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Surgical Skill and Video Games: A Meta-Analytic Review

A senior thesis submitted to
The Department of Psychology
College of Arts and Sciences

In partial fulfillment of the requirements
for a Bachelor of Arts degree in Psychology

by

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Abstract

As the popularity of video games has grown over the past decade, so has interest in their capacity to serve as tools for education. The technology behind modern laparoscopic surgery draws strong parallels to modern video games, and as such has inspired initial research into the potential relationship between video game play and surgical performance. To date, a number of researchers have conducted studies on this relationship; however, no structured, statistical review of accessible data has taken place. Thus, the goal of this analysis was to examine the available literature and report the significance of the cumulative findings. Through my process, a total of 21 studies involving 1220 participants were gathered through multi-step review, and organized into one of three experimental domains - game training, VR training, and gaming history. Effect size analysis using Hedge's G and Fisher's Z yielded statistically significant results in all three domains, thus supporting the consensus belief that video game play has a positive effect on laparoscopic surgical training and performance. Given the particularly strong effect of virtual reality training on surgical performance, it would be valuable to investigate the differential effects of virtual reality, and how these effects might be further developed into more effective educational instruments.

Keywords: Video Games, Laparoscopic, Surgery, Serious Games, Virtual Reality

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In dedication to my Grandfather,

whose passion for science will forever be the greatest gift I ever received from him.

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Surgical Skill and Video Games: A Meta-Analytic Review

With the growing popularity of video games as a form of entertainment, a substantial amount of investigative research is being done into the secondary effects of video game play (Anderson & Bushman, 2001; Gee, 2003; Ryan, Rigby, & Przybylski, 2006). Defining what is and is not a “video game” proves surprisingly difficult. Most generally, a video game can be defined by both the terms “video” and “game” independently. A “video” being defined as “the use of a…signal to produce…imagery” (Wolf, 2001, p. 16) while a game is most broadly defined as an activity involving rules, in which the player interacts upon the game to manipulate the game state to resolve conflict in search of a desired outcome or goal (Wolf, 2001; Crawford, 2003). Additionally, it is the nature of a game to involve various “failure states” (either explicit or implied) should the player fail to complete game objectives, whilst also lacking any sort of external incentive. Further consensus is required in order to establish formal definitional boundaries for video games and their requisite characteristics.

Amid video game research is the popular notion that playing various types of video games may influence different performance abilities. Of particular note is video games’ observed correlation with surgical performance. Specifically, endoscopic surgery skill, involving robotic surgical equipment (as opposed to traditional, manual surgical techniques) has been repeatedly observed as correlating with video game play (Lynch, Aughwane, & Hammond, 2010; Rosser et al., 2007). This correlation may involve a number of different factors, including but not limited to dexterity, coordination, attention, learning, and performance skills; however, a summary effect size for the correlation has yet to be determined. Given the distinct lack of current meta-analyses reporting on this subject matter, there is significant potential value in an extensive analytic review of available scientific studies. Furthermore, the different forms of available related research may provide a valuable opportunity for supplementary statistical comparison regarding a variety of variables including control systems, genre, and graphical fidelity. Primarily, the ability for video games to exercise a variety of different skills may be a central factor in the informally quantified disparity between gaming and non-gaming populations during surgical task performance.

Since their inception, video games have become a primary source of entertainment within the United States. According to the Entertainment Software Association, United States consumers spent $23.5 Billion dollars on video games and associated peripherals in 2015 (Entertainment Software Association [ESA], 2016, p. 13). This figure is over double the industry sales some twelve years prior (Rosser et al., 2007, Conclusion section, para. 2). This growth is indicative of widespread interest in gaming across American consumers, and thus a pervasive familiarity with the medium. Granic, Lobel, & Engels (2014) cited that 97% of children and adolescents within the United States play video games for at least one hour per day. The primary research interest arising from this expansive familiarity is overwhelmingly purposed towards the investigation of the various effects of video game play on human behavior. Thus, it is important to evaluate this research for validity and logical consistency, as well as to analyze the collective data in order to obtain a more refined understanding of the influence of the medium.

In general, it stands to be reasoned that the level of ubiquity of a particular phenomenon adds validity to the nature of its study. The prevalence of gaming as a form of media entertainment qualifies it as a social and cultural phenomenon. As such, any secondary effects associated with exposure to video games should be qualified. The ideal method of doing so would be a meta-analytic review of available studies, in order to objectively quantify the effects of game exposure. These measurements may then provide the scientific community with an improved understanding of the effects of video game play, and will serve as a platform for continued exploration of the theoretical constructs and practical applications of such information in the future.

Given the prevalence of modern video games, it seems a valuable endeavor to further investigate the effects of their exposure. Preliminary evidence suggests that they may not only function as effective tools in the facilitation of active learning, but may also have direct correlations with changes in a variety of different skills. These skills correlate closely with those required for laparoscopic surgery, and therefore some skill transference may occur between the two. Thus, a collective analysis of current study data would allow for a better understanding of the effect size of such correlates, as well as potential factors that may influence the effectiveness of skill acquisition, should such a correlation be observed. Therefore, the purpose of this meta-analytic review is to evaluate the collective significance of videogame play on surgical performance under the hypothesis that a positive statistical correlation will be found between gameplay and surgical performance. Secondary correlations may be observed in areas not directly related to skill development, including control mechanisms, graphical quality, and game genre.

Literature Review

The following review of accessible literature seeks to define, modify, and modernize much of the conceptual framework for how video games influence cognitive skills. With the rate at which technology evolves, academic research must endeavor to remain accurate in its articulation of information. Many foundational studies were conducted well before the conception of modern game technology, and thus becomes increasingly outdated as time develops. Herein I will attempt to assemble study information that might be used to construct a more substantial framework through which to discuss gaming within the scientific space.

Landmark Studies

To begin, it is necessary to recognize the basis upon which this claim – that gaming can affect surgical skill – is based. The most referenced study by a substantial margin is Rosser and colleague's "The impact of video games on training surgeons in the 21st century" (2007). They reported that participants who played more than three hours a week made 47% fewer errors, performed 39% faster, and scored 41% better ($P<.001$) than control groups on validated tests of laparoscopic ability. These results are striking, and for this reason alone Rosser has been cited frequently in scientific and popular literature alike – the 46th most cited publication to date from *Surgical Education* (Matthews, Abdelrahman, Powell, & Lewis, 2016). However, it is worth noting that despite the strong statistical results, the participant group was small ($n=33$) and involved only surgical attendings and residents. Furthermore, the experiment took place in 2002, some five years prior to the article's publication. Given this delay in publication, the lasting statistical significance of this evidence is waning faster than the community may realize, and thus calls for further investigation.

The task of experimental investigation into the topic was also taken up by research teams like that of Schlickum and colleagues (2005), who found results consistent with those of Rosser et al. when observing a selection of 40 participants divided across 3 experimental groups. Rosenberg, Landsittel, and Averch elaborated further by describing game playing as a good predictor for inherent laparoscopic skill, but an insignificant method of skill improvement (2005). Instead they indicated that surgical simulators are a better tool for surgical practice. Finally, Lynch, Aughwane, & Hammond published a literature review of 12 related studies, and found a general trend towards surgical performance and endoscopic skill acquisition (2010). These studies substantiate the foundation upon which the necessity for basic meta-analytic review, such as that provided here, is qualified.

On the topic of surgical simulations, there is a case to be made that a game made for entertainment and a simulation designed for education exist along the same continuum. Ricciardi and De Paolis propose a spectrum, extending from pure simulation to games fully purposed for entertainment (2014). Along this continuum sit simulation games, and serious games, both of which will be analyzed further in coming chapters. Nevertheless, this spectrum propositions the idea that simulations (regardless of fidelity, intricacy, or immersive realism) are fundamentally game systems. This is compelling, given studies like that of Seymour et al. which extend the possible benefits of “gaming” to include virtual reality simulation training (2002). The most cited article in the publishing history of *Surgical Education*, Seymour et al. laid the foundation for subsequent study of digital simulation systems as a means of training surgeons (Matthews, Abdelrahman, Powell, & Lewis, 2016). Continued research into simulation tools, coupled with the research of those like Rosser et al. and Schlickum et al. on both active and historical effects of gaming on surgical performance, may give us a basic understanding of the ways digital simulative environments affect cognitive performance tasks, and how we might leverage these advantages for practical purposes.

