

The Pennsylvania State University

The Graduate School

College of the Liberal Arts

**SCIENCE FICTION MEETS SCIENTIFIC INQUIRY:
A TASK-TECHNOLOGY FIT/COMPUTER-BASED TRAINING FRAMEWORK
AND A META-ANALYSIS OF VIRTUAL REALITY APPLICATIONS FOR
INTERVENTION, TRAINING, AND THERAPY PURPOSES**

A Dissertation in

Psychology

by

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Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Doctor of Philosophy

December 2015

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Abstract

In the current document, an integrative CBT-TTF framework is created, which proposes: technologies that require large amounts of working memory are best at improving outcomes that require little working memory to develop, and vice versa. Then, a meta-analysis of virtual reality (VR) training programs (which require great amounts of working memory) is performed to test their effectiveness across various outcomes. VR training programs are more effective as the outcome's working memory requirement decreases; however, these results are only true for cognitive outcomes, most important to organizational researchers, and new theories are needed to understand the effect of technologies on developing social, emotional, and physical outcomes. Further, I also perform a meta-analysis which demonstrates that specialized display hardware (i.e. head-mounted displays, surround screen displays, etc.), video game elements (i.e. score, competition, etc.), workplace samples, and no-treatment control groups positively impact VR intervention effectiveness. Alternatively, specialized input hardware (i.e. motion sensors, floor pads, etc.), multi-user environments, child samples, and special samples have no effect on VR intervention effectiveness. Together, these results can guide future research and practice in creating more effective VR interventions for developing cognitive, social, emotional, and physical outcomes.

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SCIENCE FICTION MEETS SCIENTIFIC INQUIRY: THE CREATION OF A NEW TASK-TECHNOLOGY FIT PERSPECTIVE AND A META-ANALYSIS OF VIRTUAL REALITY TRAINING PROGRAMS

Chapter 1

Introduction

In recent years, the popularity of virtual reality (VR) has greatly expanded, and the technology has been applied to an array of leisure and work settings (Barrett, 2014; Newman, 2014; Seth et al., 2011). Gaming remains the most popular application (Saposnik et al., 2010; Wuang et al., 2011), but workplaces are implementing VR at increasing rates – particularly for training purposes. Indeed, many organizations have already implemented VR training programs, discovering that VR can reduce the number of trainers and other costly resources while improving outcomes (Lee et al., 2012; Mirelman et al., 2010; Van Dongen et al., 2011). Modern VR systems can also present a wide array of real world scenarios to provide depth to the training environment, and the training possibilities are only limited by the coding abilities of programmers and the associated development costs. Most importantly, once these programs are created, training can proceed at much lower costs. As such, VR can reduce the overall costs of training programs, while providing better trainee outcomes, and can be applied to almost any workplace. For these reasons, the popularity of VR for training purposes is expected to steadily grow in the future.

While VR training programs are certainly cutting-edge, authors have warned against their over-zealous and unwarranted use (Mantovani et al., 2003; Stone et al., 2011; Tichon, 2007). As Bedwell and Salas so clearly note, “sometimes the lure of what seems to be *exciting training* overshadows what really matters – *good training*” (2010, p. 239, italics in original). Many authors have investigated the actual effectiveness of VR training programs, and extant research

remains mixed. Several have demonstrated that these programs are effective across an array of contexts (Aoki et al., 2007; Cho et al., 2002; Farra et al., 2013; Hays & Vincenzi, 2000; Stone et al., 2011), but others have provided contradictory results (Agazio et al., 2002; Butavicius et al., 2012; Man et al., 2012; Stone, 2001). As Fletcher and Tobias (2006) note, many VR training programs provide positive benefits to trainee reactions, but they often struggle with providing adequate skill development. While it is important for trainees to have positive actions and be engaged in the process, developing the necessary job related skills and underlying knowledge of the training program are the ultimate requirements. These results and others have created uncertainty towards the true efficacy of VR training.

Many causes can be ascribed to disparities in VR training results, and possibly the most noteworthy is the application itself. Several authors have applied Task-Technology Fit (TTF) Theory, which posits that technologies should be used only when they “match” a task. This suggests that VR is effective for only certain training purposes (Gallagher et al., 2013; Goodhue & Thompson, 1995; Snyder et al., 2011); however, many concerns arise when applying this theory. TTF Theory does not provide explanatory mechanisms or boundary conditions for the proposed effects, and authors cannot be certain when good fit has been achieved – or even why good fit is beneficial. In other words, TTF Theory predicts that the effects of technologies are dependent on the application, but the theory cannot predict these effects or provide other useful information regarding the specific application. Due to the deficiencies of TTF Theory, this study seeks to integrate other theoretical approaches in the Computer-Based Training (CBT) literature to create an integrative TTF-CBT framework that is specific to training. In doing so, explanatory mechanisms and boundary conditions are proposed for the differential effectiveness of all CBT

programs across training outcomes. Specifically this new approach applies a novel framework to predict the differential impact of VR training programs.

Further, as noted by prior authors (Anderson, 2003; Gamberini et al., 2008; Gurusamy et al., 2008; Irish, 2013), a comprehensive and integrative analyses of TTF Theory has yet to be performed despite widespread use, and the ideal applications for most technologies are still unknown. In determining the differential effectiveness of VR training programs, this study likewise tests both TTF theory and the new, integrative TTF-CBT framework. To do so meta-analytic methods are applied to systematically evaluate the efficacy of VR across seven different applications.

To achieve these objectives, the work is organized as follows: First a description of the theoretical rationale and concerns of TTF Theory, focusing on boundary conditions and explanatory mechanisms is provided. Then, modern CBT theories and perspectives on TTF Theory to address relevant concerns are offered, resulting in an integrative CBT-TTF framework. Next, an overview of CBT technologies and commonly trained outcomes is presented. Then, several predictions about the differential effects of VR for the development of the reviewed outcomes are made. These predictions are tested through a meta-analysis. Lastly, the benefits for theory and practice across the research and application of training and technology are discussed.

Chapter 2

An Integrative Task-Technology Fit and CBT Framework

Task-Technology Fit Theory

Researchers have tested CBT programs to improve almost every possible aspect of personal development, ranging from cognitive to social to emotional to physical outcomes (Baños et al., 2011; Rus-Calafell et al., 2014; Saposnik et al., 2010; Su & Cheng, 2013). Throughout these tests, authors have recognized that particular CBT programs are more effective at developing certain outcomes more so than others. As an example of this differential success, simulations consistently improve declarative knowledge but they have lackluster success in developing complex skills (Veermans et al., 2006; De Jong et al., 1999). This finding and similar ones have led Goodhue and Thompson (1995) to create Task-Technology Fit (TTF) Theory (Dennis & Kinney, 1998; Valacich et al., 1994).

TTF Theory proposes that researchers and practitioners should match tasks with appropriate technologies, whereas a “match” is defined by, “the degree to which technology assists an individual in performing his or her portfolio of tasks” (Goodhue & Thompson, 1995, p. 216). Since the original publication, authors have remained true to the original premise of the theory, only changing details to better fit the application of interest (e.g. “TTF ... [is] the extent to which the website facilitates the accomplishments of a user’s tasks”; Liu & Goodhue, 2012, p. 1246); however, a “match” is defined in many different manners in modern research. Daft and colleagues, for example, judge a “match” on the amount of feedback, cues, language variety, and personal focus required by the task and provided by the technology (Daft & Lengel, 1986; Daft et al., 1987; Trevino et al., 1987; 1990); van der Land and colleagues (2013) consider a “match” as a task which requires the interpretation of visual information and technology which presents

visual information; and Maruping and Agarwal (2004) note that a “match” can be defined by degrees of coordination, communication, and information processing required by a task and provided by a technology. As evident from these instances, a “match” is defined in a vague manner, possibly even to the level of circularity, leading authors to attribute many aspects of the task and technology to outcome success.

While TTF Theory is succinct and often invoked, its application poses several concerns. First, any true theory should be falsifiable (Eisenhardt & Graebner, 2007; Sutton & Staw, 1995; Weick, 1995). If a theory cannot be explicitly unsupported, then researchers can never be certain if it is a reasonable explanation for an observed phenomenon. TTF Theory’s vagueness does not allow the theory to be falsifiable. Imprecise conditions are provided for a “match,” and any well (poor) performing CBT could be claimed to possess good (bad) fit, giving further rise to circularity or the confound of process with outcome. For example, a VR program that ineffectively teaches aviation skills could be claimed to provide insufficient visual information for optimal learning, and a researcher could continuously alter the visual information provided. At each iteration, the researcher could claim that the amount, realism, design, or any other aspect of visual information is still not sufficient. Even yet, at each iteration, the author could also claim that any other element is also a poor fit, and at no point could the researcher claim that maximum fit is achieved. In practice, authors often claim that the technology with the best outcomes has the greatest fit – even if researchers are unable to identify which aspects of the task and technology actually “match.” Thus, TTF theory is not falsifiable.

Second, theories are meant to identify explanatory mechanisms or boundary conditions (Eisenhardt & Graebner, 2007; Sutton & Staw, 1995; Weick, 1995). TTF Theory does not satisfy this requirement. No explanatory mechanism is provided for the benefits of a “match,”

such as increased motivation, cognitive engagement, or schema activation. Also, because the theory does not specify when a “match” occurs, it fails to provide boundary conditions. Thus, TTF Theory does not provide sufficient information to predict the occurrence or outcomes of actual task-technology fit.

Given these concerns, TTF Theory may be insufficient to understand the interaction between CBT programs, including VR, and various applications. For this reason, the current study identifies and integrates other theoretical perspectives to create a more complete TTF-CBT framework; one that provides explanatory mechanisms and boundary conditions for task-technology fit in a training context. The incorporated perspectives are centered on working memory, experiential knowledge, and entertainment (Bedwell et al., 2012; Kolb, 2014; Pass et al., 2003; 2010). Each perspective proposes competing cognitive mechanisms for the impact of CBT programs on outcome development; however, it is argued here that they can provide a complementary view of CBT.

Competing Cognitive Mechanisms

Researchers have applied many other perspectives to explain CBT successes. Three of these perspectives relate to working memory, experiential knowledge, and entertainment.

The working memory perspective arises from cognitive load theory (Paas et al., 2003; Plass et al., 2010) and seductive detail theory (Garner et al., 1992; Rey, 2012). Both theories propose that extraneous aspects of a training program, such as unnecessary instructional information reduce learning outcomes by encumbering trainees’ limited cognitive resources. The two theories differ, however, on the methods that extraneous aspects encumber cognitive resources. Cognitive load theory proposes that individuals’ working memory is limited, and

extraneous details encumber working memory that would otherwise encode learning material (Paas et al., 2003; Plass et al., 2010). Alternatively, seductive detail theory proposes that, in addition to encumbering working memory, extraneous details may trigger irrelevant schemas which deter the encoding of information and associates incorrect details (Garner et al., 1992; Rey, 2012). In modern research, support has been provided for the proposed mechanisms of both theories, working memory encumbrance and irrelevant schema activation, and extraneous aspects of a training have repeatedly been shown to reduce learning outcomes (Rey, 2012).

When viewing CBT from the working memory perspective, the best CBT reduces as many elements as possible to eliminate extraneous aspects. With this logic, simple CBT programs, such as simulations, should be more effective than complicated CBT programs, such as VR. This may explain why many Business schools use simulations for course instruction.

Alternatively, the experiential knowledge perspective stems from experiential learning (Kolb, 2014; Kolb & Kolb, 2005) and fidelity research (Lee, 2006; Macciarella et al., 2006). Both of these domains posit that the training environment should be as similar as possible to the transfer environment. Experiential learning research proposes that certain skills can best be developed through doing, and certain people may prefer to develop all skills through doing – even when alternative methods may be more effective (Kolb, 2014; Kolb & Kolb, 2005). Many justifications can be provided for the effectiveness of experiential learning. Notably, experiences can clarify abstract concepts and ease the interpretation of difficult information. As Kolb states,

“Immediate personal experience is the focal point for learning, giving life, texture, and subjective personal meaning to abstract concepts and at the same time providing a concrete, publicly shared reference point for testing the implications and validity of ideas created during the learning process. When human beings share an experience, they can share it fully, concretely, and abstractly.” (2006, p. 21)

Additionally, realistic training tasks and experiential learning provide many other benefits (Lee, 2006; Macciarella et al., 2006). Experiences can often provide immediate, clear feedback, and learners can reflect upon their observations to form knowledge. In other learning methods, feedback may be less clear or unavailable altogether. Also, realistic training tasks reduce the difficulty of transfer to natural environments, as individuals do not need to modify their behavior any further after the training. Whereas other methods may require individuals to “translate” their learned knowledge to the application environment, training programs focused on experiential learning do not possess these detriments. Through these benefits, many authors have heavily supported experiential learning.

When viewing CBT from the experiential knowledge perspective, the best CBT programs present training environments that are as realistic as possible to the transfer environment. With this logic, complex CBT programs, such as VR, should be more effective than simple CBT programs, such as simulations. This may explain the widespread use of VR to train doctors and surgeons, as well as the growing interest in VR for other applications.

Lastly, the entertainment perspective emerged from the serious game movement (Arnab et al., 2015; Connolly et al., 2012; Ritterfeld et al., 2009). The serious game movement applies game elements, such as score and suspense, to CBT programs to improve trainee enjoyment, engagement, and motivation. Initially, the rationale behind serious games was simple. Authors proposed that people enjoy video games as a pastime, and trainees should likewise enjoy educational CBT programs with game elements. Recent research has applied motivation theories to understand when and how game elements improve training outcomes (Bedwell et al., 2012; Connolly et al., 2012). Amongst the most popular theories to understand serious games is self-determination theory, which proposes that individuals will be motivated towards a task if they

experience autonomy and competence (Thompson et al., 2008; Wouters et al., 2013). Many serious games are self-paced and challenging, directly relating to self-determination theory. More importantly, the incorporation of motivation theories indicates that serious games incur motivational rather than cognitive effects. That is, although trainees may need to allocate some working memory to game elements, their continued impact may occur subconsciously. Thus, serious game elements improve motivation and related outcomes with or without taxing working memory.

When viewing CBT from the entertainment perspective, the best CBT programs present fun and exciting training elements. With this logic, entertaining CBT programs, such as serious games and VR, should be the more effective than standard CBT programs, such as simulations. This may explain the widespread use of serious games in school settings.

Together, these three perspectives – working memory, experiential knowledge, and entertainment – provide conflicting views to the ideal technology for outcome development. This study seeks to combine these perspectives to create a unified understanding of CBT. As such the model underlying this study is that training programs should not tax working memory with extraneous details, but it is also important to provide an entertaining training with satisfactory fidelity. The combination of these notions is the premise for the integrated TTF-CBT framework; however, commonly applied technologies and training applications need to be reviewed to subsequently identify conditions of task-technology fit and the relevance to working memory, experiential knowledge, and entertainment.

CBT Technology

As mentioned, many different CBT programs exist, and their varying properties cause their effects to differ. For example, simulations have differing effects and outcomes compared to VR programs, and theories should not treat these technologies identically. For this reason, authors have identified many categories of CBT programs. In the current study, CBT programs are differentiated by their technologies – software, output hardware, and input hardware.

Software

Simulations. Simulations present working representations of reality (Veermans et al., 2006; De Jong et al., 1999). Originally, simulations were applied due to computing limitations. Early computers could not process complex digital environments, but they could present simple representations of workplaces. Today, simulations may range from only text to the inclusion of pictures, videos, and interactive elements. While varying in complexity, simulations reduce the workplace to be understandable. For example, many Business schools use simulations for MBA education. The simulations present faux business reports, and students allocate organizational resources to maximize outcomes. Most information is text-based, and any interaction is performed through buttons in the computer program. Through this method, students and trainees may develop an understanding of organizational dynamics, among other topics, without being distracted by irrelevant aspects of the transfer environment. Of all CBT software, simulations are likely the least complex, requires little working memory, and present the lowest fidelity.

Virtual Reality. VR programs present a three-dimensional digital replication of reality, and users control a representation of themselves, called an avatar, to navigate the environment (Burdea & Coiffet, 2003; Rheingold, 1991; Steuer, 1992). Trainees must continuously monitor their complex digital surroundings, and learn new controls to navigate their environment. Most often, trainees perform the desired skills in the digital environment, such as a surgical procedure,

to transfer behaviors to the workplace. In these instances, the training material is integrated into the digital environment. Sometimes, however, VR is solely used to increase trainee excitement, and the material is not integrated into the environment. For example, a VR program could teach declarative knowledge by having trainees find facts scattered about the environment, such as written on hidden notes. Of modern CBT software, VR is likely the most complex, requires much working memory, and present the greatest fidelity. Also, VR is fun and enjoyable.

Serious Games. Serious games are computer programs that include common video game elements to enhance learning and user reactions, and they are possibly the quickest-growing type of CBT (Connolly et al., 2012; Ritterfeld et al., 2009). Several authors have created taxonomies of video game elements to understand their individual effects. Likely the most popular is Bedwell and colleagues' (2012) which includes 19 different serious game elements. Amongst the most popular and effective elements are assessment, control, immersion, and rules/goals. Currently, several theories have been applied to explain serious game effects, often proposing that serious games prompt greater motivation. Also, serious games exist in many forms. In fact, serious games may be simulations, VR, or something else altogether. Therefore, serious games may or may not be complex and/or realistic, but they generally prompt user enjoyment.

Hardware

Output

Monitor. The most common CBT output device is the monitor. The widespread use of the monitor likely stems from its low cost and wide availability; however, other practical factors support its application. When compared to other visual output devices, the monitor is the only one that can natively present each of the software noted above. Of all hardware output, the monitor is the least complex, requires little working memory, and presents the lowest fidelity.

Immersive Displays. Surround-screen and head-mounted displays (HMDs) are the two most popular immersive displays (Mon-Williams et al., 1993; Shibata, 2002). Surround-screen displays involve a number of two-dimensional displays placed around users to imitate an immersive environment. Alternatively, HMDs are digital screens placed in front of users' eyes, appearing similar to night-vision goggles, encapsulating the entire field of vision. HMDs provide point-of-view changes by tracking head movements. Of modern hardware output, immersive displays are the most complex, require much working memory, and present the greatest fidelity. Also, users generally like immersive displays, increasing enjoyment.

Input

Keyboard & Mouse. The most common CBT input is the keyboard and mouse. Most any trainee has likely used a keyboard and mouse, eliminating the need to acclimate to new technology. Further, most software is designed to be controlled by a keyboard and mouse, allowing organizations to use their existing resources. Of all hardware input, the keyboard and mouse are the least complex, requires little working memory, and present the lowest fidelity.

Specialized Input. Some CBT programs involve specialized input hardware that provide a natural interface to perform tasks. For example, a CBT for aviation may include hardware that presents a complete replication of a cockpit. Similarly, in some cities, bus drivers are trained with hardware that faithfully reproduces a bus. While still rare today, specialized input are quickly becoming more popular. Further, of all hardware input technologies, specialized inputs are the most complex, require much working memory, and present the greatest fidelity.

Applications of CBT

With CBT technologies reviewed, it is important to now consider applications of CBT programs to differentiate the effects of technologies on various training outcomes. In doing so, we can categorize outcomes by the amount of working memory required for development. Further, organizations are largely interested in training cognitive outcomes, and this integrative TTF-CBT framework solely focuses on cognitive outcome development due to their workplace importance (Baldwin & Ford, 1988; Burke & Hutchins, 2007; Woehr & Huffcutt, 1994). Cognitive outcomes involve the incorporation of new information to memory, and can be defined as “a class of variables related to the quantity and type of knowledge and the relationship among knowledge elements” (Kraiger, Ford, & Salas, 1993; p. 313). Through adapting existing taxonomies (Anderson et al., 2001; Bloom, 1956; Byun et al., 2012; Ford et al., 2009; Kraiger et al., 1993), cognitive outcomes can be distilled into seven different categories.

Possibly the most working-memory intensive cognitive outcome is the development of declarative knowledge, also synonymous with verbal knowledge, basic knowledge, procedural knowledge, and tacit knowledge (Alexander & Judy, 1988; Kozlowski & Bell, 2006; Kraiger et al., 1993; Reber, 1989). Declarative knowledge involves the direct interpretation and cognitive encoding of information, and most tasks are impossible without relevant declarative knowledge (Kozlowski et al., 2001; Szymanski, 1988). Welding is impossible, for example, without extensive knowledge of welding equipment and materials. To incorporate declarative knowledge to memory, trainees must repeat information in their conscious thoughts, also called mental rehearsal, which requires continuous use of working memory resources (Davis & Yi, 2004; Yi & Davis, 2003; Squire, 1992). Because declarative knowledge development largely does not rely on subconscious processes and automatization, unlike many other cognitive outcomes, it is amongst the most working memory intensive cognitive outcomes.

