Can Game Design Be Leveraged to Enhance Cognitive Adaptability?

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Abstract: Adaptability is a metacompetency critically important to the United States Department of Defense and is considered a key component of 21st Century skills by the U.S. Department of Labor and the U.S. Department of Education). Video games are seen as learning environments supporting the acquisition of 21st century skills. Can games, then, be used as components of an effective learning environment that support the development of adaptability?

Initially this paper describes the metacompetency of adaptability. Next is how adaptability can be functionally and discretely measured by focusing on its most granular or micromomentary level which we describe as cognitive adaptability. The authors then examine both the nature of cognitive adaptability, interventions that support its development, and how those interventions might be translated into game design features. Toward this end, the paper will also discuss how these features are exhibited in a popular commercially available video game, Portal 2, and how it was employed to test the hypothesis that a play frame of 12 consecutive hours would increase cognitive adaptability, measured by a set of cognitive functions and abilities as well as metacognitive attributes, in 18-24 year old enlisted Air Force personnel. The paper discusses the results of this study as well as exploring the usefulness of the CANTAB battery for measuring cognitive adaptability.

Keywords: Adaptability, Cognition, Cognitive Adaptability, Games, Serious Games, Measures of Cognitive Adaptability, Game Design
Introduction

Adaptability is a metacompetency critically important to the United States Department of Defense and is considered a key component of 21st Century skills by the U.S. Department of Labor (U.S. DoL, 1991) and the U.S. Department of Education (U.S. DoEd, 2012; Partnership for 21sts Century Skills, 2008). There is a need for organizations, leaders, and individuals to adapt to an increase in the type and intensity of stressors and ambiguity existing in today’s business, political, and defense environments, a need that is not limited by organizational or generational boundaries. ACT21S (Assessment and Teaching of 21st Century Skills) have identified three “ways of thinking” skills as part of defining 21st century skills: creativity and innovation; critical thinking, problem solving, decision making; and learning to learn, metacognition (Binkley et al., 2011). Creativity, problem solving, and metacognition are all crucial cognitive skills facilitating competence in being adaptable.

Training for adaptability and an “adaptive stance” (Grisogono, 2010) have been a longstanding interest of the United States (U.S.) Department of Defense (DoD), commensurate with the rise of asymmetric and irregular warfare. Adaptive stance and adaptability, while an important competency at a performance level, begin on a cognitive level. That is, micro-momentary decisions and cognitive processing (i.e., adaptive cognition) are the basis for adaptable behavior and performance, which in turn comprise adaptability at a human systems level. Therefore, utmost importance must be placed upon understanding and fostering adaptability at its origin: the cognitive level.

To address the exigencies of organizations within military and industry, and the educational outcomes defined as 21st century skills, learning environments need to support the types of activities fostering these skills in a manner that is highly engaging motivational, leverage generational differences, ubiquitous, easily accessible, and have broad appeal to a variety of learners and age groups. Games and serious games support both generational differences and a varied, ubiquitous set of technological opportunities that can be leveraged for learning (TRADOC, 2010). As such, if games and serious games do indeed have the ability to foster the cognitive adaptability they could be employed more extensively as components of virtual learning environments.

However, in order to utilize the full capabilities of computer-based games for training adaptability, it must be identified which design characteristics specifically contribute to an increase in cognitive adaptability. In defining these traits, the knowledge generated can be used to identify games currently available that might foster cognitive adaptability, as well as to design games in the future for the specific purpose of training adaptability. This requires gaining understanding of cognitive adaptability as a construct and how existing video games might be leveraged as a learning environment that could increase cognitive adaptability in the players.

Adaptability

A performance-based definition defines “adaptability” as described by Grisogono (2010) in her discussion of an adaptive stance. This refers to an individual’s ability to repeatedly try new or different strategies to solve problems while incorporating useful feedback with the purpose of improving overall success. White et al. (2005) described a taxonomy that included three types of adaptability: interpersonal adaptability, physical adaptability, and mental adaptability. Mental adaptability can be equated to what we refer to here as cognitive adaptability.
Adaptability is also defined by its components. Tillson, Freeman, Burns, Michel, LeCuyer, Scales, and Worley (2005) described adaptability as the result of the integration of specific skills, both cognitive and relational, and Kemp, Zaccaro, Filippo, and Jordan (2004) defined it similarly, but adding dispositional factors (e.g., tolerance for ambiguity, openness, resiliency, etc.) to the set of competencies that comprise adaptability, which were reiterated in White et al. (2005). As relational and interpersonal skills seem to be mostly influenced by dispositional traits which are not as easily altered, the need for emphasis on the developable cognitive skills that contribute to adaptability is significant.