Through critical review of the theories of Apperley (2006) regarding video game genres, I have developed four distinct categorizations of video games based on unique gameplay characteristics. These genres are critical in the contextualization of study evidence supporting video game influence of cognitive skills such as memory or attention, as well as physical attributes including dexterity and coordination. Throughout the following portion of my literature review I will operationalize my gaming elements, as well as review the available research literature regarding the influence of video games on cognitive skills and abilities.

Gaming Operationalization

It is important to define specific terminology used throughout this analysis, and in doing so ensure accurate articulation of concepts and ideas. This can be difficult, as expressed by Nicholas Caldwell:

> different genres of game, even different subgenres of game, deployed such diverse representational strategies as to make general claims seem untenable... Games might share some basic purpose—to entertain—but each new game that appeared on my screen could well have been in a

> different medium, or a different language, altogether. (Caldwell, 2004 as cited by Apperley, 2006)

Generalized concepts such as “games” or “entertainment” require more strict definitions to ensure the scientific stability of the subsequent research. A game can be defined as “[an] activity directed towards bringing about a specific state of affairs, using only means permitted by specific rules…and where the sole reason for accepting such limitation is to make possible such activity” (Suits, 1967, p. 156). While an adequate definition for a game itself, Suits neither describes a game’s relation to other forms of entertainment, nor how different kinds of games are distinct from one another.

Game designer Chris Crawford stratified the idea of games more thoroughly. His taxonomy of creative expression classifies games as a form of entertainment that is interactive, contains goals, involves competitors, and allows interaction between competing parties (Crawford, 2003, p. 6). Crawford considers simpler games to be “toys” or “puzzles” considering they lack the taxonomical characteristics that would otherwise qualify them as games. He states that players’ “perception” of the task influences the way in which the “game” is classified (Crawford, 2003, p. 8). Crawford neglects to recognize the potential role of the game itself as an active party in the game experience, and in doing so excludes distinct digital experiences from the definitional categorization of games.

Crawford failed to recognize the existence of failure states, which are an essential component of video gaming and a distinguishing feature that differentiates video games from other game types. Failure states are situations in which the player is considered to have “lost” the game. These states may be explicit, typically expressed as some form of an archetypal “game over” screen. They may also be implied, in which the player has failed to complete a goal or task that must be accomplished for the game to be considered completed. Crawford makes the inherent argument that games with implied failure states are more accurately classified as “toys” or “puzzles”, due to their lack of goals, competitors, or interactions. He cites simulation games (The Sims, SimCity) as “software toys” (Crawford, 2003, p.7) due to their lack of explicit gameplay goals. These games, however, have specific elements of gameplay that, without intervention from the player, will result in the cessation of their gameplay experience. Thus, these games possess implied failure states.

Moreover, Crawford presupposes that some games have no competitors, and others no competitive interaction. This assertion is challenged yet again by the existence of game timers, which have existed since the beginning of video gaming itself. The inclusion of timed periods in in which the player can perform tasks makes time (and by extension the game itself) a competitor. Video games are continuous simulations, and as such a player inside a simulated digital space is in competition with the simulation itself. The difference between an unattractive competition (ice skating, for example) and a video game is the fact that a competition may still occur without participants. The lack of a victor does not invalidate the fact that people participated in the event who were not direct competitors. Video games, on the other hand, require the presence of the player in order to exist. Simulating the game and attaching it to a visual interface implicates the perceiving party in the task of completing the game, thus making them a competitor in completing a task that otherwise goes uncompleted. As such, unlike competitions, puzzles, or toys, video games are designed in such a way as to create an inherent, interactive competitive space in which the person responsible for the simulation is, at very least, responsible for its completion. This commonality, however, does not imply a mechanical or otherwise characteristic homogeneity amongst games as a medium. Thus, it is prudent to classify games based on objective similarities to better analyze their shared effects.

Video Game Genres

Video games, like most entertainment media, are classified into genres based on certain artistic or mechanical characteristics. Unlike other media, however, Video Games are not typically developed and released under a specific set of qualifying, genre-based criteria, and may change significantly over its lifespan. Some genre characteristics are resultants of a phenomena known as emergent gameplay – consequences of player actions that produce logical, yet unforeseen gameplay experiences (Sweetser & Wiles, 2005). The result of emergent gameplay is the potential for “a large amount of gameplay experiences from a much smaller set of interconnected game rules,” (Pfeifer, 2004 as cited by Bailey & Katchabaw, 2008).

Consequent to this fact, games rarely fit neatly within objective categories. As such it becomes a more difficult task to operationally define game categories for subsequent comparison. Even so, I have developed four representational genre categories and cross referenced them with Apperley (2006) definitional categories. I have decided to exclude Role-Playing Games (RPG’s) from this analysis, as incorporated studies are unlikely to involve RPG’s as their instructive tool. RPG’s can be excellent tools for instruction on perspective-taking and behavioral immersion, but are unlikely to train specific, mechanical skillsets without contributing elements from one of my other primary genres (Peng et al., 2010). In place of this, I am including a sub-classification of games as a separate genre not recognized by Apperley known as “arcade” games, which will be thoroughly defined hereafter along with the other three genres.

Simulation. Games qualifying as **s**imulation games are explicitly designed to emulate familiar, real-world experiences. Simulation games endeavor to give the impression of task replication, the authenticity of which is widely variable. A consequence of this variability is the necessity for distinction between a “simulation” and a non-simulative game experience, given the complication that all games are inherently simulations (Frasca, 2003). This division, I propose, relies upon the scope of the simulated experience. A game included within the simulation genre should be confined to the simulation of *tasks,* versus that of *experiences*. By this definition, a simulation game seeks to specifically replicate the performance of a task or tasks using a 1:1 interactive interface. Therefore, a simulation game cannot be an “experience” simulation – *CALL OF DUTY* (2003) is not a “soldier simulation” because the act of being a “soldier” has not objective, mechanical interface. It can be described as a “gun simulator”, and could be evaluated as such through semi-objectively comparison of control input to gameplay output.

Implicated in this concept of simulative authenticity is the existence of variable mechanical inputs. Driving simulations may be controlled using either button controllers or auxiliary driving wheels, and similar devices exist for a variety of simulative experiences. It could be considered that the availability of alternative control inputs strengthens a games qualification as a “simulation.” Moreover, modifying a game to be controlled using an input mechanism that is more reflective of the emulated experience may qualify the specific gameplay instance as a simulation when it otherwise would not.

The conceptual advantage of simulation games, and the reason for their inclusion as a distinct genre in this study, is the possibility that immersive experiences improve memorization, special perception, and skill acquisition as compared to their non-immersive alternatives (Gee, 2003). Advantages observed within the simulation genre as compared to other game types may indicate a possible relationship between immersion, interfacing, and skill acquisition.

Strategy. By definition, “strategy” games can be understood as emphasizing player’s abilities to plan, contextualize information, and respond appropriately using value-based assessments of available gameplay options. While an argument can be made that all games involve a degree of “strategy”, two primary subcategories of strategy games exist: Real-Time Strategy (RTS) and Turn-Based Strategy (TBS), which are distinctly “strategic” as they “…remediate the playing of strategy table-top board games” (Apperley, 2006, p.13). Thus, while other games may have strategic elements, strategy games emulate the activity of controlling representative “pieces” upon a “board” and dictating the various ways they operate.

An important aspect of strategic gaming is the idea of expert play – player behavior characterized by an improved understanding of game systems, and the use of supplemental resources to develop tangible gameplay advantages (Apperley, 2006). The nature of strategy games implies that knowledge of game systems is more valuable than other gameplay skills (reaction time, attention, etc.). Thus, expert play involves player learning through research, trial and error experimentation, and collaboration with other players in order to develop the requisite knowledge to improve game performance. This aspect of strategy gaming becomes the basis for its experimental investigation, as the combined effects of both strategy game skills and expert play behaviors may provide tangible advantages in the acquisition of other skills.