Second, wayfinding is closely related to declarative knowledge, and can be defined as the navigation of environments to find an object or location (Bliss et al., 1997; Vilar et al., 2014). Memorizing paths and environments require a great extent of working memory, and can be conceptualized as consciously encoding several similar and related pieces of declarative knowledge (i.e. take a left at the landmark, continue for a mile, etc.). Thus, wayfinding likely requires about as much working memory as declarative knowledge to develop – if not more.

The third cognitive outcome category is cognitive strategies, defined as mental tactics to incorporate, access, and apply information (Pressley, 1990; Tetlock et al., 1989), and the most commonly studied cognitive strategy is metacognitive skills, the recognition and regulation of cognitions (Decety & Lamm, 2007; Dinsmore et al., 2008). Metacognitive skills include planning, monitoring, and revising goal-appropriate behavior, and applying mental strategies to facilitate knowledge acquisition and application. Prior research has shown that trained experts have superior metacognitive skills to novices, and those with effective metacognitive skills are more likely to discontinue problematic problem-solving strategies, accurately estimate task difficulty, and efficiently achieve goals (Kipnis & Hofstein, 2008; Veenman et al., 2006).

Several cognitive strategy training methods exist (Batha & Carroll, 2007; Chen, 1991; Soliman & Mathna, 2009). Most programs require trainees to perform desired activities, but they are periodically removed from the training environment and questioned about the activity (Montague & Bos, 1986; Winkens et al., 2009). This process prompts trainees to consider their interpretation of information and cognitive processes (Ghatala et al., 1985; Winkens et al., 2009). Therefore, cognitive strategy training programs prompt trainees to occasionally devote their working memory towards their own cognitions, causing cognitive strategy development to be working memory intensive but not to the extent of declarative knowledge and wayfinding.

The fourth cognitive outcome category is knowledge organization, the categorization and structuring of information in relation to prior knowledge, and knowledge organization is often conceptualized as mental models (Davis et al., 2003; Ford et al., 2009; Mohammed et al., 2010). Compared to novices, experienced employees possess mental models with a greater number and more accurate connections between elements, and those with more complete mental models can identify and address problems more efficiently (Anderson et al., 2005; Gentner & Stevens, 2014; Jacobson, 2001). Elements can be people, objects, places, events, concepts, or even oneself.

Several methods can develop knowledge organization (Lewis, 2003; Palmunen et al., 2013; Schmidt & Ford, 2003). Many such training programs occur over the course of several weeks, as trainees require repeated exposures to a concept or environment to understand the inter-relationships of elements. Also, a primary outcome of cross-training is to improve knowledge organization (Marks et al., 2002; Volpe et al., 1996). Cross-training educates trainees in an array of workplace duties to better understand the relationship between the duties. In these examples, and others relevant to knowledge organization, some conscious thought and mental rehearsal is required, but knowledge organization is also developed through subconscious processes and repeated exposure to information. While knowledge organization requires some working memory to develop, it is likely less than the aforementioned outcomes.

Fifth, skills are series of sequentially and hierarchically organized behaviors. Most training programs develop skills, as workplace duties are completed through integrating several types of knowledge to perform behaviors (Davis & Yi, 2004; Ford et al., 2009; Taylor et al., 2005). For example, knowledge of welding tools is required to weld, but an array of knowledge and knowledge organization is needed to be a successful welder. Though skills are complex to develop, they may actually need less working memory than other cognitive outcomes (Dienes,

2012; Kolb, 2014). Skills require mental rehearsal to initiate development, but are gradually improved through subconscious processes and automatization that inherently involve a reduction to working memory taxation in favor of autonomic processes (Davis & Yi, 2004; Marcus et al., 2013). In short, skills require mental rehearsal to initiate development, but transition into less thoughtful behaviors. Therefore, skills require little working memory to develop.

Mental ability is the sixth cognitive outcome category, and does not involve the encoding of information to memory. Instead, mental ability is the quickness of thought, thinking logically, and using novel methods to solve problems (Burgess et al., 2011; Harrison et al., 2013; Unsworth et al., 2014). Employees with greater mental ability are better performers, prompting organizations to be interested in mental ability development. Developing this abilities solely involves subconscious processes rather than mental rehearsal, as the encoding of knowledge is not necessary. Thus, mental ability requires little working memory to develop.

The seventh and last cognitive outcome category is spatial ability, which is the capability to understand three-dimensional relations among objects (Just & Carpenter, 1985; Williams & Meck, 1991). This ability is used in navigation, movement, and the manipulation of objects. Spatial ability development is considered an autonomic process that requires little working memory to develop, as spatial abilities do not involve the encoding of knowledge.

Together, in decreasing order of working memory necessary for development, the seven cognitive outcome categories are: declarative knowledge, wayfinding, cognitive strategies, knowledge organization, skills, mental ability, and spatial abilities. With the focus on working memory and the outcomes noted, an integrative TTF-CBT framework using the reviewed theories, which is then subsequently applied to better understand the discussed technologies and outcomes.

Integration of Theories, Technologies, and Contexts

Together, TTF theory is insufficient to understand the dynamics and differential outcomes of CBT programs, including VR training programs. To create a new and integrative TTF-CBT framework, an analysis of the past research and underlying theories has been supplemented with the work on working memory, experiential knowledge, and entertainment value. Layered on the above it is noted that CBT programs have differential dynamics and effects depending on the technology and application, especially in regards to working memory. Given these cumulative inferences, an integrative TTF-CBT framework is offered.

The premise of the integrative TTF-CBT framework is: For a CBT to be effective, the technology should present as realistic and/or entertaining of an experience as possible without burdening the trainees' working memory resources necessary to develop the outcome of interest. In other words, outcomes which require little (much) working memory to develop should be paired with technologies which require much (little) working memory to maximize training outcomes. The benefits of the technology should only be viewed in addition to the cognitive requirements of the outcome itself. In this definition, a "match" occurs when the technology provides as much fidelity and/or entertainment as possible without burdening working memory resources required by the training application. Also, when applying this framework, increased fidelity may ease the transfer of developed outcomes to naturalistic environments through the clarification of abstract thought through concrete experiences, whereas entertainment may increase trainee motivation. Together, this framework provides understandable guidelines for CBT effectiveness, suggestions for explanatory mechanisms, and clear boundary conditions.

The integrative TTF-CBT framework explains several findings that were unclear with TTF Theory alone. Particularly, the framework indicates which technologies may be appropriate

for particular outcome development. Table 1 notes the technologies' impact on working memory, perceived fidelity, and enjoyment. Table 2 presents a spectrum of working memory required to develop the discussed cognitive outcomes. When predicting conditions of training and technology match, authors should consider the amount of working memory utilized by the technology (Table 1) and the spectrum of working memory required to develop the outcome (Table 2). For example, skills may be best trained on a VR program using a HMD and specialized hardware, whereas declarative knowledge may be best trained on a simulation using a keyboard, mouse, and monitor. To clarify the implications, Figure 1 addresses the combination of technologies and applications in predicting outcome development success.

With a new framework proposed, the framework is applied to better understand a particular technology – VR. As mentioned, VR is amongst the fastest growing CBT technologies, and authors have applied the technology for an array of purposes; however, the ideal applications of VR are still unknown. Predicted by the integrative TTF-CBT framework, technologies that demand working memory should be paired with applications that require little working memory. VR, which requires ample working memory resources, may produce lackluster results when applied to applications that also require working memory resources, such as learning declarative knowledge, but provide beneficial results when paired with applications which do not require working memory resources, such as developing skills. Therefore, the poor outcomes of certain VR training programs may be due to the application.

To test this prediction, the integrative TTF-CBT framework is applied to hypothesize that VR training programs are most effective when applied to develop outcomes that require little working memory. Of the cognitive outcomes reviewed, it is predicted that VR training programs are, when compared to alternative training programs, less effective at developing declarative

knowledge and wayfinding; roughly equal at developing cognitive strategies and knowledge organization; and more effective at developing skills, mental ability, and spatial abilities. Also, the predicted order of VR program outcome effectiveness, from least to most effective, is declarative knowledge, wayfinding, cognitive strategies, knowledge organization, skills, mental ability, and spatial abilities.

Hypothesis 1: VR training programs are less effective than comparable training programs at developing declarative knowledge.

Hypothesis 2: VR training programs are less effective than comparable training programs at developing wayfinding.

Hypothesis 3: VR training programs are as effective as comparable training programs at developing cognitive strategies.

Hypothesis 4: VR training programs are as effective as comparable training programs at developing knowledge organization.

Hypothesis 5: VR training programs are more effective than comparable training programs at developing skills.

Hypothesis 6: VR training programs are more effective than comparable training programs at developing mental ability.

Hypothesis 7: VR training programs are more effective than comparable training programs at developing spatial abilities.

Hypothesis 8: The order of VR training program effectiveness, from least effective to most effective, by outcome is: declarative knowledge, wayfinding, cognitive strategies, knowledge organization, skills, mental ability, and spatial abilities.

Together, the proposed TTF-CBT framework and relevant hypotheses make certain predictions about the efficacy of all VR training programs. Likewise, methods and statistical analyses used to test the framework and hypothesis should be able to provide overarching inferences about VR training programs. For this reason, I conduct a meta-analysis to analyze the framework and hypotheses. Meta-analyses aggregate the statistical results of prior studies to estimate the overall effects. In the context of the current article, a meta-analysis can combine the

results of previous tests of VR training programs to determine their overall effectiveness. More importantly, the method can determine the effectiveness of VR training programs for developing individual outcomes, allowing each hypothesis to be tested. Therefore, I present the methods and results of a meta-analysis investigating the efficacy of VR training programs, followed by a discussion of the results and implications for research and practice.

Chapter 3

Meta-Analytic Methods

Literature Search

Multiple strategies were employed to identify all published and unpublished articles that empirically analyze VR training programs. First, searches were conducted in December 2014 in PsycInfo, EBSCOhost, Dissertation Abstracts International, and Google Scholar. Relevant keywords were “virtual reality”, “digital simulation”, and “computer simulation” (quotations included and searched separately) followed by training, intervention, therapy, enhance, promote, or support. Second, reference sections of previous relevant meta-analyses and review articles were cross-referenced. Third, emails were sent to prominent authors in VR training research inquiring about any unpublished data that could be made available.

Inclusion Criteria

Initially, 4,646 articles were recorded after performing the searches described above, but the articles had to meet several specific criteria to be included. For each criterion, listed below, trained coders independently coded the same set of articles, and interrater agreement was calculated. If the ICC(2, k) value was above .8, then the coders continued coding the articles independently. If the ICC(2, k) value was below .8, the coders discussed their decisions until a consensus was reached, and the process was repeated until an ICC(2, k) value of .8 was reached.

To be included in analyses, articles must include an empirical study. This resulted in 2,780 articles retained from the initial search. Second, articles must include (1) quantitative statistics, (2) a sample size larger than nine, and (3) human participants. After removing these, 1,950 articles remained. Third, articles must analyze the effectiveness of a VR training program

to alter participant characteristics, resulting in 706 retained articles. Fourth, articles must include a control group and a post-test. Once removing these, 288 articles remained. Fifth, articles must include a VR training program to develop cognitive outcomes, resulting in 120 retained articles. Lastly, many articles did not report sufficient statistical information to be included. If an article did not report sufficient information, the corresponding author was contacted and two follow-up emails were sent. If the author never replied, any outcome that could be included was recorded, but many articles were forced to be excluded. Therefore, 84 articles were included in the analyses. One of these articles was a conference proceeding and five were dissertations.

Cognitive Outcome Category Coding

After the article selection process, two trained coders coded effect sizes on their cognitive outcome category. The two coders independently coded every article and discussed their coding decisions, even after their ICC(2,2) value exceeded .80. Disagreements were resolved as a team.

Each effect size was categorized by the cognitive outcome category it represented. For instance, if an effect size represented the difference between a VR training program and a comparable training program in developing the ability to weld, it was coded as skills. Each effect size was coded as either developing declarative knowledge, wayfinding, knowledge organization, cognitive strategies, skills, mental ability, or spatial abilities. The description of each coding category is provided below:

Declarative Knowledge. Declarative knowledge largely refers to objective facts, and can be thought of as information about who, what, when, where, why, and how. Great amounts of working memory are required to commit declarative knowledge to memory, as mental rehearsal is often necessary.

Wayfinding. Wayfinding is navigation of environments to find an object or location. Great amounts of working memory are required to develop wayfinding abilities, as trainees must remember direction, orientation, and sequences of events to arrive at desired destinations.

Knowledge Organization. Knowledge organization is the meaningful categorization and structuring of information. Moderate amounts of working memory are required to incorporate knowledge organization information to memory. Mental rehearsal is often necessary, but trainees begin to subconsciously understand the relationship between objects, locations, and concepts.

Cognitive Strategies. Cognitive strategies are individuals' mental strategies to incorporate, access, and apply information. Moderate amounts of working memory are required to learn new cognitive strategies. The trainee must consciously think about their thought processes before integrating them into subconscious procedures.

Skills. Skills are behaviors linked in a sequentially and hierarchically organized manner. Although counterintuitive, low amounts of working memory are required to learn skills and abilities. While requiring conscious thought to initiate development, skills and abilities are gradually developed through subconscious processes and automation that inherently involve a reduction to working memory taxation in favor of autonomic processes

Mental Ability. Mental abilities are considered cognitive outcomes that are unrelated to knowledge incorporation. Instead, cognitive abilities involves quickness of thought, thinking logically, and using novel methods to solve problems. Cognitive abilities require little to no working memory to develop. In general, developing these abilities solely involves subconscious processes rather than mental rehearsal

Spatial Ability. Spatial ability is the capability to understand and remember spatial relations among objects, and it is used within navigation, movement, and the manipulation of objects. Spatial knowledge requires little to no working memory to develop, and it is often considered an autonomic process.

Statistical Procedures

First, analyses were performed to gauge publication bias, also known as the “file drawer problem.” Attempts were made to reduce publication bias, such contacting researchers for unpublished data, but it is likely that biases still exist in the dataset. In fact, some authors argue that publication biases can never be fully eliminated in meta-analyses. To determine the extent of publication bias, funnel plots, fail-safe N, Egger’s test, and the trim-and-fill method were used.

Second, the heterogeneity of studies was assessed using the I^2 statistic, which is the percentage of total variation between studies due to heterogeneity rather than random chance or sampling error. A large I^2 statistic indicates that some variation in the observed results is due to study design or sampling biases rather than error, and further analyses into this systematic variance is warranted. Alternatively, a small I^2 statistic indicates that the variation in the observed results is largely due to error, and no further analyses are needed. No standard cutoff exists for an I^2 statistic. So, when interpreting the I^2 statistic, previous studies were referenced.

Third, results were calculated with Comprehensive Meta-Analysis (Borenstein, Higgins, & Rothstein, 2005) using a random effects model to calculate standardized mean differences (d), Hedges g (which adjusts for small sample sizes; Rosenthal, 1991), and other relevant statistics. For all analyses, the standard deviation of change scores were used to standardize results when such data was available, but standard deviations of post-training data were used otherwise. Also,

multiple effect sizes for the same category of outcome in a single study were averaged together. For example, if a study tested a VR training to develop declarative knowledge and three outcome measures were used to gauge effects, these three effect sizes would be averaged together.

No corrections were made when calculating results, and this decision was made for three reasons. First, for certain outcomes, the vast majority of authors did not provide any reliability estimates, making corrections for unreliability extremely difficult if not impossible. When making comparisons across outcomes, as done in the current study, it is inappropriate to correct for unreliability (and increase effects) for certain outcomes and not others. Second, recent authors have placed great concern towards correcting for unreliability (LeBreton et al., 2015). These authors argue that correcting for unreliability overinflates relationships when reliabilities are low, resulting in inaccurate conclusions. This view is shared in the current study. Third, uncorrected meta-analytic results should be interpreted when outcomes serve practical or operational purposes, such as selection results (Griffeth et al., 2000; Harrison et al., 2006; Van Iddekinge et al., 2012; Zimmerman, 2008). In the current study, the analyzed articles' results compare training programs, often in a random confirmatory trial, to determine the superiority of a training beyond others. Given that these results were used for practical and operational purposes, it is not appropriate to correct for unreliability. Fourth, none of the samples posed concerns towards range restriction, circumventing the need to correct for range restriction.

Chapter 4

Results

First, to observe instances of bias, several methods were used. When analyzing all cognitive outcomes, the funnel plots indicated that many studies fell outside the expected range of standard error and effect size (Figure 2). The outliers fall on both sides of the mean effect, indicating that the publication bias may exist for either positive or negative effects. Further analyses are warranted to determine the true nature of the publication bias, and these analyses are included in Table 3. For all outcomes together, the fail-safe n was 3688, indicating that the overall effect would require an extreme amount of missing studies to alter the interpretation of results. For individual outcomes, the fail-safe n ranged from 16 to 1266. Given the difficulty in performing VR research, it is assumed that most inferences would not be greatly swayed by missing studies. Lastly, the trim-and-fill method with a random effects model indicated that 14 implied studies were missing from the right of the mean when looking at all studies together. Of individual outcomes, only skills and declarative knowledge demonstrated any implied missing studies, with 9 and 6 respectively. Overall, it appears that efforts to find all studies on VR training programs were largely successful in reducing publication bias, but some biases were still observed in the dataset. In agreement with previous meta-analyses, only effects which were calculated with more than three studies are considered reliable results, and readers should still consider the possibility of biases when interpreting all results.

When analyzing all categories, the overall I^2 is 85, indicating that most of the observed variability in results was due to true differences and not sampling error. This figure is well beyond the cutoff chosen by other authors for a “high” I^2 value, such as 25 (Carpenter, Berry, & Houston, 2014). Further analyses to determine the cause of this underlying variance, such as the

outcome of interest, are warranted. Also, the Q -value was 483, also indicating a significant difference between studies, and further analyses into these differential effects are warranted.

Primary Research Questions about Outcome Effectiveness

To determine the effect of VR training programs on cognitive outcomes, all results are presented as the standard difference of the means (d) between the VR group (treatment group) and the comparison group. Table 4 presents these effects as calculated by a random effects model and without any corrections. Table 5 presents these effects as calculated by a random effects model, without any corrections, and only including studies which the control group received an alternative training. Table 6 presents the same effects as Table 5, but only includes studies that explicitly tested a training program that occurred in a workplace.

In some instances, the fixed effects model may be more appropriate than the random effects model when the effects sizes can be considered homogeneous, often indicated by a Q statistic. Borenstein, Hedges, and Rothstein (2007) note, however, that the random effects model reverts to a fixed effects model when homogeneity is large, eliminating the need to apply a fixed effects model. Other authors have likewise noted the superiority of random effects models for meta-analyses (Murphy, 2015). Therefore, only the random effects model calculated with studies that included an alternative treatment group is discussed (Table 5).

Compared to alternative training programs, VR training programs had a moderate, positive, and significant overall effect on cognitive outcomes ($d = .475$; 95% C.I. = .287 - .663; $p < .001$). In regards to specific cognitive outcome categories, when compared to alternative training programs, VR training programs demonstrated a small, positive, and non-significant effect on declarative knowledge development ($d = .197$; 95% C.I. = -.044 - .438; $p > .10$). For wayfinding, VR training programs demonstrated a moderate, negative, and non-significant effect

compared to alternative training programs ($d = -.592$; 95% C.I. = $-1.275 - .090$; $p < .10$). Cognitive strategies could not be tested, as no article studied the impact of a VR training program on this outcome. VR training programs had an extremely large, positive, and significant effect on knowledge organization beyond alternative training programs ($d = 1.765$; 95% C.I. = $1.158 - 2.372$; $p < .001$); however, the result only consisted of a single effect size, and should not be interpreted. Compared to alternative training programs, VR training programs had a moderate, positive, and significant effect on skills ($d = .585$; 95% C.I. = $.288 - .881$; $p < .001$). VR training programs had a large, positive, and significant effect on mental ability development compared to alternative training programs ($d = .775$; 95% C.I. = $.470 - 1.080$; $p < .001$). Lastly, VR training programs had a very large, positive, and significant effect on spatial knowledge when compared to alternative training programs ($d = 1.118$; 95% C.I. = $.156 - 2.080$; $p < .05$). When comparing cognitive outcomes, the order of the sub-dimensions from smallest to largest is: wayfinding, declarative knowledge, skills, and mental ability, and spatial abilities.