**Cognitive Adaptability (CA)**

An adaptive stance is an observed set of behaviors emanating from the quality of adaptability; however, adaptability itself can be described as a mode of thinking. Adaptability, as with other modes of thinking, is considered to be a competency that can be learned, measured, and assessed (Haynie, 2005).

Both adaptive stance and adaptability begin on a cognitive level. As a unit of analysis, the cognitive skills that contribute to adaptability provide a means to understand adaptability at the individual cognitive level not confounded by relational or dispositional variables. Cognitive adaptability exists mostly at the level of micro-momentary cognitive decision processes and is closely related to the concept of fluid intelligence, a complex human ability that allows one to adapt to novel cognitive problems or situations and is critical to cognitive tasks and learning. Although long considered static and hereditary, there is compelling evidence that fluid intelligence is closely related to working memory and can be trained or improved (Jaeggi et al., 2008). These gains were shown to exhibit transference; however, it is not known if the effect is persistent over time (Sternberg, 2008). Good (2009) has discussed cognitive adaptability in the perspective of cognitive agility which consists predominantly of predominantly of cognitive openness, focused attention (the ability to attend to relevant stimuli and ignore distracting ones), and cognitive flexibility.

Metacognitive ability is a cognitive competency that has been tied as a contributing factor to adaptability by several past studies (Brown, Bransford, Cockey, Donovan, & Pelegrino, 2000; Haynie, 2005; Haynie & Shepherd, 2009). Brown et al. (2000) define adaptability as the ability to actively monitor one’s levels of understanding, decide when it is inadequate, and adjust one’s actions, thoughts, and decisions according to that level of adequacy, as well as to the current environment or situation. Closely associated with metacognition and considered a key component of cognitive adaptability is metacognitive awareness. Metacognitive awareness is the awareness of metacognition and of one’s own metacognitive abilities (Moncarz, 2011) also defined as an aggregation of five dimensions of metacognition: goal orientation, metacognitive knowledge, metacognitive experience, metacognitive control, and monitoring (Haynie, 2005). These dimensions of metacognition are actuated through one’s own metacognitive awareness with individual levels influenced through various experiences indicating positive correlation between metacognitive awareness levels and age.

Cognitive flexibility is the ability to cognitively control and shift mental sets. This ability requires the use of cognitive monitoring and cognitive control, which makes it often discussed as synonymous with metacognitive ability. Assessments of cognitive flexibility most often include assessments of working memory, divided attention, and shifting behavior. In addition to metacognitive awareness, cognitive flexibility is considered by many to be the key components of cognitive adaptability and crucial to adaptive expertise and problem solving (Canas, 2003; Haynie & Sheppard, 2009; Moncarz, 2011).
Measuring CA
Assessment of executive function is difficult due to the range of and diversity of skills associated with it. No single test can assess all of its various components; therefore, a battery is required (Anderson, 2001). Cognitive testing using a battery allows components critical to cognitive adaptability (i.e. cognitive flexibility, focused attention, and fluid intelligence) to be assessed empirically (Cambridge Cognition, 2012) and have been validated recently through functional imaging (Anderson, 2001). Multiple battery administrations can be used as repeated measures, allowing the detection of changes over time. Typical battery components have been historically associated with the testing of executive control in subnormal populations due to the ceiling effect found in assessment tasks such as the Wisconsin Card Sorting Test (WCST) and the Stroop Color Test (Anderson, 2001). Currently, however, assessment tasks do exist as valid and reliable measures available to supernormal populations due to testing modes with high ceiling properties (Cambridge Cognition, 2011). Examples of these tasks and the modes which would allow these assessments are Attention Switching task (AST), Reaction Time (RTI), Spatial Working Memory (SWM), Rapid Visual Information Processing (RVP), and the One-Touch Stocking of Cambridge (OTS) (Cambridge Cognition, 2011).

Metacognitive awareness as a cumulative construct can be assessed through a cumulative measure producing a snapshot of the level of an individual’s metacognitive awareness as a function of life experiences over time. Through a series of 36 questions, a valid and reliable instrument called the Metacognitive Awareness Inventory has been developed, tested, and successfully deployed in multiple organizational environments and academic studies (Haynie, 2005; Haynie & Shepherd, 2009; Moncarz, 2011).

Fostering Cognitive Adaptability
There is no literature directly describing interventions to foster or improve cognitive adaptability. There are directly related concepts and constructs in clinical and educational psychology from which principles of game design can be inferred.