Action. Similar to strategy games, action games are divided into two subcategories based on the players viewing perspective: First-Person games and Third-Person games (King & Krzywinska, 2002). These subdivisions have significant bearing over the gameplay experience, which will be covered more thoroughly later in this chapter when discussing immersive digital environments. In addition to perspective, action video games involve rapid assessment of gameplay obstacles and subsequent reflexive response. Action games, as Apperley (2006) points out, tend to be “intensely performative, in a manner distinctly different from other genres of performative games…” (p. 16). This centers around the fact that action games rely upon the player’s performative ability as a metric, or even requirement, for success.

Unlike other game genres, the player’s ability to perform (move, dodge, shoot, interact, etc.) is directly associated with their ability to succeed. As compared to simulation games, whose implicit failure state is dependent on when, not if, the player completes their task, action games require skills such as perception and spatial awareness, as well as manual dexterity and reaction time in order to complete objectives. Action games provide the opportunity to investigate the ability for games to improve these skills, thus allowing for the assessment of the value of skill advantage in surgical settings.

Arcade. Arcade games is an operational category I have designated in place of RPG games in Apperley’s theory. Preliminary study review indicates that a fair number of experiments use classic arcade games (Tetris, Pac-Man, etc.) as their game of choice. This is likely due to their ease of access to a general audience and their public familiarity as compared to other types of games. While compelling to define arcade games by release date and distribution medium (arcade cabinets), it is simpler and more inclusive to define “arcade” as any game that involves the manipulation of a character or object within a single, stationary screen. This sub-classification is merely an organizational device through which to analyze study results; although, it may provide insight into how immersion as it pertains to the technological and graphical development of video games can affect the acquisition of skills.

Other. Any game not otherwise contained within the above genre categories shall be coded as “other.” It is necessary to include a “catch-all” genre to organize any games that do not otherwise satisfy coding criteria. While it is not expected that many (if any) games will be included in this category, given the comparativeness of the other four genres, it is a recognized possibility and has thus been accounted for. Retrospective analysis of game outliers may provide information regarding the strength of individual genre effects, through analysis of individual game characteristics.

Serious Games and the Gaming Spectrum

Transcending the confines of genre is the concept of “serious games”. Serious games have been defined in a variety of different ways, the most comprehensive of which is “an interactive computer application, with or without significant hardware component, that has a challenging goal, is fun to play and engaging, incorporates some scoring mechanism, and supplies the user with skills, knowledge, or attitudes useful in reality” (Howard, 2017, p. 318). Although still somewhat ill-defined, serious games can be considered a moderate designation between games designed for entertainment and realistic simulators, as outlined by Ricciardi and De Paolis in their gaming spectrum (2014, p.2). Even still, these definitions use conditions such as “realistic,” “fun,” “engaging,” and “imaginative” to distinguish between different game strata. These qualifications leave much to be desired especially if they are to be used operatively in experimentation. Ostensibly, this rough spectrum could be transposed to a Likert scale. Possible questions could be as follows:

- How would you rate the games realism?
    - 1 Not realistic at all – 5 Very Realistic
- How accurate is your control of the game to the actions taking place within it?
    - 1 Not accurate at all – 5 Very Accurate
- How closely did you identify with the games main character?
    - 1 Not closely at all – 5 Very Closely
- How likely would you be to play this game for fun?
    - 1 Not Likely at All – 5 Very Likely

A series of questions similar in nature to these could be validated, coded into distinct dimensions, and then used to assess participant’s impressions regarding gaming elements such as simulative immersion (realism, responsivity, perspective taking) or entertainment (enjoyability, ease of use, motivation for play). Different game concepts, such as serious games, could then be assigned a distinct range into which games may be scored and categorized (4 being simulation and 20 pure entertainment in the above questionnaire). Thus, it may be possible to develop a semi-standardized system of measurement to assess game realism and entertainment values, and in doing so establish a better framework for understanding the function of different digital simulations.

While serious games may be a gateway to skill training and acquisition, they represent what is only a moderately-realistic form of simulative experience. Effects seen in serious games pertaining to realism and immersion may be magnified in studies involving greater simulative experiences. Serious games are an excellent resource readily available that can give insight into the differences in effect between serious and non-serious design and gameplay mechanics, and a gateway to accessible simulation experiences.

Virtual Reality

When contemplating the aspirations of high-fidelity digital simulators, VR technology increasingly comes to mind as a valuable resource in the persisting search for simulative realism. Virtual reality involving full stereoscopic immersion of the user has only become technically feasible for the average consumer within the last year. Even then, the technology is largely relegated to enthusiasts due to the high cost of both product and operating hardware, as well as a rather limited range of available experiences. The next few years will reveal whether or not stereoscopic VR has the potential to be a lasting technological trend; but, even in the absence of public adoption, VR may hold value in scientific and research domains.

Virtual reality is a disruption to the conventional gaming experience. This can be seen as desirable in instances where individuals are looking for highly immersive simulated worlds. In exchange for increased immersion, VR suffers from a variety of mechanical limitations including restrictions on player control, player perspective, and player motion. Games are relegated to the first-person perspective, and often involve minimal (if any) movement. VR users can suffer from motion sickness, eye and neck strain, and other physical side effects, possibly as a consequence of the dissonance between kinesthetic motion and cognitive perception. Overall, VR gaming may be considered more stressful to the user than standard gaming practices, and is recommended by manufacturers of these products that users avoid prolonged use.

While gaming in virtual reality may be limited to novel game experiences, simulations which inherently operate under the restrictions inherent to VR may hold lasting potential. Surgery is conducted from the first-person view, with minimal area movement, using standard physical or mechanical tools. Thus, it may be possible to design simulations using rotational tracking instruments

Immersive Digital Environments and Role Adoption

Immersive technology like VR increases the capacity for the user (player) to integrate seamlessly into the digital space and assume the identity of the game character. This sense of immersion is integral to player experience, and is a critical distinguishing factor amongst game genres. Consequently, differential effects correlating with game genre and operative infrastructure could be indicative of differences in the type and efficacy of immersive experiences. Moreover, immersion facilitates the process of role adoption and avatar identification, which may have implications on behavioral expression and self-identification.

The concept of immersion can be analyzed from a number of different perspectives. Ermi and Mäyrä (2007) proposed several types of immersion, all of which play important roles in the player experience. Furthermore, the degree to which these immersive experiences are developed both architecturally and technologically may influence player learning, and thus may play some role in determining the gaming effect as it pertains to different game genres.

Firstly, Ermi and Mäyrä (2007) described the concept of sensory immersion – or the audiovisual fidelity of the gaming experience. They reduce the discussion of sensory immersion to stereoscopic audio, screen size, and player proximity to the two. It is worth recognizing, however, that the nature of sensory immersion is more complex than that. Not only might ideal immersive screen size vary amongst players simply due to preference, it could also be influenced by game type. Moreover, player familiarity has the potential to play a significant role in the potential for immersive experiences, and yet is a mediating variable yet unrecognized within the literature. As time goes on and technology continues to develop, the ability for individuals acquainted with modern 3D technology to immerse themselves in rudimentary 3D environments may be limited, thus impairing their experience thereafter. While this may not be an issue for all players, nor for all genres, it is an important consideration in the analysis of immersive potential.

Regarding immersion technology, recent advancements within the videogame industry have led to the release of virtual reality (VR) devices for use with game play. The existence of commercially-available VR devices is a profound advancement for science and gaming communities alike. While the effects of this technology have only just begun to be observed, the ability for VR technology to provide unparalleled immersive experiences may hold exciting new potential for immersive learning environments.