Together, Hypothesis 1 (declarative knowledge) was partially supported. Although VR training programs were not worse than alternative training programs for developing declarative knowledge, they were not better either. Also, of all cognitive outcomes, the second smallest effects were observed with declarative knowledge, supporting the notion that VR is poor for developing this outcome. Hypothesis 2 (wayfinding) was supported. VR training programs were worse than alternative training programs at developing wayfinding, and this effect was marginally significant. Hypotheses 3 (cognitive strategies) and 4 (knowledge organization) could not be tested due to the lack of studies. Hypothesis 5 (skills) was supported. VR training programs were significantly better than alternative training programs at developing skills. Hypothesis 6 (mental ability) was supported, as VR training programs were significantly better

than alternatives at developing mental ability. Hypothesis 7 (spatial abilities) was supported, and VR training programs were significantly better than alternative training programs at developing spatial abilities. Lastly, Hypothesis 8 was largely supported. The predicted order of the cognitive outcomes that could be tested was: declarative knowledge, wayfinding, skills, mental ability, and spatial abilities. The actual result was wayfinding, declarative knowledge, skills, mental ability, and spatial abilities – very similar to predictions.

Chapter 5

Discussion

Although often invoked, TTF Theory may be insufficient to understand the complex interaction between training technologies and the development of outcomes, as it does not specify any mediating mechanisms or boundary conditions. In the current article, a more complete process for understanding TTF was created by integrating a TTF-CBT framework, which proposes: For a CBT to be effective, the technology should present as realistic and/or entertaining of an experience as possible without burdening the trainees' working memory resources necessary to develop the outcome of interest. Outcomes which require little (much) working memory to develop should be paired with technologies which require much (little) working memory to maximize training outcomes, and the benefits of the technology should only be viewed in-addition-to the requirements of the outcome itself.

To test this framework and investigate VR training program differential effectiveness, a meta-analysis of VR training programs across several cognitive outcomes was conducted. The results demonstrated that VR has differential effectiveness dependent on the outcome, supporting both TTF Theory and the integrative TTF-CBT framework. Further, the TTF-CBT framework was successful in predicting the effects of VR on cognitive outcome development, which could not be done with TTF Theory alone. VR training programs were less effective at developing outcomes that require extensive working memory for improvement, wayfinding and declarative knowledge, but they were more successful at developing outcomes that require little working memory for improvement, skills, mental ability, and spatial abilities. Likewise, the predicted order of outcomes (declarative knowledge, wayfinding, skills, mental ability, and spatial abilities) was largely in agreement with expectations (wayfinding, declarative knowledge, skills,

mental ability, and spatial abilities). Therefore, the hypotheses that could be tested were largely confirmed, providing support for the future application of the integrative TTF-CBT framework. With these findings in mind, implications and future directions are discussed.

Implications and Future Directions

These results have several implications for the development and implementation of training. To begin, TTF Theory is warranted (Dennis & Kinney, 1998; Dennis & Valacich, 1999; Mennecke et al., 2000; Suh, 1999; Valacich et al, 1994; Vessey, 1991). As mentioned, TTF Theory is often cited as a justification for well-performing technologies, but integrative and comprehensive tests of the theory have yet to be performed. The current study demonstrated that, in a training context, VR demonstrates differential effectiveness which is dependent upon the application. Nevertheless, while the premise of TTF Theory is sound, the theory still has many concerning aspects, such as its falsifiability as well as diagnostic and predictive capabilities. Also, no justification is given for conditions of task and technology match, and no explanatory mechanisms or boundary conditions are provided. For these reasons, it is important to analyze the current results in the context of the integrative TTF-CBT framework.

As predicted by the integrative TTF-CBT framework, VR training programs were less effective at improving outcomes that require great working memory to develop, such as declarative knowledge, and superior at improving outcomes that require little working memory, such as skills. The predictive ability of the integrative TTF-CBT framework lends support for its future application. Five future research streams, among many possible others, should further the application and sophistication of the integrative TTF-CBT framework.

First, future research should apply the integrative TTF-CBT framework to better understand the effects of other CBT technologies. Particularly, simulations and serious games are extremely popular training and education methods (Arnab et al., 2015; Connolly et al., 2012; Ritterfeld et al., 2009). Like VR, many current studies compare a simulation or serious game against an alternative training, and claim that the better performing training program is a better “match.” With the new framework, authors can explicitly test the proposed cause of a better “match” and understand exactly which mechanisms cause a CBT to be effective. Further, in alignment with the TTF-CBT framework, these technologies are expected to require little working memory. They should be effective for the development of cognitive outcomes that require little working memory to develop, but relatively ineffective for the development of working-memory intensive cognitive outcomes. Future research should explicitly test this notion, possibly through a meta-analysis.

Second, future research should apply the integrative TTF-CBT framework to better understand the dynamics of a particular CBT applications. The current article focused on VR, an important CBT technology, across several outcomes, but authors could likewise focus on a particular outcome, such as skill development, to better understand a particular CBT application. As demonstrated in Table 6, skill development is the most popular outcome developed in organizational training programs, and future research should begin by focusing on this outcome. In doing so, a future study could further validate the integrative TTF-CBT framework, and determine the best-practices in developing a particular outcome.

Third, future research should extend the integrative TTF-CBT framework to account for other CBT dynamics. Particularly, certain individual differences likely have a large impact on CBT success, but the integrative TTF-CBT framework does not explicitly incorporate individual

differences into predictions. For instance, individuals with prior experience with a technology likely endure less working memory taxation from using it. Likewise, individuals with greater working memory capacity will be less affected by technologies that utilize working memory. A working-memory intensive technology may successfully develop a work-memory intensive outcome if trainees have prior experience and/or greater working memory. Future research should incorporate individual differences into the integrative TTF-CBT framework (Brown, 2005; Orvis, 2009; Sitzmann et al., 2008).

Fourth and similarly, future research should account for contextual factors in the TTF-CBT framework. Many authors have demonstrated that context can have a large impact on CBT success. For instance, organizational transfer climate has been shown to significantly predict successful training outcomes (Kozlowski & Salas, 1997; Machin & Fogarty, 2005; Sookhai & Budworth, 2010). Although transfer climate is unlikely to impact the working memory requirements of tasks and technologies, this contextual factor and others nevertheless have a large effect on training outcomes. Through integrating these factors into the TTF-CBT framework, CBT predictions can be more accurate.

Fifth, the integrative TTF-CBT framework only discusses cognitive outcome development. It is altogether possible and reasonable that the framework can accurately describe and predict the development of other outcomes, such as physical and emotional, but future research should integrate other types of training outcomes into the framework. Particularly, trainees can have an array of reactions to a CBT program, such as perceptions of utility and enjoyment (Burke & Hutchins, 2007; Madera et al., 2011; Tracey et al., 1997). Although these reactions may not be direct indicators of CBT success, they nevertheless represent important outcomes of training programs. Further, when direct outcomes of training success cannot be

obtained, whether due to logistical difficulties or organizational constraints, trainee reactions may be the only measurable training outcome. For these reasons and others, it is suggest that future researchers integrate trainee reactions into the integrative TTF-CBT framework.

Aside from the integrative TTF-CBT framework, the results of the current article likewise support the other adapted perspectives – working memory, experiential knowledge, and entertainment. As mentioned, many authors have applied these perspectives to understand the success of specific CBT programs. While these authors have provided support for the perspectives, they are also usually applied in isolation. This may be because the perspectives appear to predict conflicting viewpoints of effective CBT programs. Nevertheless, the current study demonstrated that the perspectives may be most effective when applied together. Future research should likewise apply multiple CBT perspectives simultaneously to understand the resultant effects of the technology, training application, and their integration.

Further, authors should consider the development of new theories and frameworks. The integrative TTF-CBT framework solely predicted the effect of CBT programs on cognitive outcome development. It was believed that the developed TTF-CBT framework should be specific, as specific theories and frameworks tend to predict better than general ones. Also, specific theories can provide more detailed inferences about phenomenon of interest, which was a large detriment to TTF Theory. For these reasons, future TTF theories and frameworks should likewise be specific to predict relevant outcomes of interest. For instance, a large amount of research has applied VR programs to reduce phobias towards certain objects or concepts, and TTF Theory is often applied to predict the relative effectiveness of these programs (Choi et al., 2005; Opdyke et al., 1995; Windich-Biermeier et al., 2007). A new theory or framework should propose the differential effectiveness of VR for emotional outcomes, particularly for therapy

purposes. Likewise, many authors have used VR to develop physical outcomes, such as strength and motor abilities. A new framework could accurately predict the effects of CBT programs on physical outcome development, while providing explanatory mechanisms and boundary conditions – an impossible feat with extant theory.

Additionally, the results provide direct implications for VR training programs. The most popular application of VR for cognitive outcome development is to improve skills, even when restricting analyses to only workplace contexts (Table 6). VR training programs were superior to alternative training programs in this domain, thereby supporting the large interest in VR for skill development. Nevertheless, certain alternative explanations should be considered. It is possible that the technologies applied in VR training programs to improve skills are more sophisticated than other VR applications, as researchers appear to place more interest in these technologies. If this were the case, however, it would be expected that other areas that have seen much less research, such as VR training programs for cognitive abilities and spatial abilities, would demonstrate much smaller effects than skill development. This was not the case, as these outcomes demonstrated even larger effect sizes than skill development. Likewise, the second most popular application of VR training programs, declarative knowledge development, demonstrated very small effects. Therefore, the results of the meta-analysis are likely due to the actual effects of task-technology “match,” rather than greater interests in certain application of VR training programs.

Relatedly, much less research has applied VR for mental ability and spatial ability development, despite the large observed effects of the technology to develop these two outcomes. Likely, the dearth of research is due to perceptions that these abilities are relatively fixed (Cherniack, 2011; Optale et al., 2010), but VR may provide a unique opportunity to

improve these outcomes. Future research should take a great interest in applications of VR to develop these lesser-studied outcomes, as they may have important workplace implications. Further, VR may have very specialized effects when developing these outcomes, allowing the otherwise relatively-fixed outcomes to be susceptible to training and development. Future research should also test this notion.

On the other hand, VR is least advantageous at developing declarative knowledge and wayfinding. Surprisingly, a large amount of research has applied VR to develop declarative knowledge, particularly in an education context (Bailenson et al., 2008; Bricken & Byrne, 1993), and the cumulative effects of these studies are lackluster. Researchers and practitioners may want to allocate their efforts towards testing other CBT programs to develop these outcomes, as the integrative TTF-CBT framework predicts that VR has great difficulties in developing declarative knowledge. As predicted by the framework, more basic CBT programs, such as simulations, should be effective at developing declarative knowledge and wayfinding, which should be tested in future research and practice.

Very little research analyzed VR training programs for cognitive strategies or knowledge organization, despite their workplace importance. Future research should investigate the impact of VR on these two cognitive outcomes. Such analyses would provide theoretical implications, as they would identify the impact of VR on outcomes which require moderate amounts of working memory. Likewise, they would provide practical implications, as practitioners could employ VR to develop these outcomes if successful.

Lastly, these results can efficiently be applied to many applied settings. First, business schools often apply simulations for MBA education. Typically, these simulation programs are very basic, and are meant to train MBA students on identifying patterns. For example, the

simulation may present numerical data about a company, including revenue, profit, expenses, resources, and other information. In the simulation, students are meant to allocate company resources, and they are subsequently provided feedback on the success of their allocations. Then, in a recursive process, students are meant to continuously adjust their allocations in order to produce the best outcomes possible. When applying the integrative TTF-CBT framework, simulations for MBA education seems ideal. The skills being developed, declarative knowledge and knowledge organization, require ample working memory to develop, whereas simulations require little working memory to use. For this reason, business schools should continue using simulations for learning and education purposes.

Second, modern organizations are beginning to use VR for employee training purposes, most often for the development of skills. By far, the most popular application of VR for organizational training purposes, when restricted to skill development or otherwise, is towards the development of surgeons. In these instances, surgeons interact with a digital representation of a patient that presented on a monitor, much like the method used when performing surgery naturally. The surgeons interact with this representation via realistic tools that accurately mimic tools used in actual surgery. In instances such as these, when applying the integrative TTF-CBT framework, VR for organizational skill development is ideal. VR requires much working memory to use, whereas skills require less working memory to develop. Organizations should continue using VR for similar purposes and expanding the use of VR for other training that is predominantly skills focused.

Third, many authors have tested the efficacy of VR to develop declarative knowledge in primary school students. Typically, in these programs, students are expected to learn about an event or location through exploring a digital location. Throughout exploring, students either talk

to digital avatars to learn more about the event or location, or they are provided direct messages with declarative information. As the meta-analysis results demonstrated, VR is not overly effective for developing these outcomes and provides only marginal improvements beyond relevant comparisons. Likewise, when applying the integrative TTF-CBT perspective, VR is predicted to be relative poor for teaching declarative knowledge. Therefore, it is recommended that authors should consider the use of simpler technologies to instruct students.

Fourth and last, serious games are being rapidly applied for both organizational training and classroom education programs. As mentioned, these programs may be simulations, VR, or something else entirely. Authors should review the individual applications of the programs to determine the extent of working memory that these programs use. Likewise, authors should determine the typical applications of these programs. As many reviews have noted, serious games are often applied for student education. In these contexts, authors need to ensure that the game elements do not detract from the working memory required for learning declarative knowledge. Therefore, when applying the integrative TTF-CBT framework, serious games may or not be an effective training and education tool.

Limitations

As with all studies, some limitations should be noted. Certain limitations are relevant to meta-analyses in general. To obtain accurate meta-analytic estimates, a large number of studies are needed. Two outcomes, cognitive strategies and knowledge organization, could not be analyzed in the current work due to the small number of respective studies. Future research should analyze the impact of VR on these two outcomes and incorporate results into the integrative TTF-CBT framework.

Also, although individual differences and contextual factors were suggested for future research, they were not studied in the current paper because a sufficient number of studies likely do not exist which investigate relevant effects. For instance, in accordance to the proposed framework, individuals with lower levels of working memory capacities would likely perform worse with VR training programs. It is unlikely that a sufficient number of studies have directly tested this effect to subsequently analyze, through meta-analysis, and alternative research methods are more appropriate for this research question.

Other limitations are specific to the current meta-analysis. Some authors would criticize the decision to not correct for unreliability. As mentioned earlier, this decision was made for theoretical and practical justifications, and correcting for unreliability may obfuscate the true impact of VR training programs across outcomes. It is still believed that not correcting for reliability is the correct decision to best understand these results.

A comment should be made about the decision to use studies with a control group. If only studies were chosen without a control group, then the results could not be direct inferences about the efficacy of VR training programs to develop outcomes. Instead, these results may only reflect the malleability of a construct, and any training would demonstrate similar effects – whether VR or otherwise. When using studies with a control group, the results reflect the efficacy of VR training programs to develop constructs beyond an alternative, which draws more accurate inferences about the efficacy of VR training programs. It is possible, however, that the alternative training programs in certain outcomes were particularly (un)sophisticated when compared to others, thereby altering the apparent efficacy of VR training programs. This is not a large concern for outcomes with a large number of studies, but it could have affected others with

fewer representative studies. Nevertheless, it is believed that any bias from using studies with control groups is less than the bias from solely using studies without a control group.

Relatedly, TTF Theory contains an implicit notion that the effectiveness of a technology is compared to a standard set by relevant alternatives. In the current study, the standard is different for each outcome and could only be obtained through analyzing comparison groups. Given that alternative treatment groups allow such comparisons, the most appropriate method to test TTF Theory and relevant frameworks is to use alternative treatment groups. Together, while the meta-analysis has its limitations, they appear to be less severe than the possible alternatives.

Chapter 6

Conclusion

TTF Theory appears to be insufficient to understand the complex interaction of CBT programs across relevant applications, among many other concerns. For this reason, a new integrative TTF-CBT framework was presented, which indicates that the effectiveness of a CBT program is reliant on the required amount of working memory to use the technology and the amount of working memory required to develop the outcome. To test this novel framework, a meta-analysis of VR training programs was performed with the goal of understanding the differential effectiveness of VR across multiple outcomes. The results supported the new framework for cognitive outcomes. VR was less effective at developing declarative knowledge and wayfinding, but effective at developing skills, mental ability, and spatial abilities. Therefore, the proposed framework appears valid for CBT contexts, and future research should further study the dynamics of VR training programs and the integrative TTF-CBT framework.

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Table 1 – Effect of Technology on Three Perspectives

	Working Memory Requirement	Fidelity	Entertainment
Software			
Simulation	Low	Low	Low
Virtual Reality	High	High	High
Serious Game	Varies	Varies	High
Hardware – Output			
Monitor	Low	Low	Low
Immersive Display	High	High	High
Hardware – Input			
Keyboard & Mouse	Low	Low	Low
Specialized Input	High	High	High

Table 2 – Overview of Cognitive Outcome Categories

Cognitive Outcome Category	Working Memory Required to Develop Outcome	Predicated Effect of VR	Rank-Order of Predicted VR Effectiveness
Declarative Knowledge	High	Ineffective	5
Wayfinding	High	Ineffective	5
Cognitive Strategies	Moderate	Moderate	4
Knowledge Organization	Moderate	Moderate	3
Skills	Low	Effective	2
Mental ability	Low	Effective	1
Spatial Abilities	Low	Effective	1

Table 3 – Publication Bias Analyses Results and I^2

	I^2	Number of Articles	Fail Safe n	Egger's Test β_0	Egger's Test t	Studies Trimmed Left of Mean	Studies Trimmed Right of Mean
1.) All Cognitive Outcomes	86.10	84	3688	1.54	2.72**	0	14
2.) Declarative Knowledge	88.40	24	161	.79	.63	0	6
3.) Wayfinding	81.38	8	16	1.03	.52	0	0
4.) Knowledge Organization	-	1	-	-	-	-	-
5.) Cognitive Strategies	-	0	-	-	-	-	-
6.) Skills	83.31	49	1264	1.77	1.79*	0	9
7.) Cognitive Ability	9.92	9	65	-.27	.13	0	0
8.) Spatial Abilities	94.17	4	39	5.74	2.56	0	0

Table 4 – Meta-Analysis Results with All Studies Included (Random Effects)

Primary Applications	<i># of Articles</i>	<i>k</i>	<i>n</i>	<i>d</i>	<i>S.E.</i>	95% Confidence Interval	Hedges <i>g</i>	Z-value	<i>p</i>
Cognitive Outcomes	84	374	4041	.575	.096	.386 – .764	.559	5.968	<.001
Declarative Knowledge	24	68	2049	.297	.139	.025 – .570	.292	2.137	<.05
Wayfinding	8	37	289	-.428	.343	-.1.100 – .244	-.413	-1.249	>.05
Knowledge Organization	1	1	58	1.765	.310	1.158 – 2.372	1.741	5.702	<.001
Cognitive Strategies	0	0	0						
Skills	49	191	1618	.697	.148	.407 – .987	.671	4.706	<.001
Cognitive Ability	9	69	275	.733	.137	.465 – 1.000	.712	5.367	<.001
Spatial Abilities	4	8	557	1.118	.491	.156 – 2.080	1.098	2.277	< .05

Table 5 – Meta-Analysis Results with Only Alternative Treatment Groups (Random Effects)

Primary Applications	<i># of Articles</i>	<i>k</i>	<i>n</i>	<i>d</i>	<i>S.E.</i>	95% Confidence Interval	Hedges <i>g</i>	Z-value	<i>p</i>
Cognitive Outcomes	75	308		.475	.096	.287 – .663	.462	4.959	<.001
Declarative Knowledge	23	60	1965	.197	.123	-.044 – .438	.194	1.604	>.10
Wayfinding	7	22	266	-.592	.348	-1.275 – .090	-.570	-1.702	<.10
Knowledge Organization	1	1	58	1.765	.310	1.158 – 2.372	1.741	5.702	<.001
Cognitive Strategies	0	0	0						
Skills	43	161	1428	.585	.151	.288 – .881	.564	3.862	<.001
Cognitive Ability	8	56	238	.775	.156	.470 – 1.080	.752	4.985	<.001
Spatial Abilities	4	8	557	1.118	.491	.156 – 2.080	1.098	2.277	<.05