Cognitive remediation therapy (CRT) is a neurocognitive psychotherapy technique aimed at improving three distinct executive functions: cognitive flexibility, working memory, and planning (Delahunty & Morice, 1993; Delahunty, Reeder, Wykes, Newton, & Morice, 1999). Though it was designed to benefit those with sub-normal abilities, its principles can be extracted and applied with increased complexity to cognitive flexibility training for psychologically healthy, unimpaired individuals and those with super-normal abilities and functioning as well.

CRT is divided into three modules, each focusing on a specific neurocognitive function (Wykes, Reeder, Landau, Everitt, Knapp, Patel, & Romeo, 2007), including metacognitive awareness and cognitive flexibility, two components of adaptability (also included is memory) and emphasizes cognitive “microskills.”. Many of the tests administered before therapy can increase cognitive microskills and include the Wisconsin Card Sort Test (WCST) (Wykes & Reeder, 2005) and the Stroop Color Word Test (also known as the Stroop Neuropsychological Screening Test) (Trenerry, Crosson, De Boe, & Leber, 1989), among others. The WCST (designed to measure “set-shifting” ability) (Berg, 1948) and the Stroop Test measuring directed attention are most relevant to fostering and measuring cognitive flexibility (De Young, n.d.; Stroop, 1935).

While practicing these tasks themselves can help strengthen cognitive adaptability microskills, there are several that have been shown to further improve cognitive flexibility: having the patient verbalize their
responses to the task while performing it (Rossell & David, 1997; Stratta, Mancini, Mattei, Casacchia, & Rossi, 1994), increasing the amount verbal information contained in the task while still keeping the rules and relationships in the task purposefully non-explicit (Young, Zakzanis, Campbell, Freyslinger, & Meichenbaum, 2002), using scaffolding techniques (Young et al., 2002), and employing errorless learning, which uses positive reinforcement and shaping instead of correcting errors (Kern, Wallace, Hellman, Womack, & Green, 1996).

Halpern, Hansen, and Riefer’s (1990) Feature Overlap Theory as well offers insight into how cognitive adaptability may be fostered. According to Halpern and colleagues, if training is too similar on a surface level to the actual event, when encountering a situation that requires them to use their skills in real life, they reach for superficial surface connections and fail to utilize their deep, causal understanding of the material. Accordingly, if the training teaches the trainee a deep, causal understanding of the material but is far enough removed, on a surface level (e.g., aesthetics, circumstances and details of a problem, etc), from an actual replication of reality, it forces trainees to exercise their ability to make deep connections and adapt their knowledge to new situations—and thus will result in a higher likelihood of increased performance in any environment or situation, and a higher level of transfer as trainees successfully adapt to new or changing environments by applying their fundamental, causal knowledge in new ways.

**Game Design Features for Cognitive Adaptability**

Successful methods of increasing metacognitive awareness and cognitive flexibility in other arenas can provide insight into design characteristics that could make a game an agent for increasing cognitive adaptability. Though some of the concepts drawn upon for insight into improving the cognitive processes that contribute to adaptability were designed for those with sub-normal cognitive capabilities, and could have a ceiling to their effectiveness for those with normal or above-average capabilities, their basic tenets can be extracted and applied in more complex and challenging ways to game design.

If using the MDA (mechanics, dynamics, aesthetics) model of game design proposed by Hunicke, LeBlanc, and Zubek (2002), where mechanics are the components of a game at the level of data representation and algorithms, dynamics are how the game components interact with the player and vice-versa, and aesthetics comprise the emotional response evoked by the mechanics and dynamics, the characteristics we posit below could be said to represent “features,” or more accurately, “sub-features” within a set of features, a level of game design to come before mechanics in what could be deemed an “FDMA” model. These are the general design ideals, represented by a taxonomy of features and sub-features, which are then translated into the specific mechanics of a specific game, which then in turn are integrated into a game’s specific runtime dynamics and evoke a particular aesthetic during gameplay. Their place within the FDMA framework is represented in the diagram below:
The features themselves are more design “categories,” and the sub-features are the specific options of design ideals within the categories. For instance, in the diagram below, the features are “Rules,” “Location,” and “Conflict.” The sub-features for each of these features would be implicit or explicit rules, realistic/high-fidelity or fantasy-based location, and violent or non-violent conflict.
However, not all sets of features and sub-features are this simple. There can, in fact, be an entire taxonomy of features, sub-features, and sub-sub-features that can be selected for at each level. Take the example of the “Rules” feature, below:

![Rules Feature Ex.](image)

Within the feature of “Rules,” there are categories of “Transparency” and “Consistency,” with various levels of consistency and transparency manifesting in sub-sub-features.

It is with this theory of game design in mind that the following specific sub-features are posited to improve cognitive adaptability.