The second of Ermi and Mäyrä's (2007) immersion types is challenge-based immersion, a concept which emphasizes the necessity of gameplay tasks that are neither too easy, nor too difficult for the player to accomplish. Either extreme is likely to result in the player getting bored, distracted, or frustrated, thus breaking immersion. Conceptually, this is not unlike Lev Vygotsky's (1980) foundational theories on proximal development regions, and has similar implications for learning and skill acquisition. In this scenario, it is more appropriate to think of the game itself as the teacher, whose responsibility it is to simultaneously challenge and support the "learner" so as to develop skills, as well as maintain immersion.

Lastly, imaginative immersion is the ability for the player to feel integrated with game narrative, world, and characters. Particularly important is the capacity for the player to identify with the main or player character (PC), to further immerse the player in the game experience. Some games involve the creation of a custom PC, or avatar, while others have preconstructed characters which the player controls. In both cases, digital avatars have observed effects on user behavior and cognition.

User-avatar identification affects several diverse aspects of human behavior. Study evidence has demonstrated that individuals identifying with the digital characters felt positive attitudes towards their character (Suh, Kim, & Suh, 2011) and engaged in avatar-consistent behaviors in the real world (Greitemeyer & Mügge, 2014; Yoon & Vargas, 2014). This evidence suggests that player-avatar identification plays an important role in the immersive gameplay experience by extending the self-identity to within the game space. Additionally, Jin (2009) indicated that avatars who represented the player's ideal-self perceived the game as more immersive than those whose avatars reflected their actual self, as conceptualized by Higgins (1987).

Based on the data from the aforementioned studies, player-avatar identification appears to be critical to effective immersion. Having already qualified immersion as an important aspect of the gameplay experience, it is then possible to postulate that improved identification as the character within the digital space has the capacity to increase game effects, such as learning. This conclusion would hold compelling implications with regards to genre, control scheme, and immersion technology. With this in mind, it is possible that we will see stronger effects in genres where the player's identity is necessarily implicated in that of the game character. Specifically, it is possible that first-person games in which the player visualizes the digital space through the eyes of the acting character may facilitate learning. Moreover, the implications of using the player as the avatar (rather than creating an avatar in the image of the player) has yet to be researched due to the recency of VR technology. Future research will be necessary to study the effects of improved player-avatar identification due to VR on the cognitive and behavioral changes of the player.

Active Learning

Thus far, this discussion has been focused on video games as a digital medium, and their composite characteristics. While valuable tools in describing and analyzing the ways in which games and user interact with one another, these characteristics fail to provide insight into how video games might directly affect performance on complex tasks, such as surgery. This relationship is dependent on the process of active learning. Active learning, defined as an instructional method that directly engages the learner

(Prince, 2004, p.1) is fundamental to the discussion of game-based systems. Active involvement of the learner requires thinking tasks such as analysis, synthesis, and evaluation in order to solve complex problems (Bonwell & Eison, 1991, p. 5). Videogame interaction requires the player to persistently perform these thinking tasks, often in increasingly difficult or stressful situations in order to maintain challenge-immersion (Ermi and Mäyrä, 2007). Operating under the assumption that developing an understanding of task information is integral to task performance, the process of active learning and its relationship to the understanding of complex systems is increasingly relevant.

I have separated my discussion of active learning into two divisions, each focusing on a different aspect of active learning. My overview of memory will discuss the features and limitations of both declarative and non-declarative memory. I then direct discussion to the development of tangible performance qualities, such as visual-spatial attention, and coordination. In conjunction with one another, these aspects of active learning substantiate the necessary skillset for complex skill execution. Thus, training of these skills through game simulation should result in increased performance on surgical task-performance metrics like those measured in my study.

Active Learning: Memory. With regards to memory, there is a recognized difference between declarative and procedural knowledge. Ullman (2003) defined declarative memory to be the knowledge of facts and events; although, while not "informationally encapsulated," not all declarative memories may be accessible (p. 235). Procedural memory, comparatively, involves the learning and execution of sensory-motor and cognitive skills, which may be partially or even entirely unavailable during conscious recollection (p. 237).

The consideration of the declarative/procedural model of memory raises concerns regarding conventional methods of education, specifically regarding the efficacy of knowledge transfer from classroom lecture to applied environments. As can be the case, however, time and other resources can be obstacles to applied instruction. While not applicable in all learning environments (particularly those involving complex systems of conceptual knowledge, such as philosophy, or some mathematical disciplines), educational settings focusing on the instruction of tasks and skills could benefit from a method of instruction that is less declarative, and more procedural in nature. Immersive digital environments or simulations provide the opportunity for safe, active instruction for procedural tasks which may prove more effective than traditional, lecture-based instruction.

To evidence the advantages of simulative environments, a study of thirty-two participants demonstrated that individual’s ability to both recognize and generalize knowledge regarding the topographical layout of a space was enhanced through use of a virtual environment simulation, as compared to passive viewing of static images (Christou & Bülthoff, 1999). Similarly, a randomized, controlled study of 182 adults demonstrated that active engagement through electronic training programs that “very intensely stimulate neuromodulatory structures” enhances memory recognition, and has both generalized effects as well as longevity (Mahncke et al., 2006, ET Program Design, Para. 1).

Together, these studies begin to demonstrate the potential for simulative environments to increase performance of both declarative, as well as non-declarative memory processes. While future research may aid in clarifying the nature of these effects, it is also important to recognize that memory constitutes only a portion of surgical task performance, the rest of which consist of various cognitive and coordinative skills. Therefore, further explanation of active learning as it pertains to surgical performance is necessary.

Active Learning: Attention, Cognition, and Coordination. In addition to improvements to memory, active engagement in learning processes improves a variety of cognitive functions. These functions, extending from visual attention to reaction time, ostensibly provide tangible benefits to surgical professionals. Thus, observing the effects of video games on various cognitive processes may help support our understanding of how gameplay improves task performance.

Attention to detail, and the ability to observe discreet abnormalities in the body, is a necessity for an operating surgeon. As such, effectively managing spatial distribution of one's attention can help to avoid dangerous mistakes while operating. Green and Bavelier (2006) observed visual acuity, or "the ability to discriminate small changes in shape in central vision" (para. 2), and its relation to video game play. Through their study they found that video game player's ability to focus their attention on a central stimulus task in the presence of distractors exceeded that of non-video game players (General Discussion, para. 1). Similarly, Greenfield et al. (1994) observed that not only did experienced video game players receive an attentional benefit from playing the game, but they did not suffer the detriments to reaction time as a result of their experience. Furthermore, consistent with Orosy-Fildes & Allan's findings (1989), Greenfield and colleagues observed a video game experience as a causal factor in improving strategies of divided attention (1994). Thus, not only have video games been observed as increasing visual attention, but extensive experience appears to mitigate reactionary deficits, resulting in a net decrease in reaction time in attentional tasks.

While encouraging, reaction times alone are not sufficient in justifying games as good training tools. Particularly because faster actions conventionally mean less attention to detail, resulting in more mistakes. However, by demonstrating that processing speed increases in conjunction with reaction time, a stronger case for games can be made. Dye et al. (2009) expanded upon the work of researchers like Green and Bavelier by observing accuracy measures in game-based tasks. Their analysis of literature sources demonstrated that video games increased reaction time, without sacrificing accuracy. This evidence supports games as what Dye and others referred to as "training regiments" (2009) for a variety of tasks, serving as tools for improving applicable skills independent of the intended activity.

With the foundation of attentional and reactive benefits in place, the final element necessary to realize the effects of video game play on task performance is ensuring that coordination, like accuracy, is not impaired by the preceding alterations to cognitive performance. Griffith et al. (1983) compared 31 video game users and 31 non-users in a study of eye-hand coordination using a photoelectric rotary pursuit unit. Their study found video-game players to have "substantially superior" eye-hand coordination than non-users (p. 158). Griffith et al. rejected a causal relationship between game play and improvements to coordination on account of a lack of relationship between amount of game exposure and coordinative performance. Instead, Griffith et al. postulated that individuals with inherently high coordination are drawn to gaming as a leisure activity. Ultimately, this study failed to account for the additional possibility that game play is related to hand-eye coordination in a non-linear fashion, with a maximum potential benefit resulting from minimal amounts of exposure. Researchers (like those cited previously) published since 1983 and involving gaming exposure as one of their experimental variables appear more confident in associating gameplay time to cognitive-behavioral changes. Nevertheless, it would be valuable for more rigorous and modernized research to be conducted on the specific relationship between coordination and gameplay experience.