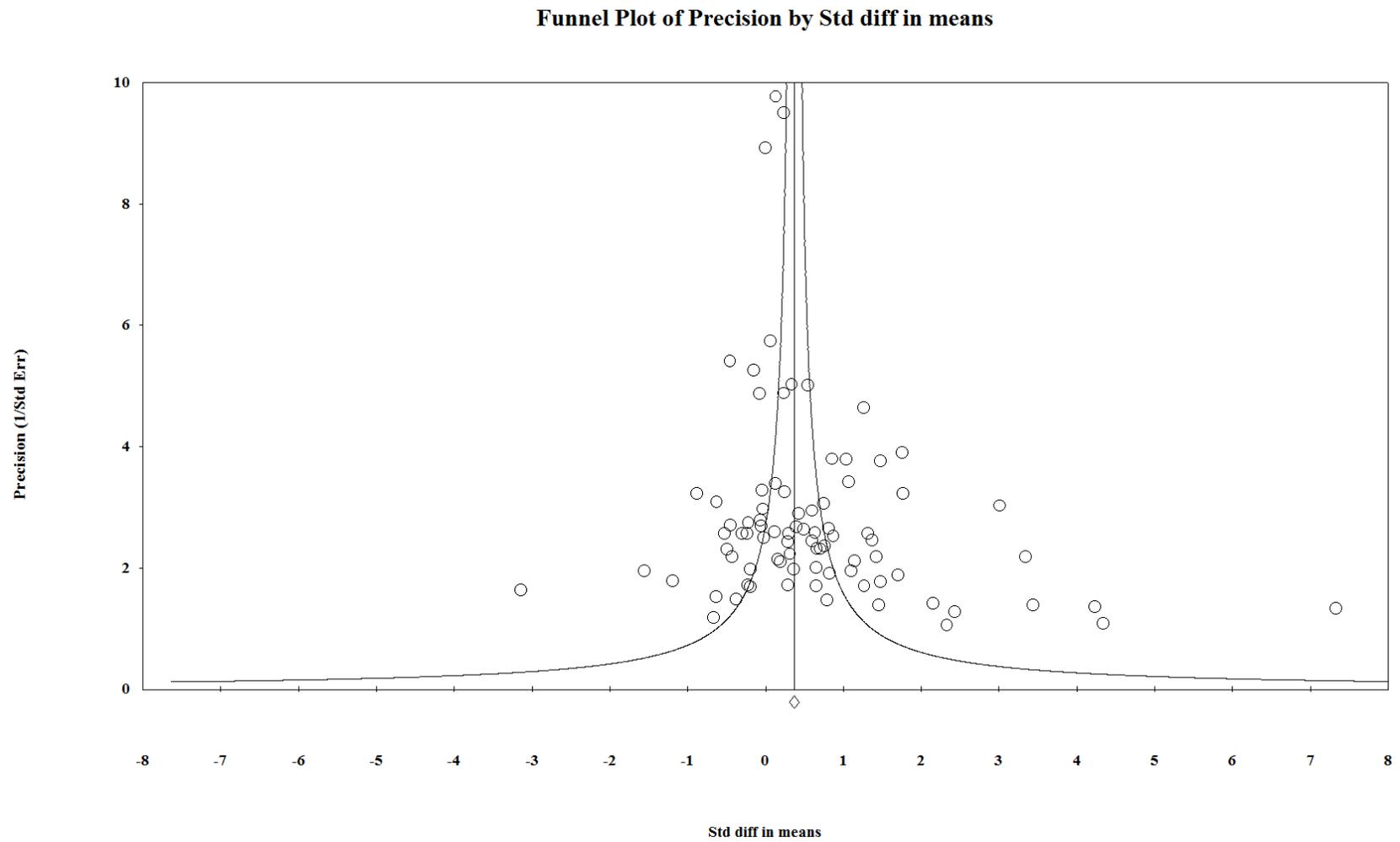
Table 6 – Meta-Analysis Results with Only Alternative Treatment Groups and Workplace Training Programs (Random Effects)

Primary Applications	<i># of Articles</i>	<i>k</i>	<i>n</i>	<i>d</i>	<i>S.E.</i>	95% Confidence Interval	Hedges <i>g</i>	Z-value	<i>p</i>
Cognitive Outcomes	32	134	1005	.559	.206	.154 – .963	.539	2.709	<.01
Declarative Knowledge	4	13	148	.088	.240	-.382 – .558	.086	.368	>.10
Wayfinding	1	2	20	-1.552	.513	-2.557 – .546		-3.025	<.01
Knowledge Organization	0	0	0						
Cognitive Strategies	0	0	0						
Skills	29	119	933	.700	.223	.263 – 1.138	.674	3.138	<.01
Cognitive Ability	0	0	0						
Spatial Abilities	0	0	0						

Figure 1 – Relationship of Technology and Application

Working Memory Required by Application	High Working Memory Required	Intervention- Technology Match (Maximized Outcomes)	Overburdening Working Memory (Reduced Outcomes)
	Low Working Memory Required	Underutilizing Working Memory (Reduced Outcomes)	Intervention- Technology Match (Maximized Outcomes)
		Low Working Memory Required	High Working Memory Required
		Working Memory Required by Technology	

Figure 2 – Funnel Plot of Publication Bias for All Cognitive Outcomes



Appendix A

Physical Outcome Review

When working on my dissertation, there were two outcome subgroups which I had little previous knowledge – physical outcomes and social outcomes. For this reason, I performed extensive reviews into these two subject areas and wrote-up rough-draft of my reviews. Because the reviews were not central to my dissertation, they were not included in the background sections; however, I feel that they should be included as appendices. Please do not feel the need to read these reviews unless you want to learn more about VR, physical outcomes, and social outcomes.

Physical Outcomes

A Systematic Literature Review of Virtual Reality Administered Physical Rehabilitation Programs: What Do We Know, Not Know, and Need to Know?

Throughout life, individuals are greatly reliant upon their physical abilities, as the modern world is largely constructed with physically-capable individuals in mind. Everyday activities, such as turning doorknobs or climbing stairs, demand a certain aspect of bodily functioning. Unfortunately, many neurological disorders and life events can reduce individuals' physical capabilities, amongst the most widespread being Parkinson's disease (50,000 to 60,000 new cases each year in U.S.; NPF, 2015), cerebral palsy (10,000 new cases each year in U.S.; CerebralPalsy.org, 2015), and stroke (795,000 new cases each year in U.S.; StrokeCenter.org, 2015). Individuals with these conditions often incur great difficulties in performing the aforementioned everyday tasks, resulting in reductions to life satisfaction and well-being (Achten et al., 2012; Colver, 2012; Gustafsson et al., 2015). For this reason, authors have devoted great interest in the rehabilitation of physical abilities through regimented training programs.

Authors have applied an array of methods and technological devices to provide effective rehabilitation programs. One of the most recent advancements is the application of virtual reality (VR), which is the computer-simulation of an environment that can imitate a physical presence in real or imagined worlds. To date, VR has been used to enhance gaming experiences (Blascovich & Bailenson, 2011; Burdea & Coiffet, 2003), therapy outcomes (Klinger et al., 2005; Opreș et al., 2012), student learning (Monahan et al., 2008; Selvander & Åsman, 2012), and the popularity of VR has recently spread to physical rehabilitation programs.

Authors have proposed that improved outcomes, beyond prior rehabilitation programs, can be obtained if trainees interact with a VR environment while performing repetitions of

effective behaviors, largely due to the natural mental benefits of VR environments (Jang et al., 2009; You et al., 2005). Also, the application of VR follows previous notions computer-based training scholarship – improvements to technology can provide improvements to training outcomes (Bedwell & Salas, 2010). Despite this enthusiasm, much remains unknown about VR-administered rehabilitation programs. Primarily, mixed support has been seen for the efficacy of VR for rehabilitation purposes, and authors have provided differing justifications for any observed effects. Due to the importance and centrality of these two research questions for studies on VR-administered physical rehabilitation programs, the current article reviews extant scholarship upon VR and physical rehabilitation to derive research answers. This review is separated into several sections.

First, the current paper provides a brief introduction to VR-administered physical rehabilitation programs. Second, detailed reviews are provided of each domain of VR-administered physical rehabilitation scholarship: motor control, balance, gait, and strength. Third, the current paper integrates all research streams and proposes future directions for research and practice. Simultaneously considering each subsection of VR-administered physical rehabilitation scholarship may solve research questions within particular areas which have been addressed in alternative applications. More importantly, an integrative consideration may derive theoretical conclusions which have only been partially addressed in each area, but an overall point-of-view may provide enough information for definitive inferences. Therefore, it is believed that the current article provides several inferences for future research and practice upon VR, physical rehabilitation, and their combination.

VR-Administered Physical Rehabilitation Programs

All physical rehabilitation programs involve the repetition of certain bodily movements, and most utilize certain hardware which can aid or apply resistance to these movements, such as a treadmill or simple weights (Batson et al., 2011; Fung et al., 2006; Mirelman et al., 2010). The current article is not interested within hardware which physically interact with the trainee. Instead, recent physical rehabilitation programs, in addition to utilizing prior hardware, have begun applying other devices which presents a visual experience to match the repetition of bodily movements. These new hardware are meant to alter trainees' mental states to provide subsequent physical outcomes (Henderson et al., 2007; Moreira et al., 2013). Likely the most widely-used and promising of these new applications is VR – the focus of the current article.

As mentioned, VR is the computer-simulation of an environment which can imitate a physical presence in real or imagined worlds. Often, users control digital recreations of their physical bodies, called avatars, to perform tasks within these virtual environments. To present VR environments, an array of technologies have been used. Most often, a standard computer monitor is used (Burdea & Coiffet, 2003; Steuer, 1992), but more cutting-edge research has applied surround-screen displays (Cruz-Neira et al., 1993). To create a surround-screen display, multiple monitors or projectors are placed around the user to provide a more encapsulated feeling. Currently, the most cutting-edge VR hardware is head-mounted virtual reality systems (HMVRS; Bowman et al., 2004; Hinckley & Wigdor, 2002). A HMVRS is self-contained hardware worn on an individual's head, akin to night-vision goggles, with a digital display that covers the wearer's eyes. Individuals' entire field of vision becomes the hardware display, and the HMVRS tracks the user's head movements to align the visual presentation accordingly. Further, in typical VR applications, users interact with this environment through a keyboard and mouse, but more innovative technologies, such as sensor gloves, are usually used in

rehabilitation programs (Hinckley & Wigdor, 2002). Thus, many technologies are used to present and interact with a VR environment, allowing for great flexibility in experiences.

Currently, the majority of VR-administered physical rehabilitation scholarship can be largely differentiated by the targeted skill or ability. For this reason, a review of VR-administered physical rehabilitation research is provided, below, and it is separated by four primary foci: motor control, balance, gait, and strength. Before continuing, however, an additional note should be made. This review began as a general overview of all VR-administered physical training programs, but a paucity of studies have applied the technology for developing physical abilities within non-disabled populations. While the current review is solely focused upon VR-administered physical rehabilitation, it also represents extant knowledge on the vast majority of all VR-administered physical training programs.

Motor Control

Several authors have investigated the ability of VR to rehabilitate motor control abilities, defined as the integration of sensory information and application of muscle forces to generate a desired movement or action (Holden et al., 2005; Subramanian et al., 2007). An individual may be born with certain impairments (i.e. cerebral palsy) or encounter certain life events (i.e. stroke) which may prevent proper motor control functioning due to neurological dysfunction. Life becomes difficult without adequate motor control abilities, as several tasks, such as writing or typing, require the precise manipulation of objects. For this reason, authors have placed great effort in creating rehabilitation programs for motor control.

During the immediate onset of motor control problems (early childhood for those born with impairments; immediately after life event for others), individuals regularly undergo

intensive rehabilitation sessions to develop initial motor control abilities. After these initial abilities are developed, individuals are often instructed to continue their rehabilitation with a home exercise program. These home exercise programs are performed without the supervision of a trainer, and trainees are meant to adhere to a provided training schedule (Jang et al., 2005; Lucca, 2009). Authors have noted three primary concerns with these home exercise programs.

First, ethical concerns exist. Particularly, when performing constraint-induced movement therapy (CIMT) for arm and hand rehabilitation, trainees have their nonparetic arm/hand constrained through a brace or harness, thereby forcing greater use of their paretic arm/hand (Jang et al., 2005; Lucca, 2009). While CIMT has demonstrated benefits for motor control abilities, it is extremely tiring for participants. This fatigue may increase the chance of falls, and trainees may be at a greater risk of injury as the nonparetic arm/hand is constrained during the training. Second, trainees often report that home exercise programs are boring, and this boredom sometimes prompts poor compliance (Broeren et al., 2004; Subramanian et al., 2007). When non-compliance occurs, motor functioning can worsen. Particularly, patients tend to compensate with their nonparetic limbs rather than use their paretic limbs, resulting in a deconditioning of sensorimotor function. Third, trainees often see home exercise programs as meaningless, as the rehabilitation tasks are sometimes arbitrary (i.e. move your hand in a circle). This may result in decreased motivation and compliance. More importantly, the dissimilarity between training tasks and transfer tasks may result in worse transfer of training, especially if different cognitive mechanisms and neural pathways are activated (Holden et al., 1999; 2002; 2005). For these reasons, authors have sought innovative methods to (a) provide safer home exercise programs (b) while enhancing trainee motivation and compliance (c) with the hopes of improving trainees' reactions and outcomes. A recent development is the application of VR.

VR can provide a safer environment to develop motor control. As noted by Jang and colleagues (2005) and echoed by others (Lucca, 2009), as opposed to CIMT, individuals can perform a range of unconstrained activities within VR motor control programs. In Jang and colleagues' (2005) VR training, trainees played a variety of VR games which prompted unobstructed movement. One such game placed trainees within a virtual soccer environment, which trainees played as a goalie to deflect incoming soccer balls. The training improved trainees' motor functioning as well as the activation of relevant neural pathways. While the training was safer than CIMT, Jang and colleagues (2005) noted that its success may actually be due to another proposed benefit of VR within motor control programs: added excitement.

VR may add excitement to an otherwise boring training, and the increased excitement may prompt greater trainee motivation and improve training outcomes (Subramanian et al., 2007). To test this notion, researchers have developed several VR games which trainees control with their limbs (i.e. arms or feet) to complete certain playful activities (Merians et al., 2006). For instance, Bryanton and colleagues (2006) detail a VR game which trainees must use their toes to flick an on-screen coconut, among other game activities. Scores are awarded based upon trainee performance, such as the distance flicked, and trainees are encouraged to beat their high scores. Trainees found the VR training more exciting and enjoyable than a traditional training, and they performed better on all motor control measures during the VR training compared to a conventional training. Other studies have likewise demonstrated that VR trainings prompt trainee excitement resulting in positive reactions and outcomes, and these results have been seen across an array of post-training outcome measures (Broeren et al., 2004; Merians et al., 2006); however, few of these studies include a comparable control group, leaving it unclear if VR provides benefits beyond typical motor control rehabilitation programs.

Lastly, VR motor control programs may allow training and transfer tasks to be similar. Whereas trainees perform arbitrary activities during typical home exercise programs (i.e. move your hand in a circle), VR can provide context to these activities. For instance, Holden and colleagues (2002) created a VR motor control training where trainees perform everyday activities within a digital environment, such as placing an envelope within a mail slot. Further, authors have repeatedly noted the importance of “learning by imitation,” whereby motor control programs can be more beneficial when trainees perform activities which imitate desired transfer tasks (Holden et al., 1999). Authors have proposed that similar motor control tasks may activate the relevant neurological pathways during training, and this activation may prompt cognitive rehabilitation benefits as well as physical (Jang et al., 2005). This benefit is especially important, as many motor control impairments are due to neurological dysfunction.

To test these notions, Subramanian and colleagues (2013) analyzed the efficacy of a VR program which presented a shopping task, and trainees participated for four weeks at three times per week for approximately 45 minutes. Trainees were meant to reach for objects within this environment, and successful movements increased a visual score. The benefits of similarity, along with excitement, resulted in similar but slightly better improvements to motor control compared to an alternative physical motor control training which was matched for intensity, frequency, and feedback. Trainees also noted that they felt more competent practicing in the physical motor control training, but they were less anxious in the VR motor control training. The authors argued that the reduced anxiety in the VR environment may have prompted the evidenced improvements, and the perceived competence in the physical motor control training may have caused trainees to believe their skills were sufficient thereby reducing motivation.

To date, Subramanian and colleagues' (2013) study is likely the most complete comparison of a VR motor control rehabilitation program to an existing program. A host of other authors have likewise analyzed VR programs with training tasks similar to transfer tasks, but many of these studies include methodological concerns. Holden and colleagues (1999; 2002; 2005) have seen success in developing motor control skills through realistic VR "Mailbox" and "Sleeve Pull" simulations (among others); however, no comparisons were made between the VR rehabilitation programs and relevant control groups, leaving uncertainty towards the efficacy of the VR rehabilitation programs beyond extant practices. Likewise, this is true with several other analyses of VR motor control rehabilitation programs (Broeren et al., 2004; Merians et al., 2006), including those which analyze similar and dissimilar training and transfer tasks.

In addition to observing rehabilitation outcomes in realistic VR motor control trainings, authors have also analyzed the neurological pathways involved in such trainings. The activation of these pathways is of paramount importance, as many motor control deficiencies are due to neurological dysfunction. Lucca (2009) as well as Bermudez i Badia and colleagues (2013) illustrated that relevant neurological pathways to motor control abilities are active during and after a VR training with training tasks similar to transfer tasks; however, neither analyzed the effectiveness of their training for motor control development itself. While similar VR tasks may activate neural pathways, extant research is unable to conclude that this mechanism actually prompts the improvements observed within VR motor control trainings.

Together, some inferences can be drawn about VR motor control rehabilitation programs. VR motor control rehabilitation programs are able to improve motor control abilities (Holden et al., 1999; 2002; 2005). When methodological designs allow for such comparisons, they are often more effective than traditional programs (Bryanton et al., 2006; Subramanian et al., 2013);

however, VR motor control programs applied in conjunction with a traditional training may not be more effective than a traditional program alone (Yin et al., 2014). Also, regardless of their effectiveness, VR motor control rehabilitation programs generally prompt greater trainee enjoyment than traditional programs (Jang et al., 2005; Subramanian et al., 2007), and they also activate neurological pathways relevant to motor control abilities (Lucca, 2009; Bermudez i Badia et al., 2013). Unfortunately, it is largely unknown whether this mechanism actually prompts VR motor control rehabilitation success. Table 1 includes basic information about many important VR-administered motor control rehabilitation studies, including their use of a control group, measurement occasions, sample size, outcome measures, and a one sentence article summary.

Balance

Many authors have investigated the ability of VR to train balance. Balance is the control and movement of an individuals' center of mass relative to their base of support (Heiden and Lajoje, 2010; Yen et al., 2011). Poor balance may occur from neurological disorders and other negative life events, and the inability to control balance may cause falls resulting in serious bodily injury. This is a particular concern for individuals reliant upon wheelchairs and the elderly, as they are often unable to recover from a fall themselves (Cho et al., 2012; Rahman, 2010). For these reason, the training of balance is an important endeavor for many individuals.

Modern balance rehabilitation programs occur within a lab setting and involve goal-oriented, task-specific behaviors, such as leaning forward and backward (Cho et al., 2012; Singh et al., 2012). Many drawbacks may exist with these programs. Particularly, trainees may see the repetition of goal-oriented, task-specific behaviors as boring (Bisson et al., 2007; Thorton et al., 2005). Additionally, certain cognitive demands are present within naturalistic settings which

may not be present in typical balance rehabilitation programs, such as the necessity to attend to dual tasks (i.e. balance and talking) or respond to unexpected stimuli (Suárez, et al., 2006).

Authors have proposed that VR may improve several aspects of traditional balance programs.