1. **Unstated/Non-Explicit Rules.** The Wisconsin Card Sort Test measures, and is used to improve, participants’ cognitive flexibility by forcing them to determine unknown rules for sorting a deck of cards. Participants ideally reduce the amount of errors and amount of time it takes them to figure out these unstated rules, and their cognitive flexibility is measured as such. Therefore, a game or serious game which forces players to play by rules which are not stated explicitly should similarly enhance players’ cognitive flexibility, and contribute to increased overall cognitive adaptability.

2. **Unstated/Non-Explicit Changing of Rules.** Likewise, just as participants’ cognitive flexibility is challenged, strengthened, and measured by changing the rules of card sorting without notice or explanation in the WCST, a game whose rules shift non-explicitly should show the same ability to produce gains in cognitive flexibility among players.

3. **Dynamic, Shifting Environments.** Requiring trainees to reach for deep, causal understandings and apply their knowledge to situations that differ on the surface, in detail or circumstance, from their training situations, but retain the same underlying fundamentals, increases their adaptability
by essentially forcing them to adapt. Therefore, games whose environments change throughout the gameplay should foster cognitive adaptability as well.

4. **Open-Ended Game-Play.** Cognitive adaptability is comprised, in part, by cognitive focused attention, and cognitive flexibility (synonymous with metacognitive ability). Metacognitive ability was also shown to contribute to adaptability by Brown et al. (2000), Haynie (2005), and Haynie & Shepherd (2009). These components and correlates all point to the need for choices, the need to have more, as opposed to fewer, opportunities to choose a decision or action from a myriad of possible ones. Making choices requiring discerning relevant information from irrelevant information (focused attention), purposeful processing (mindfulness), a willingness to experiment and learn from doing (curiosity), and the creation of novel solutions from an expansive realm of possibilities (creativity), all of which require metacognitive processing. This all points to the need for game-play that is more open-ended than not, one that presents the player with opportunities to synergize solutions rather than choose from small, explicit list of possible actions, as well as think explicitly about and monitor their decision-making process along the way.

5. **Implicit Reinforcement for Individual Actions/Choices to Achieve Final Goal.** Implicit reinforcement for individual actions and choices a participant makes to achieve a final goal is a technique for fostering cognitive flexibility. Scaffolding techniques, which include modeling, verbal cues, and personal engagement of a student without explicitly instructing, as well as errorless learning, in which students are not corrected for their errors but positively reinforced for their successes, have both been shown to increase cognitive flexibility on the WCST (Kern et al., 1996; Young et al., 2002). The success of both these strategies at increasing cognitive flexibility suggests that players of a game should not be corrected for incorrect actions or choices they make along the way to achieving the final goal, but should see the results of their actions and choices explicitly in the final result. The results of their actions towards the final goal (and positive reinforcement should that goal be achieved) should be the only indication players have of whether or not their individual choices were correct. This also requires them to metacognitively assess their strategies and thought-processes for effectiveness.

### Experimental Design

To better understand how game design affects cognitive adaptability several research questions needed to be examined. The primary research questions we looked at were:

1. (Q1) Will 12 hours of consecutive gameplay of a video game with the design features previously described (Portal 2) cause an increase in cognitive adaptability as measured by cognitive function tests (CANTAB)?
2. (Q2) Will those playing Portal 2 have higher scores on a metacognitive awareness questionnaire (AMQ) during play than those not playing Portal 2?
3. (Q3) Will those possessing higher metacognitive awareness levels (MAL) also score higher on CANTAB after playing Portal 2 than those who played Microsoft Windows games?
4. (Q4) Are there differences of CA as measured on the CANTAB between high MAL (HMAL) and low MAL (LMAL)?
5. (Q5) Is a prior history of playing Portal 2 or like games positively correlated with higher metacognitive awareness levels?

To answer the research questions stated above, a mixed factorial design was constructed that compared cognitive adaptability characteristics of those playing Portal 2 (Valve Software); a game possessing all or
most of the features described above to a control group (between subjects design) and a within subjects design comparing pre/post scores with levels of CA.

**Intervention**

The choice of control is important to the outcome as it sets up the comparison, answering the question, “compared to what?” Previous studies have looked at the potential of cognitive capability increases after video game play but the comparisons used were to such things as looking up questions on the Internet or doing nothing (Jaeggi at al., 2008; Owen et al., 2010). To understand the utility of specific game design features, an appropriate control would be playing a video game that is identical in most respects to the experimental one but doesn’t possess the features under examination.