While practical, performative skills like those discussed above do likely act as indications of surgical performance, it is worth noting that physicians necessitate interpersonal skills in addition to performative skills. Study results suggest that patient-physician communication increases patient satisfaction and emotional health, as well as improves care efficiency (Joos, Hickam, Gordon, & Baker, 1996; Stewart et al., 2000). Role playing scenarios are already implemented as teaching tools in many medical schools (Lane & Rollnick, 2007; Nestel & Tierney, 2007). The efficacy of these methods, however, requires further review. Nonetheless, the ability for immersive simulation technology to provide medical students with training for both procedural and interpersonal tasks may prove valuable in increasing future patient outcomes.

Cognitive Skills and Surgical Performance

An example of a non-gaming performance task determined to be of relative complexity is surgery. Modern surgical residency training already involves a degree of hands-on teaching, however, patient risk and the complexity of surgical procedures is rendering traditional lecture education increasingly inadequate (Rosser et al., 2007, Conclusion section, para. 5). As such, it becomes necessary that the learning of complex tasks be done in such a way that is both efficient and effective. Active learning methods have been observed as increasing the efficiency of skill set acquisition, and improving skill performance thereafter (Baepler, Walker, & Driessen, 2014; Prince, 2004). Therefore, the development and application of active learning tools (such as games) that might aid in the comprehension of complex systems of information, and the subsequent application of learned information would be invaluable in communities in which the acquisition of complex skills is desirable.

As tools of active learning and skill development, video games inherent gameplay and control systems associate them with the development of various cognitive, sensory, and kinesthetic skills. Modern games require rapid processing of a variety of visual stimuli, and require the participant to take according action in order to avoid punishment. Thus, players are motivated to develop and advance skills that allow them to function within the context of the game itself (Green & Bavelier, 2006, Review section, para. 3). These skills include visuospatial attention (Green & Bavelier, 2006; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994) processing speed, (Dye, Green, & Bavelier, 2009) reaction time (Orosy-Fildes & Allan, 1989) and eye-hand coordination (Griffith, Voloschin, Gibb, & Bailey, 1983). Such skills are similar to those associated with laparoscopic surgery, as outlined previously. This evidence suggests that performance advantages observed within the literature thus far may extend beyond knowledge systems to demonstrable differences in cognitive and coordination abilities. On this basis, it may be valuable to determine the differential effects of videogame play and the relationship to surgical performance.

Surgical Performance and Video Game Play

Although initial research has been conducted on the relationship between video game exposure and surgical performance, results appear to be inconclusive, with large amounts of variance in the methods and results of the individual studies. Moreover, few studies address the aforementioned constructs, including active learning, skill-training, and cognitive abilities as they relate to video game exposure; however, collective analysis of these studies may address these key constructs. Thus, my goal in this thesis is to collect and evaluate the reported results of various, qualifying studies to observe the cumulative effect of video game play on surgical performance to a degree that has not been done within the literature thus far.

There are two distinct forms of video game exposure recorded within the literature. Primarily, many studies correlate gaming exposure and surgical performance experimentally, by compelling experimental group participants to play games a certain number of hours over a period of time, and comparing their subsequent surgical performance to that of a control group. Alternatively, many studies also observe gaming history over the lifespan in an ex post facto, quasi-experimental design. Both designs provide valuable information about the nature of video game effects on cognitive skill performance, and as such both will be observed and investigated within the meta-analysis.

I hypothesize that analysis of reported studies will yield evidence of a positive statistical correlation with regard to the relationship between surgical performance and video game play, both concurrently as well as historically. Any statistically significant findings will aid in either the challenging or qualification of previous claims regarding the relationship between video games and surgical skill. Should no statistically significant relationship be found, both this analysis and the studies contained within it may be evaluated and revised for more thorough exploration in the future. Regardless of outcome, this study serves as a critical step in the collection and evaluation of relevant literature, the results of which will have significant bearing on the future of the value of video games, and active learning as a whole.

Method

Meta-analysis

Aggregate statistical review of scientific studies, otherwise known as meta-analysis, is a critical to the continued pursuit of scientific integrity. First conducted in 1976 by statistician Gene Glass on Psychotherapy outcomes (Glass, 1976; Smith & Glass, 1977), the meta-analysis has since served as the ultimate review of scientific research. Meta-analyses use statistical models of analysis to evaluate the collective significance of the data included in all subsidiary studies. As such, their purpose is to determine the value of research conclusions on a population level, and to infer the potential effect size for an observed phenomenon. Consequently, meta-analysis is not only the primary aspiration for scientific research, but the terminal barrier to recognition as an effective phenomenon.

Despite being a standard for empirical measurement within the field, meta-analyses are subject to inherent design limitations. The scope of these limitations varies across a number of analytical domains, making it vitally important that researches employing meta-analytic techniques scrupulously observe, report, and regulate the intrusion of external factors which may compromise the empirical validity of the meta-analysis itself. *The Cleveland Clinic Journal of Medicine* (CCJM) recognizes four key issues implicated in meta-analysis design: study selection, heterogeneity of results, availability of information, and analysis of data. (“Meta-analysis: Its strengths and limitations: Cleveland Clinic Journal of Medicine,” n.d.) Imbalanced or non-objective study selection resulting from publication and selection bias can result in non-objective conclusions. Studies aggregating heterogeneous results require careful review in order to explicate the nature of this heterogeneity, like the circumstance cited by the CCJM where a large study reporting significant results overshadowed the results of several smaller studies reporting insignificant results (CCJM). Availability of information regarding the methods, procedure, and subject population can interfere with the way in which outcomes are measured and operationalized. Finally, the model through which data is analyzed (fixed-effects versus random-effects) can affect the overall conclusion, and thus must be considered when evaluating study limitations.

Preliminary searches on my topic yield very little evidence of any meta-analyses observing the relationship between video games and surgical performance. To date, the most extensive reviews of relevant publications are two systematic reviews with no statistical analysis, published in 2010 and 2015. The two reviews encompassed a total of 17 empirical studies, and yielded contradictory conclusions. The authors of the first review of five articles purported there was no evidence of any relationship between play and performance (Glassman et al., 2015), while in other reviews of 12 studies researchers claimed that there is a positive correlation with performance (Lynch, Aughwane, &

Hammond, 2010). These reviews are preliminary, and evidently yield conflicting conclusions. On this basis alone it would seem appropriate to conduct a meta-analysis, both for the purpose of supplying a collection of analytic data not yet existent within the literature, as well as further evaluating the current literature for correlates, inconsistencies, and possible routes of future research. To be able to not only analyze the effect size of collective data, but to potentially stratify results into categories of subsequent analysis based on a variety of involved criteria would amass additional qualification as to the value of this study.

Inclusion and Exclusion Criteria

Independent and dependent variable definitions are defined so as to include as much potential research as possible while still being representative of the main hypothesis. Video game play/experience (IV) is defined as individual interaction with a digital entertainment medium that requires participant engagement to avoid subsequent failure states, either explicit or implied. Under this definition, any “game” should qualify for use in this study, as well as simulators like those used for surgical training; however, other digital entertainment sources (such as movies) will not satisfy the criteria. Surgical skill/performance is an operational metric defined by a variety of measurements, including but not limited to: time to completion (TTC), errors made, precision, instrument path length, instrument collision, efficiency and total laparoscopic score. Metrics are quantified by either the testing simulator, using objective testing criteria, or by a medical physician.