VR is often seen as exciting, and this excitement may subsequently improve trainee motivation and training outcomes. Betker and colleagues (2007) tested this notion through a VR balance training which consisted of “twelve 30- to 45-minute exercise sessions two or three times per week” (p. 1393). Trainees sat on a pressure mat which tracked their center-of-pressure (COP). Then, interactive games were presented on a monitor, and trainees completed the games through moving their COP. The three trainees expressed positive reactions towards the training, and they demonstrated improvements upon all outcome measures. Similarly, Cho and colleagues (2012) and Rahman (2010) demonstrated that a VR balance training via the Wii in addition to a typical balance training provided greater improvements to trainees’ balance compared to those who only received the typical balance training. Rendon and colleagues (2012) demonstrated that a VR balance training via the Wii significantly improved elderly trainees’ balance compared to a group which received no training at all. The authors of these studies argued that improvements were prompted by the added enjoyment provided by the Wii; however, their results may simply be due to the added benefit of additional training altogether. This argument is supplemented by Singh and colleagues (2012; 2013) who discovered that a VR balance training via the Wii was equally effective as a traditional balance training when matched for total training time.

Additionally, several authors have investigated the possibility of VR of providing similar cognitive demands to real-life during a balance training. Heiden and Lajoje (2010) tested the possibility of a VR balance training which trainees stood on two pressure sensors that recorded their COP, and trainees’ COP controlled a paddle within a Pong-like game presented upon a

monitor. Trainees who underwent this rehabilitation program (eight weeks at two times per week for approximately 30 minutes) in addition to a typical balance rehabilitation program did not show greater improvements in balance or gait than a comparison group which only underwent a typical balance rehabilitation program; however, they improved in their ability to respond to an unexpected auditory stimulus, which was measured as the response time to providing a verbal response after hearing an auditory stimulus while balancing. Yen and colleagues (2011) demonstrated that a VR balance training, which trainees used a balance board to control interactive games, was equally effective as a traditional balance training in developing trainees' balance, and no significant changes were observed in either group for dual-task performance. Together, these results present an unclear picture towards the efficacy of VR rehabilitation programs to develop dual-task performance.

Several inferences can be seen across the study of VR balance rehabilitation programs. Trainees seem to enjoy their experiences (Betker et al., 2007; Rendon et al., 2012), but it is unclear whether this enjoyment translates to better rehabilitation outcomes. While VR balance rehabilitation programs may provide benefits in addition to typical rehabilitation programs (Cho et al., 2012; Rahman, 2010), they may be equally effective when directly compared typical rehabilitation program (Singh et al., 2012; 2013). Also, the ability of a VR rehabilitation program to develop dual-task performance is unclear, as authors have provided conflicting results (Heiden & Lajoje, 2010; Yen et al., 2011). Table 2 includes basic information about many important VR-administered balance rehabilitation studies.

Gait

Training gait is another important application of VR training for physical rehabilitation. Gait is considered the walking-related abilities of an individual, which includes the total walking

process as well as individual aspects (hip swing, ankle movement, etc.; Brüttsch et al., 2011; Shema et al., 2013). Serious falls resulting in bodily injury may occur without proper gait abilities, causing gait to be integral to everyday functioning. Unfortunately, certain neurological disorders and life events may inhibit individuals' gaits. For this reason, rehabilitation is necessary to regain these abilities to resume everyday safe functioning, and several authors have demonstrated that VR may be the ideal application for this training.

Almost all gait programs, whether VR is included or otherwise, occur in a controlled lab setting (Batson et al., 2011; Fung et al., 2006; Mirelman et al., 2010), and participants undergo one-of-two procedures. Participants either practice their gait skills on a treadmill or with the manual assistance of a trainer. In either case, specialized technologies may aid in the gradual development of walking abilities. For instance, harnesses or haptic-sensitive robots may be used to reduce individuals' perceived weight, allowing individuals with limited mobility to begin developing muscle strength. Unfortunately, several drawbacks occur when gait programs are performed within these settings.

First, rehabilitation programs are often perceived as boring, especially by children (Brüttsch et al., 2011; Koenig et al., 2008). Trainees are unable to observe a changing landscape, akin to regular walking, and this boredom may incur reductions to trainee motivation. As previous authors have proposed, the most critical factor in trainee success for gait rehabilitation may be trainee motivation (Brüttsch et al., 2010), and reduced trainee motivation may prompt worse rehabilitation outcomes. Second, trainees are heavily reliant on observational cues to develop proper walking patterns and abilities (Mirelman et al., 2010; Shema et al., 2013). For instance, individuals alter their walking patterns when they traverse sloped surfaces, and the visual appearance of a slope subconsciously prompts these altered walking patterns. Also,

naturalistic environments often contain obstacles which must be avoided while walking, and gait rehabilitation programs should develop avoidance skills. Unfortunately, these visual cues are not present when walking on a treadmill or with the assistance of a trainer, and the development of all aspects of gait may not be possible through a lab setting. Therefore, the artificiality of laboratory settings poses several concerns for gait rehabilitation programs.

Recently, authors have sought innovative methods to address these two concerns, and VR has been seen as a dual solution. Authors have noted that trainees are inherently excited by VR, and this effect may be exacerbated if the VR program is novel or interesting (Schuler et al., 2011). For instance, common video game elements, such as challenge or assessment, may be included in a VR gait training to increase trainee enjoyment and motivation (Bedwell et al., 2012; Gotz et al., 2011). In fact, Brüttsch and colleagues (2010) tested this exact possibility. The authors analyzed a VR gait training which the trainees played a virtual soccer game. The game presented a fully three-dimensional environment and trainees' avatars responded to their leg and foot motions accordingly. Within the game, trainees were meant to out-manuever two computer-controlled defenders while dribbling a soccer ball. Participants participated within a robotic assisted gait training device, Lokomat, which provided mobility assistance when insufficient weighted force measurements were provided by participants. The results revealed that (1) VR was successful in prompting greater trainee motor output compared to a baseline program without VR, (2) the motor output of trainees using VR was about equal to trainees who were only provided trainer instruction and verbal encouragement, (3) the greatest motor output was observed when trainees used VR and were also provided trainer instruction and verbal encouragement, and (4) trainees had positive reactions to VR. Together, these results provide

initial support for the ability of VR to prompt trainee motivation, but they also demonstrate uncertainty towards the efficacy of VR beyond other, less-costly training interventions.

In a follow-up study, Brüttsch and colleagues (2011) demonstrated that the VR soccer program was, again, equally effective as trainer instruction and verbal encouragement in eliciting motor output; however, the authors also demonstrated that a VR navigation program, which the trainee explored a virtual environment through their feet and leg movements, prompted greater motor output than trainer instruction and verbal encouragement. Both VR programs prompted greater motor output than a standard training while watching a DVD. Interestingly, participants reported that their motivation was highest while watching the DVD and lowest while using the VR navigation program. In yet another follow-up study which investigated the same training conditions, Schuler, Brüttsch, and colleagues (2011) reported that “the tasks with therapeutic influence (therapist, soccer and therapist) showed higher motor output in both groups in comparison to normal walking in the driven gait orthosis [Lokomat] or to tasks with VR only (soccer, landscape). These results underline the importance of the therapist’s presence in motivating the child.” (p. 409). Once again, these results further emphasize the uncertainty towards VR in eliciting trainee motivation beyond existing, less-costly training aspects, such as trainer encouragement and instruction.

In regards to these studies, an aside should be made. Brüttsch and colleagues (2010; 2011; Schuler et al., 2011) themselves note that their investigations were under relatively short timespans, possibly obscuring the true nature of VR, trainee motivation, and rehabilitation outcomes. While physical therapy sessions may last for an hour or more, the authors only analyzed sessions lasting minutes. Trainers may be unable to provide continued support and instruction beyond the initial minutes, and VR may provide diminishing returns in prompting

trainee motivation for this timespan. Therefore, other studies should also be analyzed to understand the link between motivation and outcomes within gait rehabilitation programs.

Fortunately, other authors have also applied VR as largely a motivational tool. In a study performed by Mirelman, Bonato, and Deutsch (2008), participants in both training groups (four weeks at three times per week for one hour) used the Rutgers Ankle Rehabilitation System which develops specific muscles in the ankle. The control training used this device alone, whereas the VR training used the device to move a plane or boat in a VR environment. Participants in the VR training reported less fatigue, required less rest time, and demonstrated greater training outcomes. Also, Walker and colleagues (2010) and Zimmerli and colleagues (2009) tested a VR which users traversed a landscape as they walked on a treadmill or with the Lokomat, respectively. No comparison group was used in either study. Trainees in both studies reported favorable reactions to the rehabilitation programs, and Walker and colleagues' (2010) trainees demonstrated significant gait improvements. Lastly, Hwang and colleagues (2011) compared trainees who underwent a VR treadmill training alongside physical therapy against trainees who underwent a typical treadmill training alongside physical therapy. Most differences in gait improvement within the two groups were not statistically significant, but the findings may have been due to the small sample size of 14 total trainees.

Alternatively, authors have proposed that VR environments may provide the naturalistic visual cues that are lacking in typical laboratory settings, resulting in greater dual-task performance and obstacle negotiation. In a study conducted by Mirelman and colleagues (2010), the authors compared a VR treadmill training against a typical treadmill training. In the VR environment, participants were required to, "process multiple stimuli simultaneously and ... make decisions about obstacle negotiation in two planes, while continuing to walk on the

treadmill. These decisions were made more difficult with distracters, such as changes in lighting and moving objects” (Mirelman et al., 2010, p. 2). Each training program lasted six weeks with three sessions per week. The results demonstrated that the VR training was more effective in developing dual-task walking speed and stride length, but both programs were equally effective in developing usual walking speed. The VR training was also effective in enhancing walking speed and stride length during obstacle negotiation, but no comparisons were made with the typical treadmill training in this regard. Shema and colleagues (2013) employed a similar program (five weeks at three times per week) to develop dual-task gait activities and obstacle negotiation, and their results demonstrated that participants experienced improved mobility and decreased risk of falls. Participants were reported as highly motivated, but no comparison group was used for any analyses. Similarly, Peruzzi and colleagues (2013) tested a similar program (six weeks at two times per week), and they reported that participants enjoyed the training and thought it was easy to use. Together, these studies indicate that VR may provide visual cues which are often lacking in gait programs, but the lack of comparison groups or sufficient sample sizes disallows firm conclusions to be drawn.

Relatedly, You and colleagues (2005) investigated the efficacy of a VR-administered gait rehabilitation program to activate relevant neurological pathways. Their VR program included several tasks which were unrealistic, such as avoiding sharks underwater, but it also included several tasks which were fairly realistic, such as walking up and down steps. Their results demonstrated that the VR program was effective in activating the relevant neurological pathways, more so than a control group which did not receive an intervention. Also, those within the intervention group saw great improvements to their gait abilities.

Several overall inferences can be drawn from extant gait literature. Trainees enjoy VR for gait rehabilitation purposes, but it is unclear whether VR can increase motivation more so than alternative, cheaper programs (Brütsch et al., 2010; 2011; Schuler et al., 2011). VR can also provide naturalistic visual cues and develop dual-task gait abilities, possibly more so than traditional programs (Mirelman et al., 2010). Further, VR can develop object negation abilities, but it is unclear whether it is more successful than traditional rehabilitation programs (Shema et al., 2013). Lastly, VR can activate relevant neurological pathways to gait behaviors, but it is unclear whether this prompts gait improvements (You et al., 2005). Table 3 includes basic information about many important VR-administered gait rehabilitation studies.

Strength

Each of the reviewed areas seek to improve individuals' performance within certain domains of activities (motor control, balance, and gait). Within each of these areas, trainees must develop the cognitive mechanisms to perform these activities, but improving individuals' strength is another important component of physical rehabilitation. For this reason, several authors have directly studied the development of strength in isolation (Chen et al., 2012; Deutsch et al., 2002; Lee, 2013). Akin to the other reviewed areas, the causes of poor strength is due to certain neurological disorders or negative life events, and can result in many of the same negative outcomes. Many innovative and effective methods to develop strength exist, and VR is seen as amongst the most cutting-edge.

Currently, very few authors have proposed theoretical justifications for the impact of VR upon the strength development. Many authors, however, have noted within their discussion sections that trainees typically enjoy their VR strength training experiences, insinuating that increased enjoyment and subsequent motivation may be the cause of any observed effects.

In testing the overall effectiveness of VR strength training, mixed results have been seen. Lee (2013) demonstrated that VR training in addition to conventional occupational therapy is effective in developing shoulder and elbow strength, but it was not more effective than conventional occupational therapy alone; however, the small sample sizes may have prevented the detection of significant differences between the programs. Chen and colleagues (2012) tested the efficacy of a 12-week VR cycling training (three times per week for 40 minutes) against a control training which “was encouraged to perform general physical activity at home under parental supervision” (p. 1089). Within their study, the VR training was more effective in developing knee strength, but other changes in strength and motor function were not significantly different between the two groups. The change in knee strength may be due to the increased leg training in general within the intervention group rather than any impact of the VR itself. Saposnik and colleagues (2010) demonstrated that a VR training via the Wii was almost equally effective in developing arm and hand strength as a control training which included playing cards, bingo, and Jenga. Lastly, several authors have demonstrated that VR programs may develop strength, but many of these studies lack comparable control groups or sufficient enough sample sizes for statistical analyses (Connelly et al., 2010; Deutsch et al., 2008; Sveistrup et al., 2003). Therefore, unlike the other reviewed areas, it is still unclear whether VR has any notable impact upon strength programs, and future research is certainly needed to address this largely unknown area of VR-administered physical rehabilitation. Table 4 includes basic information about many important VR-administered strength rehabilitation studies.

Integration of Extant Research Streams and Suggestions for Future Directions

From a broad overview of VR-administered physical rehabilitation studies, several inferences can be derived. Particularly, several research questions are no longer novel or useful,

but authors continue addressing them within their studies. First, trainees generally enjoy their VR experiences across almost all domains, more so than traditional physical rehabilitation programs (Broeren et al., 2004; Merians et al., 2006). As Kirkpatrick (1975; 1979) argued, trainee reactions are the most basic outcomes of a training or intervention. It is time to move beyond analyses of trainee enjoyment, and move towards higher-level outcomes. It may be useful to apply Kirkpatrick's (1975; 1979) model to future research. This model notes that learning (immediate demonstrations), behavior (incorporation into regular activities), and results (distal outcomes) are more advanced and important outcomes for trainings and interventions. While many authors have analyzed reactions (i.e. enjoyment) and learning (i.e. immediate post-training abilities), fewer have examined the impact of VR upon behavior (i.e. ability to perform certain everyday tasks weeks later) and results (i.e. life satisfaction). Understanding these outcomes may emphasize the importance and create a deeper understanding of VR-administered physical rehabilitation programs.

Second, VR physical rehabilitation programs are capable at improving trainee physical abilities. While Holden (2005) noted the importance of demonstrating basic capabilities of VR to improve trainee skills, research within the subsequent decade has established and reestablished the ability of VR to perform this feat, and future research within this exact topic is not needed.

Third, VR physical rehabilitation programs often provide added benefits in conjunction with a typical physical rehabilitation program (Cho et al., 2012; Rahman, 2010). At this point, it is more helpful to discover instances when this is not true, and provide theory describing the source of these discrepant findings (Yin et al., 2014). Through explaining null findings, a deeper understanding of VR and rehabilitation programs can be achieved.

Alternatively, the answer to several other important research questions are much less clear, largely due to methodological limitations of prior studies. First, while authors often propose that VR may elicit greater trainee motivation, very few authors have empirically demonstrated that VR-administered physical rehabilitation programs actually prompt more motivation than comparable physical rehabilitation programs. For example, many of Brüttsch and colleagues (2010; 2011; Schuler et al., 2011) studies actually demonstrate that trainer encouragement and instruction prompts similar motivation to a VR program. Future authors should conduct similar investigations, and develop a better understanding of VR and motivation.

Second, it is largely unknown whether VR-administered physical rehabilitation programs are actually more effective than traditional and, more importantly, cheaper physical rehabilitation programs. To decisively answer this research question, future studies require relevant rehabilitation control groups which are matched for intensity, frequency, and feedback. In the current literature, this is rarely supplied. Of the modest amount of studies which supply these control groups, results are split between VR-administered physical rehabilitation program success and failure to outperform comparable control groups (Lee, 2013; Mirelman et al., 2008; 2010), and any future study investigating this topic can provide great inferences.

Third, despite a plethora of proposed possibilities, the mechanisms that prompt VR to provide greater rehabilitation outcomes are largely unknown, as authors have yet to demonstrate a consistent mediating effects of any variable between VR and rehabilitation outcomes. While increases to trainee motivation is the most attributed mechanism, it has yet to be firmly supported as a mediator (Brüttsch et al., 2010; 2011; Schuler et al., 2011). Alternatively, the current article strongly urges future authors to analyze the activated neurological pathways involved within a VR-administered physical rehabilitation program and a traditional physical rehabilitation

program. As previously mentioned, several conditions that prompt the need for rehabilitation stem from neurological deficiencies. It seems logical that rehabilitation programs for these conditions should prompt physical as well as cognitive benefits to obtain maximum effectiveness. Further, as Jang and colleagues (2009) and You and colleagues (2005) demonstrated, VR which presents realistic scenarios may activate the relevant neurological pathways during a motor control and gait rehabilitation program, but a direct link between this activation and rehabilitation success has yet to be seen. If future research can conclusively demonstrate this link, researchers and practitioners can (a) further identify the exact neurological pathways that lead to rehabilitation success, and (b) create VR programs which directly activate relevant neurological pathways to improve outcomes. Together, it is believed that this research question may be the most important for VR-administered physical rehabilitation programs.

Fourth, many VR-administered physical rehabilitations seek to improve general strength abilities, such as gait. Others attempt to improve specific strength abilities, such as individual ankle or hip movements (Darter & Wilken, 2011). Yet others still investigate methods to improve multiple physical rehabilitation at once, such as balance and gait (Kim et al., 2009). When comparing these three approaches, it is unclear which is most effective. Authors have purported benefits towards cross-training, but others have also noted the importance of specific physical rehabilitations. While this may be a distal research question, as others seem more pertinent, it is nevertheless important to discover which rehabilitation regimen is most effective when applying VR.

Fifth, two final aspects are addressed in separate sections, below. These sections note the potential for future research upon the VR technology itself as well as necessary mythological improvements within future studies.

VR Technology

Several future directions regarding the specifics of the VR technology are evident in extant VR-administered physical rehabilitation research. Authors have applied an array of technologies to present VR environments. Currently, standard monitors or televisions are the most popular presentation method (Batson et al., 2011; Fung et al., 2006; Mirelman et al., 2010). Some authors have applied surround-screen displays, which place several monitors or projectors around a trainee to provide an immersive experience (Cruz-Neira et al., 1993). The most recent development is the application of head-mounted virtual reality systems (HMVRS; Bowman et al., 2004; Hinckley & Wigdor, 2002). Despite such an array of presentation technologies, authors have yet to determine whether these newer technologies, such as HMVRSs, provide improvements of physical rehabilitations. It is possible that these newer technologies are only equally effective as prior technologies, and their added cost is fruitless. It is also possible that the newer technologies incur negative aspects of their own, such as cybersickness. Before authors shift to new technologies, more research is needed to determine their effectiveness.

Also, authors have developed innovative methods to interact with VR environments. Many of these innovative methods provide increased realism (Connelly et al., 2010; Hinckley & Wigdor, 2002). For instance, many VR gait programs track trainees' leg and foot movements, and trainees' avatars move in sync with their own motions (Brütsch et al., 2010; 2011; Schuler et al., 2011). Alternatively, some innovative methods do not seek realism but attempt to provide a novel and interesting experience (Deutsch et al., 2004; Dunning et al., 2008). Deutsch and colleagues (2004), for example, applied a device which tracked trainees' particular ankle movements, and these movements controlled an airplane within a VR environment. Despite widespread applications, results are still unclear whether these interactive hardware actually

provide added benefits to a VR-administered physical rehabilitation. For instance, Connelly and colleagues (2010) provide conflicting results towards the added benefits of a pneumatic glove within a VR strength training. Therefore, two relevant research questions are proposed: (a) does hardware which supplies added control result in better rehabilitation outcomes? And (b) does added control need to be realistic or unrealistic to provide better rehabilitation results?

Further, some authors have even applied common video-game technologies to provide cutting-edge VR-administered physical rehabilitation, including the Microsoft Kinect (Chang et al., 2011) and the Nintendo Wii (Deutsch et al., 2008; Saposnik et al., 2010). These authors have demonstrated that the technologies may prompt positive trainee reactions and outcomes, but studies rarely include a comparison group. It should be determined whether these widespread and relatively cheap technologies are comparable to other VR training technologies.

