Gears (Belicza, 2015), which is an open-source replay analysis software for SC2. This software allows replay data to be analyzed and provides several data points of the player’s performance. The data from these replays were extracted and appended to the participants’ self-report data. Once survey and replay data were linked, data was anonymized. Analyses were performed only on the data of the 51 participants who responded to survey self-reports and uploaded a replay. All analyses were performed with SPSS statistics version 22.0 (IBM, 2013).

In order to assess more representative categories of player performance, we created several composite variables based on their relevant component performance metrics as described in the SC2gears user manual. Since the replays were all of various durations, all of these component performance metrics were equalized for every player’s replay duration. For example, by dividing each player’s quantity of right-clicks by the duration of their replay, the resulting variable provides right-clicks per minute, which can more easily be compared across participants. Because no two replays are alike, it is necessary to standardize the performance metrics to enable us to judge performance across participants. Once the component variables had been equalized for time, they were converted into standardized units so that they could be combined into one representative composite variable. The resulting composite variables were: Macro Score, Micro Score, and Redundancy Score. Macro Score represents all macromanagement actions the player executes during the game (e.g., allocating resources, managing economy); Micro Score represents all micromanagement actions the player executes during the game (e.g., initiating movement and attack commands, right clicking, unit selecting); and Redundancy Score represents all actions performed which the replay analysis software classifies as redundant (e.g., inputting an identical request multiple times very quickly). Finally, because redundant actions are a component of some micromanagement actions (e.g., all right clicks are considered micromanagement actions; even redundant ones), a Corrected Micro Score was computed by subtracting the redundant actions from micromanagement actions. In essence, this score provides an estimate of players’ efficient micromanagement.

Because these analyses were conducted with a relatively small sample size, data were screened for outliers which might artificially inflate or suppress results. Screening identified only one extreme case, whose Macro Score was over 4.5 standard deviations above the mean for the entire sample. Their replay file was exceptionally short in duration, and since scores were computed with respect to replay time, their scores were disproportionately higher. No other extreme cases were identified, and this outlier was excluded from analyses.

Several multiple regressions were performed with self-reports of individual differences, user game settings, peripheral equipment use, usability perceptions and individual difference self-reports predicting behavioral data retrieved from replay analysis. Variables were entered using the forward method in order to identify which predictors accounted for the greatest share of variance in the outcome variable. Due to small sample size, predictor variables were selected which had significant zero-order correlations with the criterion score variables. This was done to minimize statistical over-prediction associated with a poor ratio of cases to predictors. Assumptions for independence of errors, absence of outliers in the solution, multicollinearity and singularity were satisfied. Further, regression residuals were screened for the assumptions of normality, linearity, and homoscedasticity, and were also satisfactory.

The multiple regression analysis on Macro Score was significant, $F(5, 43) = 7.759, p < .0005, R^2 = .47, R^2_{adj} = .41$, with number of custom hotkeys and media multitasking being significant positive predictors, and neuroticism, extraversion, and “feeling like there is too much to remember while playing” as significant negative predictors (see Table 1). Post-hoc analyses revealed that, although extraversion was a significant negative predictor for macro actions, the zero-order correlation was not significant for this specific variable ($p = .28$), thus, extraversion only predicted residual variance in micromanagement actions.
The multiple regression analysis on Micro Score was also significant, $F(2, 46) = 21.038$, $p < .0005$, $R^2 = .54$, $R^2_{adj} = .50$, where number of custom hotkeys, use of a gaming keyboard, and media multitasking were significant positive predictors, whereas “feeling like there is too much to remember while playing” was a significant negative predictor (see Table 2).

<table>
<thead>
<tr>
<th>Predictors</th>
<th>β</th>
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<th>p</th>
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<tbody>
<tr>
<td>No. of custom hotkeys</td>
<td>.440</td>
<td>3.88</td>
<td>&lt; .001</td>
</tr>
<tr>
<td>Neuroticism</td>
<td>-326</td>
<td>-2.89</td>
<td>.006</td>
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<tr>
<td>Media multitasking</td>
<td>.333</td>
<td>2.92</td>
<td>.006</td>
</tr>
<tr>
<td>“Too much to remember”</td>
<td>-.256</td>
<td>-2.24</td>
<td>.030</td>
</tr>
<tr>
<td>Extraversion</td>
<td>-.297</td>
<td>-2.58</td>
<td>.013</td>
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The multiple regression analysis on Redundancy Score was also significant, $F(2, 46) = 19.947$, $p < .0005$, $R^2 = .65$, $R^2_{adj} = .61$, where number of custom hotkeys, use of a gaming keyboard, and media multitasking were significant positive predictors, whereas “feeling like there is too much to remember while playing” was a significant negative predictor (see Table 2).