This study contains no exclusory criteria for potential participant populations. Studies are to be conducted after the year 2000, up to and including studies conducted in

2017. Eligible research design features include correlational, regression, path-analysis, as well as experimental and quasi-experimental studies

Moderator and Mediator Analyses

- Gender – Participant-identified gender association
- Age – Age of participant, measured in years.
- Experience – Years of experience within the surgical specialty, including subspecialty experience.
- Laparoscopic/Non-laparoscopic – Robotic assisted surgery involving small incisions. If a mixture of assisted/unassisted surgery is reported, it will be coded as laparoscopic.
- Gaming History – Participant reported lifetime video game experience.
- Testing Game – Interactive digital medium with clear goals and failure states. Coded for Genre.
    - Action – Active movement through game environment and meaningful engagement with surroundings through use of unique game mechanics that rely upon reaction time and dexterity.
    - Simulation – Game designed to replicate a lifelike scenario.
    - Strategy – Games emphasizing planning and thinking over dexterity and reaction times.
    - Arcade – Movement of a single object within a fixed screen.
    - Other – Genre not coinciding with other coding categories.
- Study Quality - Coded for by study quality metrics, as outlined in the coding section of this chapter.

- Simulation Type – Technological specifications of simulation systems
  - Basic – Single monitor computerized simulation.
  - Immersive – Multi-monitor setup for enhanced immersion/ information communication.
  - Virtual Reality (VR) – Head mounted display, or other immersive digital setup.
  - Other – Other methods, including phones and other mobile devices.

Search Strategies

Studies to be included in the statistical analysis are to be gathered from computerized, English databases including Google Scholar, Pub Med, and Sagepub databases. Specific search strings are limited to: ["Surgical ability" OR "surgical skill" OR "laparoscopic ability" OR "laparoscopic skill" "Video Games"]. For articles to be considered appropriate for this study, they will need to include some quantitative measurement of laparoscopic surgical performance, as well as either concurrent video game play, or previous gaming history as the two operative variables under which they are correlating their data. Furthermore, they must have been conducted since the year 2000, and may be drawn from either independent or review articles, as well as unpublished sources, otherwise known as “grey literature”. This evidence should be compared to control groups of individuals with minimal or no gaming experience, or assessed via correlation, regression, or path analysis coefficients in non-experimental studies. Other efforts to retrieve studies not otherwise available, or to gather clarifying information regarding studies to be included will include surveying of reference lists for additional resources, as well as the possibility of author contact. The need for author contact will be evaluated based on the author's work's relevance to independent/dependent variable relationship, currency, available time, and author availability. Studies considered to be of moderate to high relevance will be considered for author contact.

Study Eligibility

Study eligibility will be determined by the following three-tier review process. Each study will be screened by a single screener, myself, the limitations of which are fully recognized.

- Step 1 – Title Review: Must meet all requisite criteria to pass to Step 2.
    - Criteria 1 – Source must be written in English. Otherwise exclude.
    - Criteria 2 – Source must include reference to video games, video game play, surgical performance, laparoscopic surgery, surgery and video games, or surgical training. Otherwise exclude.
    - Criteria 3 – Source must involve analysis that is either quantitative or mixed-method. Otherwise exclude.
- Step 2 – Abstract Review: Must meet all requisite criteria to pass to Step 3.
    - Criteria 1 – Source must be written in English. Otherwise exclude.
    - Criteria 2 – Source must include reference to video games, video game play, surgical performance, laparoscopic surgery, surgery and video games, or surgical training. Otherwise exclude.

- Criteria 3 – Source must involve analysis that is either quantitative or mixed-method. Otherwise exclude.

- Step 3 – Full Text Review: Must meet all requisite criteria to be moved to coding and inclusion process.
  - Criteria 1 – Source must be written in English. Otherwise exclude.
  - Criteria 2 – Source must include reference to video games, video game play, surgical performance, laparoscopic surgery, surgery and video games, or surgical training. Otherwise exclude.
  - Criteria 3 – Source must involve analysis that is either quantitative or mixed-method. Otherwise exclude.

Unpublished studies will be used provided that they pass the three-tier review process outlined above.

Coding Procedures

Upon the confirmation of a conclusive list of studies that will be included, I will then review each study independently, and in doing so I will extract variables pertaining to participant characteristics, surgical performance metrics, gaming history, game genre, control setup, exposure time and any other mediating factors listed previously. Extracted variables will be organized in a digital spreadsheet and sorted based on variable type, function, and availability. Additionally, study quality will be coded for using the Effective Public Health Practice Project's (EPHPP) Quantitative Study Quality Assessment Tool (Thomas et al., 2003). If through this process a study's data were concluded to be inadequate for the calculation of effect size, then the study will be removed from the meta-analysis.

Statistical Methods / Data Analysis

Statistical analysis of gathered data will be done using Comprehensive Meta-Analysis v2. (Borenstein, Hedges, Higgins, & Rothstein, 2005) CMA uses Hedges and colleagues' method (Rosenthal, Cooper, & Hedges, 1994) to calculate cumulative effect sizes to yield Hedges G. Significance will be assessed at $p <. 05$. A random effects model will be used in the assessment of the data, determined *a priori.* (Field & Gillet, 2010) A fixed effects model will not be used because there is no evidence upon which to presuppose that the effect of gaming exposure is uniform or consistent across participant populations. Adjustments for data censoring include the surveying of grey literature to mitigate the influence of publication bias. Adjustments for selective reporting (e.g. from participants with regard to previous gaming experience) will be not be done, due to small population sizes and the inability to assume the representativeness of the group as compared to national averages.

Hedges G will be used to evaluate the significance of the correlation between videogame play and surgical ability. The degree of significance observed within the final findings will be the basis upon which the hypothesis is either rejected or supported, and dictates subsequent conclusions. Effect sizes may then be analyzed based on secondarily encoded criteria regarding the games used in each study. Game publishing dates will be used as a representation of general graphical quality. Game genres may be evaluated based upon the primary purpose of the game and cross-referenced with a list of major game genres outlined previously in coding genres. Game controls may or may not be analyzed, dependent on the level of reporting done within the collected studies. Through this process of data collection and review, I will attempt to demonstrate the existence of a statistical relationship between video game play and surgical performance.

Results

A total of 554 articles were collected during the literature compilation process. The subsequent review process is outlined in Figure 1. Details on selected studies, including authors, date, sample size and demographic information can be found in Figure 2.

Ultimately, twenty-one articles were analyzed using CMA software. These articles included a total of 31 studies – 14 game training experiments, 13 historical correlations, and 4 VR simulation experiments. Analysis of both gaming and VR experimental conditions using a random effects model and Hedges' g indicated medium (G = 0.676, 95% CI 0.431 – 0.920, $p < 0.001$) and large effects (G = 1.071, 95% CI 0.558 – 1.585, $p < 0.001$) respectively, as outlined in Figure 3. Additionally, random effects analysis of historical gaming experience using Fisher's Z indicated a small effect (Z = 0.250, 95% CI 0.119 - 0.373, $p < 0.001$) as seen in Figure 4. Given these results, it is not possible to reject the null hypothesis that game and simulator experience will have a non-significant effect on performance outcomes.

Discussion

Up to this point, the general perception surrounding video games as surgical training tools has been an informal acceptance of some degree of positive effect on surgical performance. This analysis of available literature lends credence to this perception, substantiated with statistically significant results in all three analyzed domains. These results are consistent with the general conclusions of a majority of previous studies; however, contradictory results should be investigated for potentially-informative mediating factors. Nevertheless, this study now serves as quantitative evidence for the support of games and game systems as tools for education, and may be used as a stable foundation upon which to justify more extensive and diverse investigations into game-based learning.

It is critically important to recognize the implications of the complexity of surgical tasks being taught. This is not an effort to perpetuate the potentially-disingenuous notion that surgery is exceedingly more difficult than any other task, but rather to use it as an example of a task which requires precise procedural execution in addition to a comprehensive mastery of conceptual information. The point here being that games have the capacity to teach information, in addition (or more accurately, as a prerequisite) to mechanical skill. The observed effects of gameplay and simulation training as well as gaming history are evidently consistent with Rosser et al. (2007), Rosenberg et al. (2005), and many others who observed the relationship between gameplay and surgical performance; however, less obvious is the evidence this study provides for research like that of Dye et al. (2009), Gee (2003), and Prince (2004) with regards to the cognitive effects of gaming. Although my research made no efforts to quantify the cognitive or psychological effects of video game play, differences in mechanical performance may be assumed to be presupposed by cognitive changes. Thus, my synthesis of evidence observing performative differences between gaming and non-gaming groups may be grounds for investigation into the logical precedent of cognitive changes.