Lastly, authors have applied an array of software in VR-administered physical rehabilitation programs. Systematic comparisons of the software has yet to be performed, leaving it largely unknown which software is the most effective. Relatedly, authors have proposed that software that provides realistic experiences may prompt the greatest rehabilitation outcomes, as previous research has demonstrated that these programs may activate relevant neurological pathways. Future research is needed to ensure that (a) these pathways are not simply activated within any VR-administered physical rehabilitation program, (b) the activation of neurological pathways actually prompts rehabilitation success, and (c) realistic VR programs prompt greater rehabilitation outcomes than non-realistic VR programs.

Methodological Concerns

Lastly, it should be noted that certain systematic concerns exist within studies on VR-administered physical rehabilitations (Brütsch et al., 2010; 2011; Kim et al., 2009). First, most studies contain small sample sizes, and many are single-case studies. Second, many analyses are not based on control group comparisons, but they instead focus on pre- and post-treatment differences within the intervention group. Even when studies contain control groups, they often undergo a drastically different training. The use of no or unequal control groups poses concerns, as it is unclear whether VR solely prompts enhanced training outcomes or any training (matched for duration and intensity) would provide similar outcomes. Third, some studies do not include randomization to treatment conditions or blinding, threatening their internal validity. Fourth, across each application, little agreement can be seen in standardized outcome measures. In Moreira and colleagues' (2013) review of VR in gait research, the authors note that no study included the same outcome measures. Together, these factors cause great concern for the inferences drawn from VR-administered physical rehabilitations, and most any extant result should be taken with caution. For this reason, the current study proposes that addressing methodological concerns within research should be the primary focus of future studies.

Conclusion

Overall, the field of VR-administered physical rehabilitation is promising. Authors have repeatedly demonstrated that these programs prompt greater trainee enjoyment and may, in fact, increase rehabilitation outcomes. It has been shown that VR programs in addition to traditional rehabilitation programs may be more effective than traditional programs alone, but it is unclear whether VR programs are effective in the place of traditional programs. Also, any mechanism which may prompt VR program success is undetermined. Therefore, it is highly suggested that authors compare modern VR rehabilitation programs against traditional programs, search for

possible mechanisms that cause VR program success (especially neurological pathway activation), and apply adequate research methodologies. Together, these suggestions may further research and practice upon VR, physical rehabilitation, and their combination.

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Table 1a – List of VR-Administered Motor Control Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Acosta et al. (2011)	No	During	7	User Behaviors (During)	VRR should be created with certain ergonomic considerations in mind.
Adamovich et al. (2004)	No	Pre, During, Post	8	Motor Control (Pre, Post) User Behaviors (During)	VRR can rehabilitate MCS and produce more efficient behaviors.
Adamovich et al. (2005)	No	Pre and Post	8	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Adamovich et al. (2008)	Yes Comparable	Pre, During, Post	8	Motor Control (Pre, Post) User Behaviors (During)	VRR elicits different results if hands and arms are trained separately or together.
Barton et al. (2013)	No	During (13 Sessions)	1	Motor Control (During)	VRR can develop trunk and pelvis coupling abilities.
Bermúdez i Badia et al. (2013)	No	During and Post	9	EEG (During) Reactions (Post)	Thinking about movement can activate neurological pathways, and EEG can control VRR programs.
Boian et al. (2002a)	No	Pre and Post	3	Motor Control (Pre, Post) Strength (During)	VRR is able to rehabilitate MCS and S.
Boian et al. (2002b)	No	Pre and Post	4	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Boian et al. (2003)	No	Pre and Post	3	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Brieren et al. (2004)	No	Pre and Post	1	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Broeren et al. (2007)	No	Pre, During, Post	5	Motor Control (Pre, Post) User Behaviors (During)	VRR can rehabilitate MCS and produce more efficient behaviors.
Broeren et al. (2002)	No	Pre and Post	1	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Bryanton et al. (2008)	No	During and Post (ABBA Design)	16	User Behaviors (During) Reactions (Post)	VRR elicits more effort and enjoyment than TR.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; MCS = Motor Control Skills; S = Strength

Table 1a Continued – List of VR-Administered Motor Control Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Cameirão et al. (2010)	No	During, Post	22	User Behaviors (During) Reactions (Post)	VRR can elicit positive reactions and relate to real-world tasks
Carey et al. (2006)	Yes Comparable	Pre, Post	20	Motor Control (Pre, Post) fMRI (Post)	VRR is roughly equal to VR in rehabilitating MCS. Few changes in neurological pathways were seen.
Chang et al. (2011)	No	During (ABAB Design)	2	Motor Control (During)	VRR elicits more movement than TR.
Cho et al. (2014)	No	Pre, During, and Post	10	Motor Control (Pre, Post) User Behaviors (During)	VRR is able to rehabilitate MCS. Proprioception feedback may aid in VR usability.
Deutsch et al. (2001)	No	Pre and Post	1	Motor Control (Pre, Post) Reactions (Pre, Post)	VRR is able to rehabilitate MCS and elicit positive user reactions.
Deutsch et al. (2007)	No	Pre and Post	6	Motor Control (Pre, Post) Strength (Pre and Post)	VRR is able to rehabilitate MCS and S, and outcomes are similar whether a trainer is/is not present.
Fischer et al. (2007)	Yes Comparable	Pre, Post	15	Motor Control (Pre, Post) Reactions (Post)	VRR can elicit MCS and positive reactions; other hardware is useful.
Fluet et al. (2012)	No	Pre, Post	1	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Heuser et al. (2007)	No	Pre, Post	5	Motor Control (Pre, Post) Reactions (Post)	VRR is able to rehabilitate MCS and elicit positive user reactions.
Holden et al. (1999)	No	Pre and Post	2	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Holden et al. (2002)	No	Pre and Post	8	Motor Control (Pre, Post) Strength (Pre, Post)	VRR is able to rehabilitate MCS and S.
Holden et al. (2005)	No	Pre and Post	2	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; MCS = Motor Control Skills; S = Strength

Table 1a Continued – List of VR-Administered Motor Control Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Holden et al. (2007)	No	Pre, Post	11	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS and S.
Jack et al. (2001)	No	Pre, Post	3	Motor Control (Pre, Post) Reactions (Post)	VRR is able to rehabilitate MCS and elicit positive user reactions.
Jang et al. (2005)	Yes Not Comparable	Pre and Post	10	Motor Control (Pre, Post) fMRI (Pre, Post)	VRR activates neurological pathways and improves MCS better than no training.
Joo et al. (2010)	No	Pre, Post	16	Motor Control (Pre, Post) Reactions (Post)	VRR can rehabilitate MCS and elicit positive reactions.
Kizony et al. (2004)	No	Post	13	Motor Control (Post) Reactions (Post)	VRR can elicit positive user reactions.
Kwon et al. (2012)	Yes Not Comparable	Pre, Post	26	Motor Control (Pre, Post)	VRR with TR may be better in developing MC than TR alone.
Merians et al., (2002)	No	Pre and Post	3	Motor Control (Pre, Post) Reactions (Post)	VRR is able to rehabilitate MCS and elicit positive user reactions.
Merians et al. (2006)	No	Pre and Post	8	Motor Control (Pre, Post) Reactions (Post)	VRR is able to rehabilitate MCS and elicit positive reactions.
Merians et al. (2014)	No	Pre and Post	1	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Piron et al. (2005)	No	Pre and Post	40	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS.
Piron et al. (2007)	Yes Comparable	Pre, Post	38	Motor Control (Pre, Post)	VRR is able to rehabilitate MCS better than TR.
Rand et al. (2005)	No	Post	6, 8	Reactions (Post)	VRR can elicit positive user reactions.
Rostami et al. (2012)	Yes Comparable	Pre, Post	32	Motor Control (Pre, Post)	VRR mixed with TR is better at eliciting MC than VRR or TR alone.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; MCS = Motor Control Skills; S = Strength

Table 1a Continued – List of VR-Administered Motor Control Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Subramanian et al. (2013)	Yes Comparable	Pre and Post	32	Motor Control (Pre, Post) Motivation (Post)	VRR is slightly better at developing MCS than TR.
Thielbar et al. (2014)	Yes Comparable	Pre and Post	14	Motor Control (Pre, Post) Strength (Pre, Post)	Alongside physical therapy, VRR is better at developing MCS and S than TR.
Whitney et al. (2006)	No	During	5	User Behaviors (During)	VRR may prompt negative user behaviors.
Yavuzer et al. (2008)	Yes Not Comparable	Pre, Post	20	Motor Control (Pre, Post)	VRR with TR is more effective at rehabilitating MCS than TR alone.
Yin et al. (2014)	Yes Not Comparable	Pre and Post	23	Motor Control (Pre, Post) Reactions (Post)	VRR with TR was equal to TR alone in developing MCS. Users had positive reactions to VRR.
Yoo et al. (2014)	No	During (AB Design)	3	Muscle Activation (During)	VRR can elicit proper muscle use better than TR.
You et al. (2005)	No	Pre, Post	1	Motor Control (Pre, Post) fMRI (Pre, Post)	VRR can rehabilitate MCS and activate neurological pathways

Note for All Tables: For a control group to be considered comparable, it must be matched for duration and intensity.

Within the measurement occasion column, “during” specifically references measurements taken during the performance of rehabilitation tasks. For instance, measuring motor output while performing rehabilitation tasks is considered a “during” measurement occasion. Further, some studies gauged participant attributes after multiple sessions of the rehabilitation program, and this measurement scheme would be considered a “post” measurement occasion.

Table 2a – List of VR-Administered Balance Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Betker et al. (2006)	No	Pre and Post	2	Balance (Pre, Post)	VRR can rehabilitate BS.
Betker et al. (2007)	No	Pre and Post	3	Balance (Pre and Post) Reactions (Post)	VRR is able to rehabilitate BS and elicit positive reactions.
Bisson et al. (2007)	Yes Comparable	Pre and Post	24	Balance (Pre and Post) Dual Task (Pre and Post)	VRR was equal to TR in improving BS and DTS.
Brien et al. (2011)	No	Pre and Post	4	Balance (Pre, Post) Gait (Pre, Post)	VRR can rehabilitate BS and gait.
Brumels et al. (2008)	Yes Comparable	Pre and Post	25	Balance (Pre, Post) Reactions (Post)	VRR can elicit better BS and reactions than TR.
Cho et al. (2012)	Yes Not Comparable	Pre and Post	22	Balance (Pre and Post)	VRR with TR was equal to TR alone in developing static BS, but better at developing dynamic BS.
Cikajlo et al. (2012)	No	Pre, During, and Post	6	Balance (Pre, Post) Gait (Pre, Post) Behaviors (During)	VRR is able to rehabilitate BS and gait, and trainees perform more correct training behaviors over time.
Deutsch et al. (2008)	No	Pre and Post	1	Perceptual Skills (Pre, Post) Balance (Pre, Post) Gait (Pre and Post)	VRR can improve perceptual skills, BS, and gait.
Deutsch et al. (2009)	Yes Comparable	Pre and Post	2	Balance (Pre, Post) Gait (Pre, Post) DTS (Pre, Post)	VRR is comparable to TR in rehabilitating BS, gait, and DTS.
Heiden et al. (2010)	Yes Not Comparable	Pre and Post	16	Balance (Pre and Post) Dual Task (Pre and Post)	VRR with TR is better than TR alone in developing DTS, but results for BS were unclear.
Kim et al. (1999)	No	Pre and Post	1	Cycling Balance (Pre, Post)	VRR can rehabilitate cycling BS.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; BS = Balance Skills; DTS = Dual Task Skills

Table 2a Continued - List of VR-Administered Balance Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Kim et al. (2009)	Yes Not Comparable	Pre and Post	24	Balance (Pre, Post) Gait (Pre, Post)	VRR with TR is better than TR alone for rehabilitating dynamic BS and gait, but equal for static BS
Kizony et al. (2005)	No	Pre and Post	13	Balance (Pre, Post) Reactions (Post)	VRR can elicit positive reactions. BS relates to performance in VRR.
Nitsz et al. (2010)	No	Pre and Post	10	Balance (Pre, Post) Strength (Pre, Post)	VRR can rehabilitate BS and strength.
Oddsson et al. (2006)	No	Pre and Post	12	Balance (Pre, Post)	VRR can rehabilitate BS.
Rahman et al. (2010)	Yes Not Comparable	Pre and Post	30	Balance (Pre and Post)	VRR with TR is slightly better than TR alone in developing BS.
Rendon et al. (2012)	Yes Not Comparable	Pre and Post	34	Balance (Pre and Post) Depression (Pre and Post)	VRR is able to rehabilitate BS, but depression did not change.
Singh et al. (2012)	Yes Comparable	Pre and Post	36	Balance (Pre and Post)	VRR is equal to TR for developing BS.
Singh et al. (2013)	Yes Comparable	Pre and Post	28	Balance (Pre and Post)	VRR is equal to TR for developing BS.
Suárez et al. (2006)	No	Pre and Post	26	Balance (Pre and Post)	VRR is able to rehabilitate BS.
Thornton et al. (2005)	Yes Comparable	Pre and Post	27	Balance (Pre and Post) Focus Group (Post)	VRR and TR were effective in improving BS. Users had positive reactions to the VRR.
Whitney et al. (2009)	No	Pre and Post	12	Balance (Pre, Post)	VRR can rehabilitate BS.
Yen et al. (2011)	Yes Comparable	Pre and Post	38	Balance (Pre and Post) Dual Task (Pre and Post)	VRR is roughly equal to TR for developing BS. No changes were seen in DTS for any group.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; BS = Balance Skills; DTS = Dual Task Skills

Table 3a – List of VR-Administered Gait Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Baram et al. (2005)	Yes Comparable	Pre and Post	28	Gait (Pre, Post)	VRR can improve gait for those with disabilities, but not healthy controls.
Brütsch et al. (2010)	Yes Comparable	During and Post (ABC Design)	18	Behaviors (During) Reactions (Post)	VRR efficacy is about equal to TR, but best when paired with TR.
Brütsch et al. (2011)	Yes Comparable	During and Post (ABCD Design)	24	Behaviors (During) Reactions (Post)	VRR elicits more effort and positive reactions than TR, but it depends on the program.
Darter et al. (2011)	No	Pre and Post	1	Motion (Pre, Post) Oxygen Use (Pre, Post)	VRR can elicit more effective gait motions and less oxygen use.
Deutsch et al. (2004)	No	Pre and Post	6	Gait (Pre, Post)	VRR is able to rehabilitate gait.
Feasel et al. (2011)	No	Post	5	Gait (Post) User Behaviors (During)	Few effects were seen for a single session of VRR.
Fulk et al. (2005)	No	Pre and Post	1	Gait (Pre, Post) Balance (Pre, Post)	VRR can rehabilitate gait and BS.
Fung et al. (2006)	No	During	2	Behaviors (During)	VRR allows users to adapt quickly and can be used for gait rehabilitation
Gokeler et al. (2014)	Yes Comparable	During	40	Movement (During)	VRR may elicit more effective rehabilitation movements than TR
Götz et al. (2011)	No	Post	45	Motivation (Post) Reactions (Post)	VRR elicits motivation and positive reactions
Koenig et al. (2008)	No	During and Post	1, 4	Behaviors (During) Reactions (Post)	VRR elicits effort and positive reactions
Mirelman et al. (2008)	Yes Comparable	Pre and Post	18	Gait (Pre, Post)	VRR is more effective than TR at rehabilitating gait.
Mirelman et al. (2010)	Yes Comparable	Pre and Post	18	Gait (Pre, Post)	VRR is more effective than TR at rehabilitating gait.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; BS = Balance Skills; DTS = Dual Task Skills

Table 3a Continued – List of VR-Administered Gait Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Mirelman et al. (2011)	No	Pre and Post	20	Gait (Pre, Post) Dual Task (Pre, Post)	VRR can rehabilitate gait and DTS.
Peruzzi et al. (2013)	No	Pre, During, and Post	10	Reactions (Pre, Post) Behaviors (During)	VRR is feasible and elicits positive reactions.
Powell et al. (2009)	Yes Comparable	During	36	Behaviors (During)	VRR with a treadmill elicits slower cadence than over ground walking in those with and without pain.
Schuler et al. (2011)	No	During, Post (ABCD Design)	17	Motivation (During, Post)	VRR is roughly equal to TR in eliciting motivation.
Shema et al. (2014)	No	Pre and Post	60	Gait (Pre, Post)	VRR can rehabilitate gait.
Walker et al. (2010)	No	Pre and Post	6	Gait (Pre, Post) Balance (Pre, Post)	VRR can rehabilitate gait and BS.
Yang et al. (2008)	Yes Comparable	Pre and Post	20	Gait (Pre, Post)	VRR is more effective than TR at rehabilitating gait.
You et al. (2005)	Yes Not comparable	Pre and Post	10	Gait (Pre, Post) FMRI (Pre, Post)	VR activates neurological pathways and improves gait better than no training
Zimmerli et al. (2013)	No	Post	19	Reactions (Post) Motivation (Post)	VRR can elicit positive user reactions and motivation.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; BS = Balance Skills; DTS = Dual Task Skills

Table 4a - List of VR-Administered Strength Rehabilitation Studies

Article	Control Group	Measurement Occasions	Sample Size	Outcome Measures	Conclusions
Chen et al. (2012)	Yes Not Comparable	Pre and Post	27	Strength (Pre, Post) Motor Control (Pre, Post)	VRR can improve S, but results were less encouraging for MC.
Chen et al. (2013)	Yes Not Comparable	Pre and Post	27	Strength (Pre, Post) Motor Control (Pre, Post) Bone Density (Pre, Post)	VRR can improve S and bone density, but results were less encouraging for MC.
Connelly et al. (2010)	Yes Comparable	Pre, During, and Post	14	Strength (Pre, Post) User Behaviors (During)	Specialized hardware may aid VRR in developing S.
Deutsch et al. (2002)	No	Pre and Post	2	Strength (Pre, Post) Reactions (Post)	VRR can improve S and prompt positive reactions.
Lee et al. (2013)	Yes Not Comparable	Pre and Post	14	Strength (Pre, Post)	Both VRR and TR can rehabilitate S.
Saposnik et al. (2010)	Yes Comparable	Pre and Post	20	Strength (Pre, Post) Safety Outcomes (Post)	VRR is roughly equal to TR for developing S. No safety concerns were observed.
Sveistrup et al. (2003)	Yes Comparable	Pre and Post	3, 14	Strength (Pre, Post)	VRR may be an good alternative to TR, as both can develop S.
Van Schaik et al. (2008)	No	Post	22	Reactions (Post)	VRR can elicit positive user reactions.

VRR = Virtual Reality Rehabilitation; TR = Typical Rehabilitation; S = Strength; MC = Motor Control

Appendix B

Social Outcomes

Integrating Scholarship on Virtual Reality-Based Social Skills Training: The Presentation of Forty Research Questions

Humans are inherently social creatures who view themselves in relation to others, consciously and subconsciously creating in-groups and out-groups to define themselves (Howard & Magee, 2013; Leach et al., 2008). People also develop an understanding of the world through these social interactions (Hughes & Leekam, 2004; Schaffer, 1996). Events, locations, and objects are ascribed importance based upon others' actions and reactions towards them. These factors cause individuals to be incredibly reliant on their social skills, constituting the reliable interpretation and adequate expression of social information (Gresham & Elliott, 2008; McFall, 1982; Trower & Hollin, 2013). If individuals are unable to interpret the social behaviors of others, they may remain unsure of their social positioning, others' behavioral intentions, and the relative importance of events, locations, objects, and people. This can lead to an array of negative outcomes, including stress, anxiety, depression, and life dissatisfaction (Bastian et al., 2005; Herbert et al., 2005; Segrin et al., 2007). Also, feelings of frustration may occur if an individual is unable to express their emotions (Bornstein et al., 1980; Pfiffner & McBurnett, 1997). For these reasons, several authors have demonstrated interest in advancing the social skills of individuals (Gresham et al., 2001; Hogarty et al., 1986; Trower & Hollin, 2013).

Most of this research is targeted towards clinical populations, including individuals with autism spectrum disorder (ASD), schizophrenia, and other psychiatric disorders (Cappadocia & Weiss, 2011; Granholm et al., 2013; Laugeson et al., 2012). These populations often incur several negative outcomes stemming from systematic difficulties in social development, and social skills trainings specifically target these systematic difficulties to improve social

functioning and related outcomes. Alternatively, some research has investigated the impact of social skills training for non-clinical populations (Baron & Markman, 2000; Durlak et al., 2010; Spence, 2003). The majority of this research investigates methods to train individuals' social skills for specific purposes, such as employability or supervisor success. In all domains of social skills training scholarship, authors have repeatedly demonstrated that certain trainings administered by a trainer or therapist¹ may improve social functioning and related outcomes (Antshel & Remer, 2003; Kurtz & Mueser, 2008; Pilling et al., 2002).