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Lastly, multiple regression analysis on Corrected Micro Score was significant, $F(4, 44) = 19.103$, $p < .0005$, $R^2 = .64$, $R^2_{adj} = .60$, with number of custom hotkeys and media multitasking as positive predictors, and neuroticism and “feeling like there is too much to remember while playing” as negative predictors (see Table 4).

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<td>&lt; .001</td>
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<tr>
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DISCUSSION

Individual Differences

Because Thompson and colleagues (2008) discovered that actions per minute are one of the most important factors that predict whether or not a player will win a SC2 match, our results are interpreted under the assumption that a greater level of macro- and micromanagement actions indicate a higher level of performance, whereas a greater level of redundant actions indicate a lower level of performance.

These results mirror previous findings indicating that neuroticism affects task performance (e.g., Szalma, 2008). Specifically, our results seem to suggest that people lower in neuroticism are more likely to show greater performance for macro-management and efficient micromanagement actions, but those higher in neuroticism are more likely to commit redundant actions. Because neurotics tend to become stressed when coping with difficult tasks (Szalma, 2008), we suggest that greater redundancy could be a behavioral manifestation of a player’s stress response to the game. Surprisingly, extraversion was not generally found to relate to game performance, as post-hoc tests revealed that it only predicted residual variance for one measure of performance. Additionally, media multitasking was a significant positive predictor in all of our analyses. This could suggest that those who more frequently multitask show better game performance, but it should be noted that this variable was a positive predictor for redundant actions as well. This might indicate that the performance benefits associated with the trait of multitasking come at the cost of decreased efficiency.

Usability and Ergonomics

Number of custom hotkeys was another consistent positive predictor for all performance metrics, except for redundant actions. This suggests that players benefit from changing some of the default hotkeys to custom values. Although we did not ask which specific hotkeys had been changed, this could be a reflection of some of the finger reach issues noted in the introduction (e.g., players changing hotkeys to easier-to-reach positions on the keyboard).

Regarding peripheral input devices, use of a gaming keyboard was the only device which was significantly related to performance. Those who reported that they used gaming keyboards had higher levels of micro actions and redundant actions. It should be noted that this relationship does not emerge for corrected micro actions, which suggests that the benefits of gaming keyboards may be questionable for performance. It is also possible that they simply increase a user’s speed to input commands without offering any efficient performance benefit. It is also possible that there is a fundamental motivational difference in those who use gaming keyboards and those who do not. Such a difference may also lead to performance differences in those who use gaming keyboards.

Finally, the only self-reported usability metric which was consistently predictive of performance was whether players felt there was “too much to remember while playing SC2.” This is a question from Lund’s (2001) modified scale, which assesses a cognitive aspect of usability. The results suggest that players who feel cognitive pressure during gameplay show lower levels of performance. Since SC2 is such a cognitively demanding game, it is reasonable that people who face cognitive difficulty while playing would see a decrease in performance.

Limitations and Future Work

The primary limitation of this study is sample size. Larger samples may be better able to detect smaller effects for which we may have had insufficient statistical power. Although the final analysis sample was around 50 and relied on self-reported
data, it should be noted that the effects we found were sizable, generally consistent across performance metrics, and did not deviate much from previous work. If anything, these results indicate promise for future research with individual differences, perceptions of usability, and video game performance in SC2 as well as other games with varying levels of cognitive demand.

Another limitation was that we only requested one replay file from participants. This could have biased their behavioral data toward maximal (as opposed to typical) performance. Future research may seek to analyze multiple replays from participants to better assess typical performance. However, it is still notable that sizable effects emerge with only one behavioral snapshot for each player. One additional concern regarding this requirement is that it may have deterred participants from volunteering if they did not have a replay they wanted to submit, or if they did not wish to submit a file containing their game account name.

An interesting question for future research to answer is “why” players make changes to their game. Gaming keyboards and custom hotkeys had an effect on performance, but we do not know whether players change these aspects of their game because they are aware that it will improve their performance, or for a non-performance related reason. For example, players who are simply more experienced may be more likely to change these game settings. It is also possible that customizing one’s game settings makes the game “fit” the player better, leading to improved usability and performance. Future work should examine such metacognitive aspects in human-computer interaction contexts to more fully investigate this topic.

REFERENCES


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