I place particular emphasis on this point in order to express the potential for gaming to be used as a learning tool in all educational domains – not just those involving spatial navigation and task execution. Games may be used to teach mechanically or conceptually, and are in fact most effective when designed to seamlessly integrate the two together. By doing so, the game develops a reciprocal system of demands which can only be met through exercising simultaneous proficiency in both conceptual and mechanical skills – not unlike any other complex task. Therefore, the effects observed in this study should not be considered to be inherently limited to surgery.

While this unity of mechanics and concept may represent the ideal for game design, games may still be deconstructed into either of these individual parts, albeit to less effect. A game may demand extensive knowledge with little mechanical or strategic requirements (trivia, for example). The skills required for a game of this format are not unlike those required for standardized academic testing for subjects that require information identification and recall. Conversely, demands for mechanical mastery are present in subjects like mathematics, where a student is required to engage directly with basic information through a specific procedure to reach the correct answer. In general, this relationship can be seen as the difference between knowing *what* and knowing *how*, with either extreme demanding little of the other. Nevertheless, the ultimate goal of education is not a single one of these, but is instead an effort to understand *why*.

This causal understanding – this ability to synthesize and engage with material in a way that is both tangible and conceptually resilient – is the basis for content mastery. Conventional educational methods such as standard or even supplemented lecture represent extremes of either informative or directive education and as a result heavily suppress learning potential. Digital, immersive environments equipped with the tools that allow users to not only learn about, but to manipulate and engage with tangible representations of their knowledge help to mediate the demand for flawless proficiency, in favor of exploration and socialization. The result of this moderation is a system in which content mastery is developed through organic processes, self-selected by individuals to optimally suit their individual interests, needs, learning styles, and motivations.

Engagement within digital environments is supplemented by immersive technology, as explained previously. Given this study's data strongly supporting VR as an effective training tool, it may be speculated that heightened levels of immersion inherent to VR experiences are related to increases in task performance (and by extension, content mastery). VR may prove to be the aspirational ideal for digital environments seeking to educate and engage their users. At this point, there is not enough data observing the entire gaming spectrum to explain or evidence this relationship clearly enough to draw conclusions. Therefore, acquiring an understanding of the operative components behind different levels of immersion is integral to future development and application of game systems as learning tools. Information regarding the differential effects of realism will have far-reaching implications on the domains of digital learning and simulation development.

Research Limitations

This study is labeled as a preliminary review of the research due to the recognized shortcomings of its method, as compared to more rigorous academic standards. While all research and statistical analysis have been reviewed repeatedly, and checked for validity, The primary limitation of this study is the lack of article retrieval in the circumstance that it was not available in full online. One unavailable article was retrieved through direct contact with one of the authors; however, many others were not contacted due to time constraints. Similarly, a number of studies failed to report adequate statistical data for the calculation of effect sizes using CMAS. This is perhaps the most disruptive limitation to the overall quality of the data, as studies that otherwise qualify for analysis go unanalyzed due to a lack of sufficient data. Future analyses should keep this in mind, and take the time to contact studies for raw participant data in order to run more thorough statistical analysis for maximum possible effect.

Furthermore, a recognized limitation is the usage of a single reviewer for the entirety of the article review process. Given the nature of this thesis, it was deemed infeasible to survey additional search strings or additional databases within the available time. Consequently, there is a realistic probability that relevant studies may have missed. Moreover, while the information within this analysis has been validated to the best of my ability, the lack of additional reviewers opens this study to the possibility of various coding errors. Future studies involving multiple reviewers would not only benefit from an increased capacity to survey literature databases, but would also possess greater reliability with regards to study validation and data entry.

Inherent to meta-analyses are several limitations, particularly in relation to study size and populations. The relatively small size of the populations reliable enough to provide accurate data regarding surgical ability means that not only is the power of reported results relatively low in its experimental power, but the degree to which participant populations are representative of the general population is highly limited. This study serves as an effective gateway through which to direct future analysis, likely directed towards addressing the issues of generalizability and power of the reported data.

There is a particular issue regarding the usage of the term “virtual reality”. While a gradual transition of terminology from one concept to the next is to be expected, it becomes problematic when a single phrase develops in such a way that it comes to mean two different things. For example, a study on spinal ultrasounds (Ramlogan et al., 2017) and a meta-analysis on rehabilitation programs (Howard, 2017) both describe their technological resource as “virtual reality”. The issue being that this broad definition of virtual reality fails to communicate with adequate specificity the nature of the involved technology interface. Howard’s usage of the term “virtual reality” refers to a digital 3D rendering, manipulated through a conventional computer interface. This (as Ramlogan and colleagues recognize) is the most common form of VR simulation. They also articulate, however, that VR technology can also include more recent developments, including surround screen and head-mounted display setups.

To clarify, this is not a value judgement on the legitimacy or currency of either of the above studies; rather, it demonstrates a fundamental failure within the literature to properly differentiate between the various forms of “VR” technology. As head-mounted VR and its subsequent iterative forms have the potential to fundamentally change the way we interact with digital media, it becomes increasingly important to delineate the various types of virtual, interactive media. Of note to the consideration of future language is the popularized definition of “VR” - almost exclusively referring to modern, head-mounted displays. While there may be value within the scientific discipline for opting otherwise, defining technology different to that of the popular definition may create barriers to accurate communication of findings to the public audience.

Much like the above issue with virtual reality, the term “simulation” has become an amalgam of different concepts, unified by a similar purpose. During my research, I found “simulation” to mean one of three things:

i. A digital simulation such as a game, simulated task, or interactive scenario.
ii. A physical simulation, using physical props to replicate real-life surgical tasks.
iii. A mock scenario, involving a combination of task execution, group organization, and personal communication, potentially involving either or both of the above scenarios.

It seems, based on the above list, that the capacity for digital simulations to emulate a wide variety of tasks has resulted in the homogenization of reference terminology. Similar to the above passage, the conflation of vocabulary in this manner makes for increasingly difficult and inefficient literature communication. Thus, linguistic differentiation of unique concepts is important to maintaining the accessibility of large portions of important experimental research. Therefore, it may be beneficial to consider the distinction of particular forms of simulation, likely using operative adjectives such as “digital”, “physical”, and “realistic”. Doing so would allow for easier discrimination between study topics in the future, without necessitating the invention of new terminology.

Another limitation, akin to that of most other self-report studies, is the possibility of inaccurate, or deliberately misrepresentative information on history inventories. Gaming has historically been a somewhat antisocial and generally disparaged activity by public perception. Only in recent years has the pervasiveness of gaming in its various forms made gaming a socially acceptable activity. Still, the effects of historical deprecation extend rather deep within the mind of affected individuals, and as such they may feel less compelled to report accurate statistics regarding their time playing video games. Alternatively, simple lack of knowledge on the duration of play across the lifespan may influence data reports. Overall, the studies involving self-report metrics should be considered vulnerable to a moderate degree of reporting bias.

Future Directions

Future meta-analysis should consider information stated previously regarding obstacles to effective data acquisition, and should endeavor to obtain more significant quantities of data at a higher quality threshold. It should be recognized that this study consists of a fraction of relevant literature, even amongst eligible studies pulled by the methodized search string. A more thorough analysis would retrieve such studies (and if possible raw data) directly from authors, and use available data to develop a more comprehensive analysis of game effects. Those results might then be used to draw more concrete conclusions regarding the effects of gaming, which may then be applied to develop more effective simulative systems.

Further research into the subject of gaming influences should consider analyzing the differential effects of game genres, as was casually observed in several studies. They should also consider investigating the differences between preoperational “warmup” gaming and "off-duty" gaming effects, in addition to the effects of both concurrent game "training" as well as simulation training. Furthermore, given the observed differences in effect between game and VR simulation training, it may be valuable to investigate the effects of immersive or realistic tools, such as head-mounted VR displays, and different control schemes. While the practicality of some setups may be prohibitive to their effective implementation whole-cloth (i.e head-mounted VR may prove exhaustive or unwieldy for simulated exercises) the lessons therein should be helpful in developing accurate and ergonomically tolerable systems.