In looking over the field of commercial games, the authors identified very few that met the requirements for the features described previously and none that met the complete set to the greatest possible degree. As they were identified, it was apparent that some features were not usually compatible with the aesthetics typically designed into commercial game play and those possessing some of the features were of very different common categories. This lack of clarity in defining features and categorization also makes it more difficult to choose an appropriate control game. Ideally, choosing the control game should be as rigorous as the process for choosing the experimental one (Gallagher & Prestwich, 2012).

One example of a game with most of the desired features is *Portal 2™* by Valve Software. In various degrees it has features 1, 2, 3, and 5 (implicit rule sets, implicit rule shifting, dynamic and shifting environments, and implicit reinforcement for actions to achieve a goal). However, the degree to which feature 4 incorporated is subtle and is under debate; it is open-ended compared to games with a persistent, side-scrolling gameplay in which the character can only move in one direction and see from one perspective, and compared to games that are timed. However, by definition, games will always have rules, and thus always have some forms of constraint; it is not possible to have a completely open-ended game. The experimental video game, Portal 2, was compared (in the control group) to four Microsoft video games having static environments and explicit, consistent rule sets (Solitaire, Minesweeper, Free Cell, and Mahjong).

**Measures**

The purpose of the experiment was to test for positive changes in cognitive adaptability that may be due to game play with the described feature set. To do this, measures identified in the literature as sensitive to the construct of cognitive adaptability were chosen.

Cognitive tests have traditionally been used for testing neuropsychological dysfunctionality and are sensitive to subnormal populations. When testing super-normal populations, therefore most tests can produce a ceiling effect. For this reason the primary set of measures was the Cambridge Neuropsychological Test Automated Battery (CANTAB) using the CANTAB Eclipse software. The current version of CANTAB Eclipse contains tests with high functioning modes allowing for sensitivity to super-normal populations (Cambridge Cognition, 2012) and was customized specifically for this study. The customized battery consisted of five cognitive psychomotor tasks using a touch screen for subject interaction. The researchers have previously argued that using a battery of cognitive tests with a high ceiling as outlined in Table 1 can validly test for the critical components of cognitive adaptability (Gallagher & Prestwich, 2012) as long as they test cognitive flexibility, focused attention, and executive functions (i.e. spatial short term memory capacity, spatial working memory ability, and cognitive planning). CANTAB tasks chosen to test these constructs were the Attention Switching Task (AST), Rapid Visual
Information Processing (RVP), Spatial Span (SSP), Spatial Working Memory (SWM), and One Touch Stocking of Cambridge (OTS).

Three of the five tests (SSP, SWM, and OTS) within the CANTAB battery used in this study have sampled normative data including one sample of 194 normal participants ranging in age from 8 to 64 years and another of 341 normal participants, aged 21 to 79 years. The populations were screened for language, education, and health issues to define what could be considered “normal” (Robbins, et al., 1998) (Luca, et al., 2003). According to Cambridge Cognition, the other tasks have extensive normative data (Rock, 2012). However these data were not available to the researchers at the time of this study.

The AST and the OTS address cognitive flexibility and metacognition, RVP addresses information processing and sustained focused attention, and SWM and SSP address working memory capacity and fluid intelligence. This battery initially included a reaction time task but it was eliminated at the time of data collection due to technical problems with the touch screen. The researchers consider these measures to be valid for repeated measures within short time spans; however, results could be confounded by a practice effect. Besides use of the control group, the intention was to mitigate the practice effect by taking an initial reading two weeks in advance of a pre-test thus containing the effect to the baseline and the pre-test. However, in practice, this step turned out not to be effective due to attrition.

Other important considerations in this design were measuring the level of metacognitive awareness present in the participants and historical game-play data of the participants. A measure of metacognitive awareness (Metacognitive Awareness Inventory or MAI; Haynie, 2005; Haynie & Shepherd, 2009) was used for the former. The MAI consists of a 36- item inventory with each item rated on an 11 point scale. This was developed as an electronic spreadsheet available on the desktop of the testing computers. In addition to the MAI, an Active Metacognitive Questionnaire (AMQ) was developed. The AMQ consisted of eight sets of six repeating questions pulled from the MAI. The AMQ was also developed in an electronic spreadsheet available on the desktop of all gameplay computers. It was employed in order to measure changes in metacognitive awareness at different points during gameplay.

Game-play history was important to understand what type (if any) of games the participants have played, hours played, and very importantly, the level of expertise on the experimental game. A Game History Questionnaire (GHQ) was developed using questions adapted from Moncarz (2011) and Singer and Knerr (2010) as well as original questions. The GHQ was developed as a 41- item paper-based questionnaire consisting of demographic questions, gameplay questions, and gameplay history questions. Items were of mixed type: short answer, multiple choice, and Likert. It was taken with the post-intervention rather than pre-intervention, to reduce the chance that experienced gamers would confound the results by overachieving, and conversely, the non-gamers underachieving.