Despite this success, scholars remain vigilant to determine more effective methods to improve trainee social skills. For decades, authors have expressed interest in the use of technology in conjunction with a trainer, believing that specialized devices may provide benefits beyond improvements to the training regime itself (Lee & Owens, 2004; Salas et al., 2012). Early technology applications involved the presentation of a recorded video which models behavior for individuals. More recent advancements involve the application of more sophisticated technology, such as head-mounted displays, demonstrating that advancements to technology may cause advancements to social skills trainings (Johnson et al., 2005; Wouters et al., 2009). Following this notion, authors have begun investigating the potential for virtual reality (VR) to improve social skills (Muscott & Gifford, 1994; Parsons & Mitchell, 2002).

VR is the computer-generated simulation of a three-dimensional environment with interactive capabilities (Burdea & Coiffet, 2003; Steuer, 1992). Users are able to enter a digital world which may represent a realistic and familiar environment (i.e. school, park, or town) or a novel and exciting environment (i.e. the moon, professional sports arena, or a fantasy world).

¹ Many social skills trainings, particularly those for clinical populations, are administered via therapist. To improve the clarity of writing, however, the current article hereby refers to the training administrator as a trainer.

Within these environments, users often control a virtual representation of themselves called an avatar, and this representation may appear similar or dissimilar to the user (Garau et al., 2003; Hemp, 2006). Most importantly, users are able to interact with other avatars, whether automated or user-controlled, within their VR environments to practice social skills and abilities.

Currently, VR social skills training is applied for various purposes and populations, such as eye-contact for those with ASD and interview skills for general populations (Irish, 2013; Villani et al., 2012). Despite widespread application, much remains unknown about VR social skills trainings. Particularly, authors seem uncertain regarding (a) *when* VR may benefit social skills trainings, (b) *why* VR may benefit social skills trainings, and (c) *how* VR may maximally benefit social skills trainings. Further, authors also appear uncertain regarding the plausibility of theories and mechanisms proposed to answer these questions, as a plethora of possibilities have been suggested within each research domain, and the possibilities largely differ between the domains. Thus, great uncertainties exist within the VR social skills training literature.

A possible cause of this uncertainty may be authors' focus on their own research area, rather than drawing integrative inferences across the study of VR social skills trainings. Indeed, the focus within domains (i.e. ASD, schizophrenia, other psychiatric disorders, non-clinical populations) prevents certain research questions from being answered, and other research questions may reappear across each domain even if they may have already been addressed within a particular application. More importantly, without a unified perspective on VR social skills trainings, authors may even be unsure of which research questions are most appropriate to pursue. For these reasons, the current article argues that, although research populations may differ, an overall understanding of VR's impact on social skills trainings can only be obtained through simultaneously considering each area, and research can progress more efficiently if this

overall point-of-view is taken. To address this concern, the current study reviews each domain of VR social skills training and explicitly notes the primary, ongoing research questions.

Several steps are taken to achieve the goals of the current article. First, a brief review of VR social skill training familiarizes readers with core aspects of this literature and addresses untested assumptions. Second, a review is provided of the four most popular applications of VR social skills trainings, which are separated by the trainee populations: individuals with ASD, schizophrenia, other psychiatric disorders, and without disorders. For each of these reviews, the current state of research is described, ongoing research questions are provided, and considerations for future research are proposed. Third, a discussion is presented which integrates the four separate research streams. Together, this review clarifies the current trends of research in VR social skills training and provides direction for future research and practice.

Virtual Reality for Social Skill Training

Authors have repeatedly praised the general effectiveness of VR, noting that the technology can improve outcomes across many applications (Burdea & Coiffet, 2003; Steuer, 1992); however, some authors have proposed a related research question: For what purposes is VR most effective? It is likely that the application of VR is particularly effective for certain applications, such as social skills trainings, whereas it may provide a null or negative effect upon others (Harris et al., 2002; Safir et al., 2012; Wallach et al., 2009). For this reason, authors have speculated upon the ideal applications of VR.

Most notably, authors have posed that VR may be particularly effective at training experiential knowledge (Dickey, 2005; Jarmon et al., 2009). Experiential knowledge describes knowledge that is best obtained through experience, and it is often contrasted against declarative

knowledge which is best obtained through instruction. While many skills have direct relevance to experiential knowledge, one of the most relevant is social skills. Social skills are focused upon interpersonal interactions, and often require a trainee to actually perform a behavior before the skill or ability can be obtained. For example, an individual can rarely become an expert public speaker through instruction alone, but repeated practice of speaking skills is required (Allen et al., 1989; Lucas, 2008). Further, trainable social skills include body language, such as eye contact and posture; confidence with others, such as business associates or romantic dates; social proficiency, such as interpersonal effectiveness or negotiation abilities; and several other potential outcomes (Erickson et al., 2008; Freshwater & Stickley, 2004; Mumford et al., 2000). Thus, while social skills can widely vary in nature, they are almost always a form of experiential knowledge. The education of experiential knowledge is possible within a VR environment.

VR environments can present any imagined or realistic environment or scenario, allowing for the performance and practice of social behaviors in innovative contexts. Further, while several authors consider the study of VR as emergent, several core attributes of the technology, especially for training purposes, has been demonstrated. Most notably, authors have demonstrated that individuals behave similarly within VR environments as they do in real-life environments, and this is even true for individuals with ASD and schizophrenia (Ku et al., 2005; Lahiri et al., 2011). Also, ample support has been provided for the generalizability of skills, even social skills (Irish, 2013), learned within a VR environment (Ahlberg et al., 2007; Larsen et al., 2009; Seymour et al., 2002). Therefore, current literature has demonstrated promising results for the premise of VR social skills training.

Together, the continued research and application of VR trainings for social skills appear warranted, and scholars across almost all applications of VR have purported general benefits for

social skills training. Due to the disjointed nature of VR training scholarship, however, authors may be unaware of each of these benefits. For this reason, the specific applications of VR social skills trainings should be considered, followed by an integration of each research stream.

Among the most popular trainee populations for VR trainings are individuals with ASD, schizophrenia, other psychiatric disorders, and without disorders. Each of these populations has various idiosyncrasies and training considerations which affects the ideal presentation of training material. For this reason, a review of VR training for social outcomes is provided below separated by the trainee population, starting with individuals with ASD.

Social Skill Training for Individuals with ASD

The most popular application of VR social skills training is focused upon individuals with ASD (Irish, 2013; Kandalaft et al., 2013; Ke & Im, 2013). Recent estimates indicate that 1 in 68 American children have ASD (CDC, 2014). A primary characteristic of ASD is difficulty with several aspects of social functioning, including egocentric and echolalic speech (Parsons & Mitchell, 2002), integrating motor and sensory experiences (Jung et al., 2006), nonverbal behavior (Reed et al., 2011), building relationships (Hendricks & Wehman, 2009), functioning occupationally (Kandalaft et al., 2013), and understanding appropriate social behaviors (Baron-Cohen & Bolton, 1993; Frith, 1989). Further, between 25 and 61 percent of children with ASD demonstrate a total deficit in communication altogether (Weitz et al., 1997). Individuals with ASD do not obtain regular social skills naturally, and they must learn these behaviors as others “learn their school lessons” (Frith & Frith, 2003, p. 221). These difficulties can result in unemployment (Howlin, 1997), poor psychological well-being (Tantam, 1988), and even suicide (Wing, 1981). These outcomes are possible even if an individual with ASD demonstrates regular intelligence and language proficiency, known as high-functioning autism (HFA). Due to the

social difficulties of this population, as well as the related negative outcomes, authors have placed an extreme focus upon improving the social skills of individuals with ASD.

Unfortunately, these trainings have certain noteworthy and systematic limitations

Notably, most trainings are restricted to interactions between a trainer and trainee, limiting the possible scenarios that a trainee can practice their social skills. While trainees may become comfortable in interacting with a trainer, their comfort may not transfer to other social interactions. The limitation of possible interactions may also cause trainings to become boring, potentially reducing their effectiveness. Additionally, individuals with ASD may be particularly fearful of trainer judgment (Pascualvaca et al., 1998). Lastly, this reliance upon trainers may cause trainings to be costly. As Goodwin notes (2008), “The total annual societal per capita cost (including both direct and indirect expenses) of caring for and treating a person with autism in the United States is estimated to be \$3.2 million ... Behavior therapy alone can cost upwards of \$60,000 per year” (p. 126). Therefore, these factors may result in reduced training effectiveness, and authors have applied VR technologies to overcome these limitations.

VR Social Skill Training for Individuals with ASD

As mentioned, VR can provide a realistic demonstration of novel or familiar environments, and these environments may include intractable avatars. Users of these VR programs may be able to interact with these avatars if this capability is programmed. More importantly, however, individuals with ASD have been shown to quickly adapt to VR environments as well as interpret VR environments as representations of real-life situations (Irish, 2013; Mitchell et al., 2007; Parsons et al., 2004). Below, a presentation of extant VR trainings which incorporated tested therapy regimens are presented, followed by the benefits and considerations of VR social skills trainings specific to individuals with ASD.

Operant Conditioning

Early trainings for individuals with ASD based upon the principals of operant conditioning was criticized for its poor generalization into real-world environments (Lovaas, 1987). Trainees repeatedly practiced specific gestures in one-on-one settings with immediate trainer reinforcement, but trainees did not practice these behaviors in more lifelike settings (Frankel et al., 1987). Modern training has improved generalizability through embedding interventions within naturalistic environments, such as home or school (Eikeseth et al., 2002; Ozonoff & Cathcart, 1998). This allows the spontaneous occurrence and practice of social behaviors with an array of important individuals, such as teachers, peers, and parents; however, certain difficult behaviors may not occur regularly enough to gain adequate proficiency (Cobb et al., 2002; Parsons & Mitchell, 2002). VR environments, however, may be naturalistic and preprogrammed to prompt certain irregular scenarios, and authors have begun to test the efficacy of VR social skills trainings based upon the principals of operant conditioning (Irish, 2013).

The most popular of these trainings, and the most popular VR social skills training altogether, instructs individuals with ASD on proper methods to choose seating in a public café (Irish, 2013; Leonard et al., 2002; Parsons et al., 2004). Trainees are placed within a virtual café which is populated with automated avatars. The trainees are asked to choose a seat, and their seating decision is meant to be based upon the notion of personal space. That is, a correct seat does not have anyone else at the table; however, if all the tables are taken, they are allowed to sit at a table with someone else. Authors have repeatedly demonstrated that individuals with ASD can become progressively better at choosing the correct seat (Irish, 2013; Brown et al., 1999; Leonard et al., 2002). Also, this ability can generalize to choosing the correct seat while viewing a video of a café or bus (Leonard et al., 2002; Mitchell et al., 2007; Parsons et al., 2004),

although one study demonstrated conflicting results (Rutten et al., 2003). Unfortunately, no author has demonstrated that this training can generalize to a real-life environment.

Also, some authors have tested the efficacy of a VR conversation partner to develop the social skills of individuals with ASD (Trepagnier et al., 2011). With this technology, trainees interact with a digital avatar and select conversation responses from a menu. For example, the avatar may say, “I am sick today,” whereas the user selects the most appropriate choice from, “I am sorry to hear that,” “The weather is nice today,” and “That is nice.” The avatar provides naturalistic feedback based upon the trainee choice, reinforcing successful interaction choices. Initial studies into this medium have demonstrated success, but these investigations usually contain small sample sizes, modest outcome measures, and little investigation into the exact causes of training success (Trepagnier et al., 2011).

Together, these VR trainings based upon the notions of operant conditioning provide particular insights. Older training using the notions of operant conditioning emphasized the repeated practice of behaviors. Modern training using these notions emphasized the importance of realistic environments, such as home or school. A VR training can present a realistic environment, as done in modern training, but also allows for the repeated practice of certain difficult skills, as done in older training. Therefore, while training based upon the principals of operant condition is among the most theoretically-simple of those directed towards individuals with ASD, the properties of VR nevertheless demonstrate the potential to improve this form of social skills training; however, the current applications are limited to café seating and conversation partners. Future studies should develop new software to train individuals with ASD in more diverse social skills.

Research Question 1: Does VR social skills trainings based upon the principals of operant conditioning effectively train simple, specific social skills?

While VR social skills trainings based upon the principals of operant conditioning have demonstrated its effectiveness for certain basic social skills, such as choosing a seat within a café, significantly fewer authors have investigated its potential for improving more advanced social skills (Smith et al., 2014). For example, training individuals with ASD to be successful during interviews is greatly different than educating correct seating decisions. The former requires the development of multiple individual social skills to prompt adequate social functioning, whereas the latter only requires the specific development of a single ability. Amongst the few studies which have developed these more complex social skills, Smith and colleagues (2014) demonstrated that individuals with ASD within a VR job interview training which instructs trainees to present certain attributes (i.e. dependability, teamwork) through providing immediate feedback were rated more favorable in job interview role-play performances than those within a treatment-as-usual condition. Future authors should further this area of research and test other VR programs to develop advanced social skills.

Research Question 2: Does VR social skills trainings based upon the principals of operant conditioning effectively train complex, integrated social skills?

Theory of Mind

ToM-oriented training is increasingly popular. Within the ToM perspective, authors posit that individuals understand others through imaginatively adopting others' conceptual perspectives, and individuals' worldview is constructed through their own perspective as well as their imagined perspective of others (Baron-Cohen et al., 1985; Bora & Pantelis, 2013; Frye &

Moore, 2014; Premack & Woodruff, 1978). Take the following example: An individual may watch a friend place an object within a drawer, and the friend leaves the room. Then, a different friend may move that object to a new location, such as a cabinet, and also leave the room. When the original friend returns to retrieve the object, the individual intuitively knows that their friend will likely look within the drawer. This is because most individuals can adopt their friend's conceptual perspective, which does not have knowledge of the object being moved, and anticipate that they will look within the drawer; however, individuals with ASD often incorrectly guess the scenario, and assume that the original friend will look in the cabinet. Proponents of the ToM perspective suggest that individuals with ASD demonstrate deficiency within social interactions because they cannot adapt others perspectives (Baron-Cohen, 1997; Baron-Cohen et al., 1985), and the ability to understand others' mental states is integral to social functioning.

ToM-oriented training focuses upon developing trainees' ability to adopt others' perspectives through certain activities. Two of these are false belief tasks and role-playing. A false belief task is similar to the example above, whereas an individual must adapt the perspective of others and understand their thought process. Providing trainees with a pictorial representations of others' conceptual perspectives allows those with ASD to envision others thoughts. For example, including thought bubbles within pictorial representations of a false belief task may help individuals with ASD understand others viewpoints. Then, over time, trainees are given fewer visual representations. This premise has already been applied within a VR environment. Moore and colleagues (2005) constructed a VR social skills training which prompted trainees to predict others feelings after observing a scenario, and feedback was given after each prediction. Although the VR training was limited in its ToM development, the results demonstrated success for improving the social skills of individual with ASD.

Alternatively, role-plays are simulations of realistic social interactions. When performing a role-play, a trainer and trainee practice an interaction whereas the trainer assumes the role of another individual, and the trainee must successfully interact with this individual. Throughout the role-play, the trainer provides suggestions to trainees whenever they perform actions incorrectly, and the trainer prompts trainees to adopt the perspective of the other individual. This is a direct method to practice perspective-taking. Authors have purported that they applied role plays to develop ToM within a VR environment (Kandalaft et al., 2013; Strickland et al., 2013), but many of these studies demonstrate little difference from role plays developed from an operant conditioning perspective. That is, many of these role plays to develop ToM provide feedback to trainings, but seem to rarely prompt perspective taking.

Together, applying the ToM perspective within a VR social skills training has demonstrated initial success; however, unlike VR social skills trainings based upon the theories of operant conditioning, much less scholarship has investigated the success of ToM-oriented VR social skills trainings. In fact, it seems that more authors have praised the potential of the ToM perspective than those who have actually tested ToM-oriented VR social skills trainings (Baron-Cohen, 2000; 2001; Parsons & Mitchell, 2002). For this reason, further research is needed to replicate the initial success of VR social skills trainings applying ToM.

Research Question 3: Does VR social skills training based upon the ToM effectively teach social skills?

Atheoretical Trainings

Some VR social skills trainings do not appear to be based upon a tested therapy, but these trainings have demonstrated notable success in several pilot studies. Strickland and colleagues

(2013) investigated the impact of a VR employment training program for individuals with ASD, and they demonstrated that trainees improved upon verbal content skills. Also, Ke and Im (2013) demonstrated that a VR training could improve participant responding, initiation, greeting, and positive conversation-ending, as well as a host of other social competence measures. While these two studies are among the most successful, other authors have also demonstrated success in creating largely atheoretical VR social skill trainings for individuals with ASD (Jung et al., 2006; Parsons & Mitchell, 2002). Together, these cumulative studies demonstrate that general VR trainings may be successful for social skill development.

Research Question 4: Do VR trainings need to be based upon a particular theory to effectively develop the social skills of individuals with ASD?

In addition to discovering the general efficacy of VR social skills trainings for individuals with ASD, extant studies have exposed several research questions presented below.

General Research Questions of VR Social Skill Training for Individuals with ASD

Authors have largely applied VR social skill training to child populations with ASD (Harris & Reid, 2005; Herrera et al., 2008; Strickland et al., 1996). These authors note that social skills can be instructed to children before other, less effective social behaviors are learned. This circumvents the difficulty of losing previous behaviors and habits before learning new skills. Similarly, other authors have proposed that children's minds are more malleable than adults, especially in regards to social skills. Nevertheless, little evidence has been provided that VR social skill training is ineffective in adult populations. In fact, a recent meta-analysis on technology-based interventions for ASD demonstrated that age did not demonstrate an effect on

intervention effectiveness (Grynszpan et al., 2014). Therefore, future investigations should analyze whether adults and children with ASD actually incur different social training outcomes.

Research Question 5: Do VR social skills training outcome differ for children and adults with ASD?

Similarly, the majority of studies investigating VR social skill training for individuals with ASD are focused upon those with HFA (Irish, 2013; Neale et al., 2002; Parsons et al., 2000; Rutten et al., 2003), but it is unclear whether this is a requirement for effective VR social skill training. Authors should investigate the whether individuals upon the entire autism spectrum are capable of developing social skills via VR.

Research Question 6: Do VR social skills training outcome differ between individuals with HFA and other forms of ASD?

Additionally, several authors have noted that individuals with ASD generally enjoy computer gaming applications (Beaumont & Sofronoff, 2008; Bernard-Opitz et al., 2001; Charlop-Christy & Daneshvar, 2003; Ke & Im, 2013; Moore et al., 2000; Silver & Oakes, 2001); however, many popular elements of computer games have yet to be integrated into VR social skill training. Fortunately, the recent gamification movement within organizational scholarship can provide guidance into potentially successful computer gaming elements. For instance, Bedwell and colleagues' (2012) recently presented a typology of video game elements, and each of these elements may be effectively incorporated into a VR social skills training.

Research Question 7: Does the incorporation of video game elements benefit VR social skills training applications for individuals with ASD more so than a general population?

Concerns of VR Social Skill Training for Individuals with ASD

While the field of VR social skills training for individuals with ASD is promising, some concerns should be noted. First, the current applications are fairly limited. By far, the most popular VR social skills training instructs individuals on proper methods to choose seating within a café setting. Two studies have demonstrated that this training is effective through trainees' ability to choose a proper seat within a video recording of a café or bus (Leonard et al., 2002; Mitchell et al., 2007), but one demonstrated that these skills did not generalize to the video recording of a bus (Rutten et al., 2003). Therefore, this training may or may not be successful in teaching the concept of personal space; however, before any further research is performed, it should be considered whether the VR café training truly teaches social skills.