Conclusion

The effects of video games on surgical performance have been a popular discussion for over a decade, and yet this analysis is the first to provide statistical evidence for the relationship between multiple dimensions of gaming exposure and simulative performance metrics. While still necessitating further analysis in order to draw more qualified conclusions, this thesis provides both significant evidence as to the positive effect of gaming, as well as additional insights and direction regarding the conceptual basis for future gaming research. Gaming remains a burgeoning realm of scientific possibility, developmentally fueled by consumers and researchers alike. It is through the continued efforts of the scientific community, aimed at uncovering the mechanisms behind human's nature as gamers, that gaming might be applied in ways that revolutionize the way we teach, learn, and engage in the world around us.

Appendix

Figure 1
Diagram tracking the process of study selection.

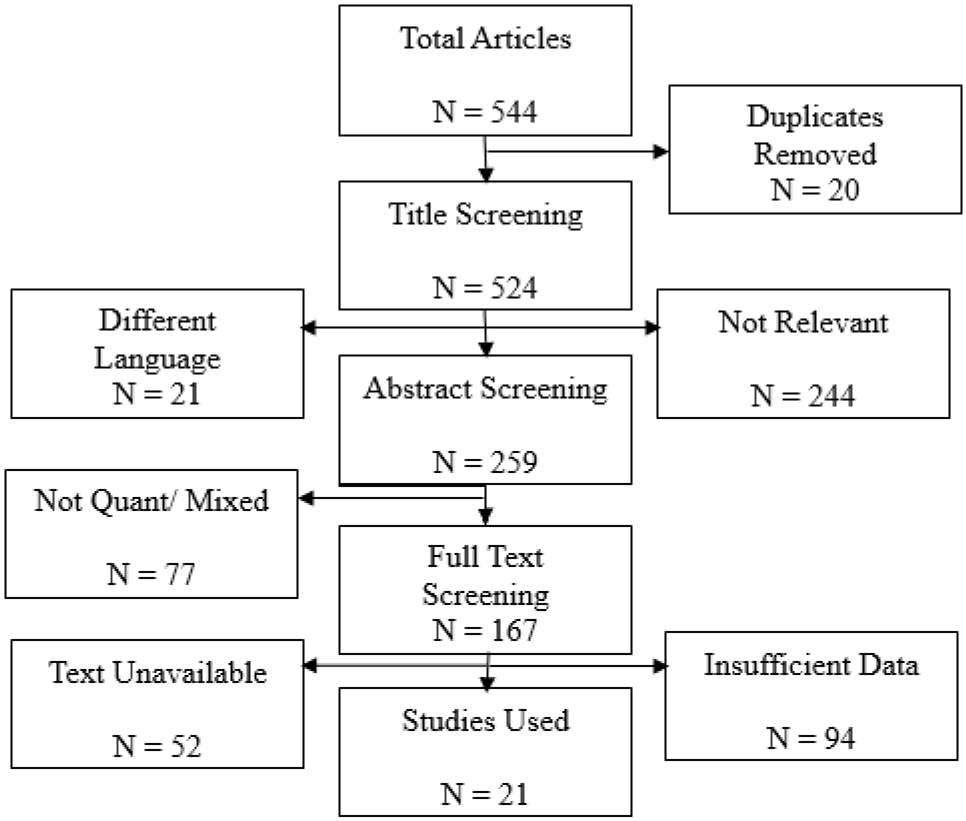

Figure 2

Table detailing demographic and organizational information of selected studies

Study	Year	Sample Size	Experimental Design	Modality	Demographic
Badurdeen et al.	2010	20	Quasi/Experimental	Game Training	Medical Students & Junior Doctors
Bronnimann et al.	2015	63	Quasi/Experimental	Game Training	Adult Laypersons
Chien et al.	2013	7	Quasi/Experimental	Game Training	Medical Students
de Arujo et al.	2016	15	Quasi/Experimental	Game Training	Medical Students (First Year)
Jalink et al.	2014	29	Quasi/Experimental	Game Training	Laporoscopic Experts
Ju et al.	2012	84	Quasi/Experimental	Game Training	Medical Students
Miskray et al.	2003	46	Quasi/Experimental	Game Training	Surgical Delegates
Rosser et al.	2016	68	Quasi/Experimental	Game Training	Surgical Residents and Attendings
Wasberg et al.	2005	64	Quasi/Experimental	Game Training	Undergraduate, Graduate, and Medical Students
Yule et al.	2011	54	Quasi/Experimental	Game Training	Surgical Residents
Akand et al.	2016	60	Correlational	Historical	Pre-Medical
Harbin et al.	2016	75	Correlational	Historical	Medical Students (Pre-Clinical)
Khatri et al.	2014	38	Correlational	Historical	Medical Students
Lin et al.	2015	370	Correlational	Historical	Medical students, interns, medical officers, surgical trainees, surgeons.
Sadandanan et al.	2008	30	Correlational	Historical	Med Students, Surgical Residents, and Surgical Attendings
Shane et al.	2007	7	Correlational	Historical	Inexperienced Undergraduate and Graduate Students
Silvennoinen et al.	2012	13	Correlational	Historical	Surgical Residents
van Dongen et al.	2011	46	Correlational	Historical	Surgical Interns and Children
van Hove et al.	2008	35	Correlational	Historical	Surgical Residents
Cannon et al.	2015	48	Quasi/Experimental	VR Training	Medical Students
Chien et al.	2013	7	Quasi/Experimental	VR Training	Medical Students
Hsu et al.	2004	41	Quasi/Experimental	VR Training	Unskilled and Skilled Operators

Figure 3

Hedge's G effect size of gathered data (relevant to training modalities).

Groups	Effect size and 95% confidence interval							Test of null (2-Tail)	
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit		Z-value	P-value
Fixed effect analysis									
Game Training	14	0.634	0.087	0.008	0.464	0.805		7.313	0.000
Historical	13	0.282	0.070	0.005	0.144	0.419		4.002	0.000
VR Training	4	0.960	0.204	0.041	0.561	1.359		4.717	0.000
Random effects analysis									
Game Training	14	0.676	0.125	0.016	0.431	0.920		5.409	0.000
Historical	13	0.456	0.127	0.016	0.207	0.704		3.598	0.000
VR Training	4	1.071	0.262	0.069	0.558	1.585		4.090	0.000

Heterogeneity				Tau-squared			
Q-value	df (Q)	P-value	I-squared	Tau Squared	Standard Error	Variance	Tau
30.511	13	0.004	57.392	0.146	0.105	0.011	0.382
16.623	12	0.164	27.811	0.030	0.047	0.002	0.174
7.090	3	0.069	57.689	0.254	0.367	0.135	0.504

Figure 4

Fisher’s Z correlation of gathered data (relevant to historical observations).

Groups		Effect size and 95% interval			Test of null (2-Tail)	
Group	**Number Studies**	**Point estimate**	**Lower limit**	**Upper limit**	**Z-value**	**P-value**
Fixed effect analysis						
Game Training	14	0.356	0.285	0.424	9.161	0.000
Historical	13	0.150	0.083	0.216	4.352	0.000
VR Training	4	0.475	0.326	0.602	5.667	0.000
Random effects analysis						
Game Training	14	0.350	0.229	0.461	5.418	0.000
Historical	13	0.250	0.119	0.373	3.674	0.000
VR Training	4	0.512	0.298	0.677	4.302	0.000

Heterogeneity				Tau-squared			
Q-value	**df (Q)**	**P-value**	**I-squared**	**Tau Squared**	**Standard Error**	**Variance**	**Tau**
40.156	13	0.000	67.626	0.050	0.031	0.001	0.223
21.990	12	0.038	45.431	0.016	0.016	0.000	0.126
8.142	3	0.043	63.153	0.060	0.079	0.006	0.245

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