**Play Time**

Time spent playing the game is another important consideration. Previous studies for brain training have used long time periods of up to six weeks with self-directed play/training sessions during that time period with opposing results (Jaeggi et al., 2008; Owen et al., 2010). In a pre/post design using cognitive testing and for practical considerations, the researchers decided to use a sustained amount of playing time of 12-14 hours over two days to ensure maximum time on task and to prevent confounding events. As the study protocol finalized, play time was set at 12 hours and used as the primary independent variable.

**Procedure**
Participants were drawn from enlisted personnel stationed at Sheppard Air Force Base, in Wichita Falls, Texas, situated approximately 130 miles between Dallas and Oklahoma City. These participants were volunteers from the NCO (non-commissioned officer) enlisted population of technical trainees or as permanent parties.

Air Force Flight or Squadron leaders announced that personnel had a choice of volunteering to participate in a study that could count towards continuing service hours. Alternately, they may have other volunteer duties that will count towards needed hours. The results of all personnel who volunteered to participate and who participated throughout the entire course of testing were collected and used in the analysis.

A pool of 80 subjects was randomly sorted into experimental and control groups prior to the first day of gameplay. To eliminate positive or negative associations with a group assignment, a list of ID numbers in both the experimental and control groups was posted with instructions on which room the participants were to go to. CANTAB data were collected three times during three weeks on military touch-screen laptop computers known as Ruggeds. Baseline data were collected first in order to mitigate the effects of practice on pre- and post-testing. However, due to high attrition between baseline testing and main data collection, an additional group of subjects were added after baseline testing had occurred, whose results only include testing during main data collection. The final participant count ended up as 12 with baseline testing and 6 without in the control group for a total count of 18, and 11 with baseline testing and 10 without in the experimental group for a total count of 21. The total sample size after mortality had an n of 39. Main data collection then occurred over four days, one week after baseline testing: pre-testing on day one, gameplay interventions on days two and three, and post-testing on day four. Gameplay of three subjects in the experimental group was captured in real time through FRAPS real time video capturing software for later qualitative analysis. Due to the information assurance requirements on base, subjects in the experimental group played Portal 2 in offline mode using external monitors, mice, and keyboards; subjects in the control group played the four Microsoft games on the same setup. Half of laptops were also used for CANTAB testing and other data collection. The timeline for the entire data collection period in 2012 was: baseline (June 8), pre-test/MAI (June 14), gameplay/AMQ (June 15-16), and posttest/GHQ (June 17).

Game history was measured by the GHQ, administered to all participants after gameplay, so as not to influence their attitudes or performance during the intervention with self-perceptions of ability. Levels of metacognitive awareness were measured by the MAI, administered to all subjects prior to the intervention and immediately after pre-testing with the CANTAB battery. Metacognitive awareness was also tracked intermittently by students’ answers on the AMQ. These questions were administered at each break point to both the experimental and control groups. This provided a snapshot over time of changes to subjects’ metacognitive awareness during gameplay.

Analysis Procedures

Analyses were performed using SPSS (Version 16). Variables in the study consisted of the following independent variables: GPLAY (time playing video games), MAI (metacognitive awareness level), and GMQ Lickert scores - GLEVEL (gamer level – high or low gamer), TIMEWK (time played per week), and game interest variables. Dependent variables consisted of the CANTAB test output variables, AML (active metacognitive awareness level). These are extensive and include multiple latency values as well as CANTAB Eclipse-computed scores. Pre and Post CANTAB comparisons between the experimental and control groups were analyzed using repeated measures ANOVA. Post hoc analyses using historical game play data (except previous Portal 2 play) as independent variables consisted of ANOVA on pretest
CANTAB results only. Comparisons of MAI to CANTAB scores by group and game history data to CANTAB scores by group used ANOVA and independent samples T-tests where appropriate. Regression analysis was used to analyze individual CANTAB scores to MAI levels. Data distributions were reviewed prior to statistical analysis to check for violations of test assumptions. Skewed distributions of data were analyzed non-parametrically to decide if parametric analyses were warranted. Also, significance levels were set at 0.05.

Results

Research Questions

The research questions posed in this study provided a focused but open-ended template for the researchers to examine the outcomes of the measures used and their implications in regards to video game design, video game play, and cognitive constructs of adaptability. In analyzing data collected from the study, it was found that all but one research question was answered in the negative. The only research question for which partial positive results were found was question 1: will 12 hours of consecutive gameplay of a video game with the design features previously described (Portal 2) cause an increase in cognitive adaptability as measured by cognitive function tests (CANTAB)? In conducting an rANOVA of the pre- and post-intervention CANTAB results, it was found that there was a significant difference in the increase in speed in the rapid visual information processing (RVP) task between the experimental and control groups following gameplay, with those who played Portal 2 outperforming those who played Microsoft Windows games (n = 21,18; F = 6.126; p = 0.018). Though part of this variance can be explained, statistically, by the differences between those that described themselves as “high gamers” (i.e., those who played games more than 19 hours a week) and those that self-reported as “low gamers” (engaging in less than 19 hours of play a week), there is still a significant difference even when gaming habits are accounted for.

Additional Findings

The hypotheses supporting the research questions failed to disprove the nulls, examining the results from different perspectives not originally articulated in the research questions yielded other, unexpected findings of significance. In particular, data collected in the game history questionnaire (GHQ) was used to create groupings to examine the findings as related to historical game play and game interests as well as presented interactions.

Previous Portal 2 Play

Previous experience with playing Portal 2 was found to have a significant effect on scores on the Spatial Span (SSP) task, a measure of working memory. Subjects across the experimental and control groups who reported playing Portal 2 within the last six months made fewer errors during the Spatial Span task in both pre- and post-test measures than those who had not (F = 7.002, p = 0.012).
Currently submitted for publication to the Electronic Journal of e-Learning Spr 2013 Special Edition on Game Based Learning

High/Low Gaming
Even more than previous experience with Portal 2, amount of gaming experience in general was found to have a significant effect on CANTAB pretest scores. Similarly to those who had previous experience with Portal 2, high gamers (>19 hr/wk), were found to have made significantly fewer errors during the Spatial Span task (F = 16.776, p = .000). Also of interest, when controlling for previous Portal 2 play, there was still a significant difference in errors between high and low gamers (p = .006).

Additionally, in the One Touch Stockings of Cambridge (OTS) task (measuring executive planning, a critical component of strategic thinking), both pre- and post-test measures showed high gamers solving significantly more problems correctly on the first try than low gamers (F = 10.335, p = 0.003). After controlling for previous Portal 2 play, the results were still significant at p = .006.

Finally, on the Spatial Working Memory (SWM) task, which measures the ability to retain spatial information and manipulate remembered items in the working memory, high gamers as well made significantly fewer errors (F = 11.872, p = 0.001).

Genre Interest
To identify gamer types, the GHQ used questions concerning interest in various games genres on a 5 point Lickert scale (1 indicating no interest and 5 indicating the most interest). When different game genres of interest were taken into account, there were four genres which showed significance to CANTAB results. When looking at changes between pre- and post-test scores, there was an interaction between Spatial Working Memory (SWM) score and interest in massive multi-player online games (MMOGs) (F = 8.965, p = .006) as well as between latency of response in the Rapid Visual Information Processing (RVP) task (i.e., the speed of their responses to visual information processing, and one of the most sensitive measures in the CANTAB battery) and card games/simple puzzles (F = 5.622, p = 0.026). Additionally, between subjects, interest in racing games had a significant effect on SWM scores (F =5.053, p = .034).

Discussion
While the focus of this study is to understand better the relationship between specific game design tenets and their effect on developing cognitive adaptability within the player, a natural bi-product was to better
understand the efficacy of potential measure of cognitive adaptability and their use in video game research. In the case of the former, although the research questions did not produce positive answers for the most part, promise still remains.

The only positive answer to the stated research questions was for Q1- Will 12 hours of consecutive gameplay of a video game with the design features previously described (Portal 2) cause an increase in cognitive adaptability as measured by cognitive function tests (CANTAB)? A difference was found between the two groups as related to one of the three primary aspects of the cognitive adaptability construct – focused attention. The literature has shown that action video games may be related to increase visual selective attention (Bjorn, Green, & Bavelier, 2010). The results in this study, however, showed that those playing Portal 2 scored higher on sustained focused attention than those playing the Microsoft games. As Portal 2 is not an action game but an immersive puzzle/logic game this may suggest that a design factor present in Portal 2 may enhance this capability. At this time, there is not enough data to identify if any of the specific cognitive adaptability design factors are responsible. To positively answer Q1, there should also be differences on cognitive testing concerning cognitive flexibility. The CANTAB AST task is designed to test cognitive flexibility but in this study no differences were found.

Another primary component of cognitive adaptability and important to answering the other stated research questions is metacognitive awareness. Although metacognitive awareness is considered a critical component of cognitive adaptability, its application in the micro-momentary is difficult to measure. Haynie’s Metacognitive Awareness Inventory (Haynie, 2005) has proven to be effective as a snapshot of one’s metacognitive awareness level but the construct is not sensitive to changes over small time intervals and relies extensively on one’s maturity and life experiences to provide increases. When looking at all group differences and individual correlations on this measure, the results were insignificant. However, the six question instrument (MAQ) the researchers used for looking at changes to metacognitive awareness over time as a function of playing video games did show potential differences between those playing Portal 2 and those playing the Microsoft games (p=0.6). The significance level was slightly over that set for the study so it was not reported as significant. Using a larger sample this may prove to be more than error. In looking at metacognitive awareness overall, the instrument was not analyzed at the subtest level which may have provided other differences.

When examining the data for other findings other than those strictly posed by the research questions, interesting findings emerged. First, even though Portal 2 as a relatively short-term intervention may not have produced gains across the spectrum of CANTAB tests, participants that reported previous Portal 2 play six months prior consistently scored significantly higher on pre and posttests of spatial memory capacity (SSP) then their counterpart reporting little or no previous Portal 2 play. Other like findings that held promise but were slightly over the level of significance included the scores of tests for spatial working memory (SWM) and cognitive planning (OTS). During these analyses there were interactions present for high gamers (>19 hrs/wk), This indicates that part of the variance was also likely due to the level of regular gameplay in general, rather than Portal 2 specifically.

In looking at CANTAB results by high/low gamers, those that reported playing video games over 19 hours/week scored significantly higher on the CANTAB pretest on tested executive function capabilities. These findings may imply that playing video games in general may contribute positively to the increase of spatial memory capacity, spatial manipulation, and cognitive planning. The differences on the cognitive tests were all significant (p=.001, p=.003, p=.001) with increased scores in high gamers. In other words, this means that playing video games seems to enhance spatial abilities such as remembering and
tracking objects in space – i.e., creating a cognitive map – as well as the processes involved in the formulation, evaluation, and selection of a sequence of thoughts and actions to achieve a desired goal.

Spatial abilities are important in navigating from one place to another in the virtual or the real world – driving in traffic, getting to the office, going home. However, they are also frequently noted as important to language acquisition and mathematical comprehension, and are important components of higher order thinking skills such as problem solving and critical thinking (Osberg, 1997). Cognitive planning makes use of these abilities as an individual thinks through the steps and sequence of steps to solve problems. This is a critical skill to reason out problem solutions and evaluate results, and supports cognitive adaptability as one mentally “tries out” various solutions to a novel problem before acting.

An increase in spatial abilities and cognitive planning in combination with an increase in quality and quickness of signal detection, suggest that frequency of video game playing generally, as well as specifically playing games with the above mentioned features, may increase cognitive capabilities in the players and specifically those capabilities important to being cognitively adaptable.

Also of note was that specific games genres may hold more promise than others. The interactions observed between games interest variables and high/low gamers on pre/post CANTAB scores indicate that the type of game one plays most often may affect executive function.

**Conclusion**

The answers to the primary research questions in this study were in themselves inconclusive, and immersive video games such as Portal 2 may not be able to produce much of an effect after only playing for a limited amount of time. However, there is a strong indication that extended video game play of multiple genres has promise in increasing cognitive skills and capabilities necessary for problem solving, critical thinking, and adaptability from the micro momentary (cognitive adaptability) to developing an adaptive stance.

To understand adaptability in these types of experiments, even if positive effects are produced, they will still need to go further. As a metacompetency, cognitive adaptability as part of the greater construct of adaptability should exhibit transfer to other situations and contexts – i.e., far transfer. Unfortunately, cognitive battery tasks as not good at establishing ecological validity or the relationship between an individual’s performance on the battery and behavior in real-world settings. This is good and bad as direct relevance to the external world would introduce many confounding conditions; however, it limits transference to these other contexts (Anderson, 2001). To check for persistence of change and true transfer, further research should also include another real-world task with the same population that tests for transference to real-world conditions and changes in context. As these tasks are usually domain specific, it may still not exhibit true generalizability and should be chosen carefully with that in mind.

There is a need to develop adaptive soldiers and leaders capable of meeting today’s challenges. Similarly, in the civilian sector there is a need to develop adaptive scholars and educators capable of adapting to, or communicating, rapidly expanding new knowledge in virtually all academic disciplines; adaptive colleagues and collaborators capable of adapting to changing practices and procedures in the world of work; and adaptive citizens capable of adapting to a rapidly changing society. To support this imperative, the researchers argue that commercial video games may be valuable components of an effective learning environment supporting the development of cognitive adaptability, and thus the greater construct of adaptability as well as the development of greater capacity in cognitive capabilities in
general.
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Currently submitted for publication to the Electronic Journal of e-Learning Spr 2013 Special Edition on Game Based Learning


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