Some authors have noted that simply teaching social rules (i.e. take a seat away from others rather than beside) is not the same as teaching complex social skills (Harris et al., 1991; Gordon, 1995; Parsons & Cobb, 2011). Others have noted that social interactions require instantaneous spontaneity, and learning direct rules may not benefit many social situations (Cobb et al., 2002; Klin & Volkmar, 2000). Unfortunately, several previous studies and reviews incorrectly have used findings upon the VR café training to support the notion that VR is successful in training general social skills, as similarly noted by other authors (Parsons & Cobb, 2011). Future authors should expand skills taught within virtual environments. For example, Kandalaft and colleagues (2013) present a multiple-phase VR social skills training which educates trainees on eight separate social skills as well as various unspecified role-plays.

It is incorrect, however, to state that no efforts are being made towards the goal of incorporating more nuanced social abilities. Several scholars have tested a VR programs which train individuals with ASD to better understand others' emotional states, especially the recognition and understanding of facial expressions (Fabri et al., 2007; Fabri & Moore, 2005;

Grynszpan et al., 2009; Moore et al., 2005; Trepagnier et al., 2005; Trepagnier et al., 2002). Future research should continue this trend and, most importantly, test the efficacy of these innovative VR programs to train more diverse social skills.

Research Question 8: Which social skills can be trained within VR environments?

Second, it should also be considered whether individuals with ASD could become reliant upon these VR environments. Several authors have noted that individuals with ASD exhibit an affinity towards learning from computer games (Heimann et al., 1995; Mineo et al., 2009), and demonstrate a preference for visual stimuli delivered through electronic screens (Buggey, 2005; Mineo et al., 2009; Shane & Albert, 2008). It is natural, then, to question whether individuals with ASD could grow too fond of these VR environments, especially considering that a VR environment is often considered a safe environment (Howlin, 1998; Latash, 1998). Parsons and Mitchell (2002), however, claim that this concern is unfounded. The authors concede that this is an important issue, but also notes that other easily avoidable factors may cause this reliance. They argue that predictability may be the primary cause of VR dependence, as the user may find comfort in the environmental control, but this can easily be avoided with the incorporation of more flexible and unpredictable events. While Parsons and Mitchell (2002) seem to dismiss the severity of VR dependence, this is still a research question that should be considered

Research Question 9: Do individuals with ASD become reliant upon VR environments through VR social skills training?

Third, individuals with ASD often interpret language and other cues literally (Mitchell et al., 1997). In many VR environments, activities are performed in a symbolic manner which may not match real world actions. For example, in several VR video games, an individual may

purchase items from a store through clicking and dragging a picture of a coin to a storekeeper. While this simplification is necessary for many VR video games, VR social skill trainings may be hindered by this aspect. Individuals with ASD may not be able to understand that these gestures are meant to symbolically represent actual behaviors (Parsons et al., 2004). More research is needed to understand whether this is a common occurrence.

Research Question 10: Do individuals with ASD translate the symbolic gestures performed within a VR environment into real-world behaviors?

Lastly, a modest amount of research has investigated vocational interventions with the goal of obtaining and maintaining employment for individuals with ASD. Taylor and colleagues (2012) review of this literature repeatedly emphasized that that much of this literature is poor quality, citing lack of control groups, random assignment, inclusion/exclusion criteria, and full disclosure of study procedures. Although vocational interventions are not identical to social skill trainings, many aspects are similar. Particularly, within a work environment, individuals with ASD are often expected to interact with customers and coworkers, and they are expected to adhere to the demands of supervisors. In regards to vocational interventions for individuals with ASD, Klin and Volkmar (2000) state, “Equal attention should be paid to the social demands defined by the nature of the job, including what to do during meal breaks, contact with the public or co-workers, or any other unstructured activity requiring social adjustment or improvisation” (p. 361). Without the necessary social skills, individuals with ASD are unable to function within these environments. For these reasons, the incorporation of social skills training scholarship into vocational intervention research may prove fruitful if not necessary.

Research Question 11: Does VR social skills training impact work-related outcomes for individuals with ASD?

Together, the study of VR social skills training for individuals with ASD is established, but many research questions still require investigation; however, it is possible that these questions may be informed by VR research within other populations. Also, research within these other populations may likewise be informed by scholarship applied towards individuals with ASD. For this reason, the current review continues through reviewing VR social skills training for the second most popular population application: individuals with schizophrenia.

Social Skill Training for Individuals with Schizophrenia

Schizophrenia is a mental disorder often characterized by abnormal social behavior and hallucinations, and regularly includes false beliefs, confused thinking, and inactivity (Endicott & Spitzer, 1978; Gottesman, 1991; Kay et al., 1987). It is estimated that between 0.3 and 0.7 percent of individuals are schizophrenic (Os & Kapur, 2009). Much like those with ASD, individuals with schizophrenia also suffer from social skill impairment which causes several negative outcomes, including depression (Pescosolido et al., 2010) and suicide (Kreyenbuhl et al., 2002). Recently, authors have become interested in the possibility of VR to train social skills within this population (Park et al., 2011; Rus-Calafell et al., 2014). Fewer studies have investigated this area of research compared to those investigating participants with ASD. Nevertheless, these well-developed studies demonstrate an understanding of social skills training for individuals with schizophrenia, and provide several important research questions.

VR Social Skill Training for Individuals with Schizophrenia

Unlike VR social skills trainings for individuals with ASD, research upon individuals with schizophrenia is largely based upon theoretical models rather than theory (clarified below). Most often, the social skills model has been applied in VR social skill training for individuals

with schizophrenia (Bellack, 2004; Choi et al., 2010). The social skills model proposes that three particular categories encapsulate individuals' proficiency in social situations: receiving, processing, and expressing skills. Current VR social skill trainings focus upon developing a particular category, believing that an improvement upon one may provide benefits to all social skills. Below, efforts within each of these categories are noted.

Several authors have noted that those with schizophrenia have impairments to their receptive skills (also call receiving skills), defined as the skills necessary for accurately perceiving relevant social information (Kim et al., 2005; 2006; 2008). Relevant social information may include the accurate interpretation of others' feelings, hearing others' speech correctly, and identifying others' motives for behavior. Also, previous authors have separated receiving skills into two categories: interpreting relevant cues and emotional recognition (Bellack et al., 1997). To initially test this notion, Kim and colleagues (2005; 2007; 2008) created a VR social skill training which focused upon gauging participants' receiving skills. For this training, trainees performed several tasks and were asked whether the task was suitable or unsuitable. Their answers were based upon the cues that they were able to recognize within the VR environment. The results demonstrated that individuals with schizophrenia were less proficient at detecting the appropriateness of the tasks, and they took longer to respond to the questions; however, the authors did not use this program to train the social skills of their participants. Future research should apply this software and determine whether the receiving skills of individuals with schizophrenia can be effectively trained within a VR environment.

Research Question 12: Does a VR social skills training improve the receiving skills of individuals with schizophrenia?

Some effort has been made towards reducing the cognitive deficits of individuals with schizophrenia to improve social processing skills (Wiederhold & Riva, 2013). Authors have proposed that social cognition, defined as the mental operations and capacities that underlie social interactions, is a primary cause of reduced social skills of individuals with schizophrenia. For this reason, if individuals with schizophrenia can improve their cognitive functioning, then their subsequent social cognition and social skills can improve. Likely the most convincing studies probing this argument were performed by Chan and colleagues (2010) and Rus-Calafell and colleagues (2014). Chan and colleagues (2010) present a ten-session, ten-week VR training meant to improve the cognitive functioning of individuals with schizophrenia. Their results demonstrated that the training was effective at improving trainees' cognitive functioning, but no measures of social outcomes were recorded. Alternatively, Rus-Calafell and colleagues (2014) authors developed a seven phase VR social skill training for individuals with schizophrenia with the intention of improving social outcomes through developing cognitive functioning. Their training included facial recognition tasks, one-on-one conversations with avatars, and practice with other specific communication skills. Results demonstrated an increase in social skill mastery as well as a reduction to negative symptomatology, psychopathology, and social avoidance; however, despite the proposal that this training may reduce cognitive deficits, this was not directly measured within the study. While Rus-Calafell and colleagues (2014) demonstrated that their training is certainly effective in improving the social skills of individuals with schizophrenia, but future research should probe the mechanisms that cause this improvement akin to Chan and colleagues (2010).

Research Question 13: Does a VR social skills training improve the social processing skills of individuals with schizophrenia?

Alternatively, some authors have noted the importance of the development of expressive skills for those with schizophrenia (Park et al., 2009), whereas expressive skills represent the ability to express appropriate responses to events (Bellack et al., 2004). Park and colleagues (2009) argue that the development of expressive skills may be more important for those with schizophrenia. They note that many receptive skills contain elements that are genetically hard-wired (Bellack et al., 1997, Bellack et al., 2004), whereas most expressive skills consist of learnable behaviors. To test this notion, Park and colleagues (2009) created a VR program to measure individuals' receptive and expressive skills before and after becoming medicated (two separate medications tested). The results demonstrated that the participants improved their expressive skills, but results were mixed for their receptive skills. These results provide initial support for Park and colleagues' proposition (2009), receptive skills may be "hard-wired" and expressive skills are trainable, but further research is certainly needed to validate this notion.

Research Question 14: Does a VR social skills training improve the expressive skills of individuals with schizophrenia?

Beyond the social skills model, other models have been applied to create VR social skills trainings for individuals with schizophrenia. Schizophrenia is characterized by several negative symptoms, including delusions and hallucinations. These negative symptoms do not have as direct of an impact upon individuals' social skills as other targeted attributes (i.e. receptive skills), but several theoretical models have proposed a link between negative symptoms and social skills (Moritz et al., 2005; 2014). While few studies have applied this perspective, some noteworthy contributions have still been made (Moritz et al., 2014). Moritz and colleagues (2014) applied the principals of Metacognitive Training for Psychosis (MCT; Moritz et al., 2005) for a VR social skill training. MCT generally argues that individuals with schizophrenia will

demonstrate improvements to their delusions if they are trained to distrust their false judgments and provided cautious reasoning skills. In a VR training, participants with schizophrenia explored a VR environment, asked whether they met certain individuals within this environment, and provided feedback upon their answers. The results demonstrated a slight reduction to paranoia, obsessive compulsive tendencies, and depression; however, the authors did not test for improvements to social outcomes. Nevertheless, this study demonstrated success in applying VR for the reduction of delusions, which may have the potential to improve social skills.

Research Question 15: Does VR social skills training reduce other negative symptoms of schizophrenia that are proximal to social abilities?

Lastly, some authors have simply tested VR social skills training for individuals with schizophrenia without any firm theoretical rationale (Park et al., 2011). For instance, Park and colleagues present the success of a VR social skills training which contained certain social tasks (i.e. introduce yourself and ask a question), and trainees were provided feedback upon the correctness of their actions. These authors have generally demonstrated success, but further research is certainly needed to understand the mechanisms that prompt such success.

Research Question 16: Do VR trainings need to be based upon a particular theory to effectively develop the social skills of individuals with schizophrenia?

In addition to results which are directly relevant to the improvement of social skills, extant studies have proposed several research questions for the field of VR social skills training for individuals with schizophrenia. These research questions are noted below.

Research Questions of VR Social Skill Training for Individuals with Schizophrenia

A major concern with social skill training for individuals with schizophrenia is the impact of motivational deficits. Those with schizophrenia often express boredom with trainings, resulting in lackluster intervention results. For this reason, some creative training methods have been applied, such as board games (Lieberman, 1972; Gobet et al., 2004), but several authors have noted that VR may provide much-needed excitement to social skill training to capture the attention of trainees with schizophrenia (Medalia et al., 2001; Tsang & Man, 2013). Park and colleagues (2011) performed a blind study comparing the effect of social skills training through role-playing against social skills training through VR. The results demonstrated that those within the VR training were more interested in the training and had greater improvements to their conversational skills. Also, Tsang and Man (2013) present possibly the most convincing application of a VR social skill training. The authors applied a program to train individuals with schizophrenia in workplace functioning, including interactions with customers. The results demonstrated that the VR social skill training was more effective than a conventional training. The authors posit that these benefits were due to the sustained interest and motivation within the training material due to the VR. While these results are noteworthy, only a single study provided empirical evidence upon this notion, prompting a need for further research.

Research Question 17: Does a VR social skills training positively impact the training motivation of individuals with schizophrenia?

Research Question 18: Does a VR social skills training improve trainee outcomes through the mediator of increased trainee motivation?

Furthermore, authors have made great efforts to determine the differential recognition and reaction to positive and negative emotions when training social skills for individuals with schizophrenia (Choi et al., 2010). Particularly, results have demonstrated that individuals with

schizophrenia are particularly unresponsive to interactions with partners demonstrating negative affect. As Choi and colleagues (2010) note, “patients with schizophrenia may have deficits of the early stages of receiving social input especially in negative emotional situations, which requires a greater activation of the social brain” (p. 834). Nevertheless, little research has investigated the possibility of VR to train the differential recognition of emotions, although it is likely a promising avenue for future research.

Research Question 19: Does VR social skills training aid differential recognition of emotions for individuals with schizophrenia?

Lastly, several research questions with VR social skills training for individuals with ASD are shared for individuals with schizophrenia. First, like traditional social skill training for individuals with ASD, several authors have noted concerns with the limited generalizability of traditional social skill training for individuals with schizophrenia, as many training sessions are solely performed within a clinical setting. Second, authors have noted that individuals with schizophrenia may feel more comfortable interacting with an avatar as opposed to a person (Ku et al., 2007), and concerns over a potential reliance upon VR environments exists. Third, some authors have noted that individuals with schizophrenia often suffer great anxiety from social interactions (Bellack, 2004; Choi et al., 2010), and a VR environment may reduce perceptions of trainer judgment. Fourth, some authors have noted the importance of VR social skills trainings in vocational interventions for individuals with schizophrenia (Tsang & Man, 2013). While it is recognized that schizophrenia greatly differs from ASD, it should be considered which dynamics of VR social skills trainings are common between the two populations. If common dynamics can be identified, then results from one population can be accurately generalized to the other.

Research Question 20: Do results on VR social skills trainings within populations with ASD generalize to VR social skills trainings within populations with schizophrenia?

Two final asides should be made. First, the research upon VR social skills trainings for individuals with schizophrenia is less developed than research for individuals with ASD. For this reasons, authors have yet to express notable concerns about the application of the technology for this purpose. Nevertheless, authors should remain aware of potential limitations, and a potential starting point is the concerns noted for individuals with ASD, above. Second, several studies have viewed VR not as a training possibility for individuals with schizophrenia, but rather a measurement possibility (Baker et al., 2006; Kim et al., 2005; 2006; 2008; Ku et al., 2007). That is, several authors have proposed that real-life trainings may be developed and have their outcomes measured within a VR environment. This would provide more objective measures of social skill performance, as behavioral ratings may be biased by rater perceptions. While this area of research does not speak directly towards VR social skills training, it is nevertheless an important avenue for future research.

With a review of VR social skills trainings for individuals with schizophrenia, the current article proceeds to review the third most popular area of VR social skills training scholarship: VR social skills training for individuals with other psychiatric disorders.

VR Social Skill Training for Individuals with Other Psychiatric Disorders

Compared to research upon individuals with ASD and schizophrenia, only a modest amount of scholarship has been performed upon VR social skills training for individuals with other psychiatric disorders (Cheng & Huang, 2012; Muscott & Gifford, 1994; Smith et al., 2014). These other psychiatric disorders vary widely and include attention deficit hyperactivity

disorder (ADHD), obsessive-compulsive disorder (OCD), anxiety disorders, and several others. Despite the varied nature of these other disorders, they often result in some type of impairment to social skills, prompting authors to group these participants together for the analysis of VR social skills trainings. For instance, Cheng & Huang (2012) examined the efficacy of a VR training to improve joint attention, which was predicted to provide subsequent benefits to social skills, in individuals with pervasive developmental disorder (PDD). The authors demonstrated that the VR training improved joint attention, but they did not measure impacts upon social skills. Also, Smith and colleagues (2014) analyzed the efficacy of a VR job interview training for individuals with psychiatric disabilities in general, demonstrating that this population could be successful at learning job interview skills from a VR environment. The participants also rated themselves as more confident during job interviews than a treatment-as-usual condition. Therefore, like research upon individuals with ASD and schizophrenia, success has been seen in improving the social outcomes of individuals with other psychiatric disorders through VR training.

These two studies also demonstrate that VR may be effective at developing specific skills, such as joint attention, as well as improving certain outcomes, such as job interview success. Also, the studies demonstrated that an array of VR social skill training methods may be effective for this population. The training used by Smith and colleagues (2014) consisted of trainee role-playing, following the principals of social learning theory, operant conditioning, and other behavioral principals. Alternatively, the training used by Cheng and Huang (2012) allowed trainees to point at objects while holding a meaningful conversation, and hand gestures were recorded with a data glove. Together, these studies provide a promising beginning for VR social skills trainings for those with other psychiatric disorders; however, it appears that more authors have noted the potential of VR social skills training for other psychiatric populations rather than

actually tested this possibility (Davies, 2005; McComas et al., 1998; Muscott & Gifford, 1994), prompting a great need for further research.

Research Question 21: Can a VR training effectively train the social skills of individuals with other psychiatric disorders?

Research Question 22: What aspects of VR social skills trainings are particularly beneficial for individuals with other psychiatric disorders?

Social Skill Training for Individuals without Disabilities

Scholarship upon VR social skills trainings for individuals without disabilities is also lagging behind research upon individuals with ASD and schizophrenia. Interest is certainly evident for these trainings, as several reviews posit that VR is the future of organizational trainings (Baldwin & Ford, 1988; Salas et al., 2012); however, few studies have actually proposed and tested VR social skills trainings. Instead, this research is largely focused upon studying VR to train procedural skills and declarative knowledge (Gallagher et al., 2005; Gurusamy et al., 2008; Seymour et al., 2002). This is problematic, as authors have noted that social skills are pivotal for employee success, and current market trends insinuate that social skills will only become more important in the future (Garcia-Milá & McGuire, 1998). While this research much less popular than scholarship upon individuals with ASD and schizophrenia, it is still important and a review of this literature is provided below.

VR Social Skill Training for Individuals without Disabilities

The most popular application of VR social skills trainings for non-clinical populations focuses on the development of public speaking skills. Most of these authors investigate the capacity of VR to improve the public speaking skills through reducing anxiety. These studies

largely propose that VR can allow individuals to approach their public speaking phobias in a safe environment, and this experience may reduce anxiety when they perform the actual behavior. It should be noted, however, that individuals still experience some levels of anxiety from public speaking within a VR environment, especially those with social phobia (Slater et al., 2006).

To test the effectiveness of a VR social skills training to improve public speaking, Harris, Kemmerling, and North (2002) subjected their participants to four weekly VR treatment sessions which the trainee performed various public speaking tasks for fifteen minutes. At the conclusion of the four weeks, the trainees reported lower public speaking anxiety, but no public speaking performance measures were obtained. Also, Anderson and colleagues (2005) tested the efficacy of a cognitive-behavioral treatment for public-speaking anxiety that applied VR exposure. Their results demonstrated that trainees reported significantly less public speaking anxiety, but they were no more likely to complete a speech in front of an audience. Lastly, Wallach, Safir, and Bar-Zvi (2009) compared a cognitive behavior therapy (CBT) with a VR social skills training. The results demonstrated that participants within both groups reported significant improvements to anxiety compared to a wait-list control, but neither group demonstrated significant difference on observer ratings of performance and anxiety on a post-training public speech compared to the wait-list control. These improvements to anxiety were sustained over the course of a year (Safir et al., 2012). While these studies provide firm support that a VR social skills training can reduce trainee public speaking anxiety, it is less clear whether these trainings are actually effective at training public speaking ability.

Research Question 23: Does a well-constructed VR social skills training improve the public speaking of individuals without disabilities?

Seemingly, only one study has applied VR to develop the integrated social skills of a non-clinical population. In a comprehensive study, Baker, Parks-Savage, and Rehfuss (2009) present an analysis of a VR social skills training for seven aspects of children's social functioning. The proposed VR allowed trainees to practice social skills while being guided on their performance, and trainees were able to digitally interact with other trainees. Their results demonstrated that the VR social skills training was successful in improving four of the targeted skills, indicating that applying VR to improve social skills is possible for individuals without disabilities. Nevertheless, Baker, Parks-Savage, and Rehfuss (2009) only present the results of a single study, and further research is needed to empirically support the effectiveness of VR social skills trainings for non-clinical populations.

Research Question 24: Does a well-constructed VR social skills training improve the social skills of individuals without disabilities?

Research Questions of VR Social Skill Training for Individuals without Disabilities

Aside from these investigations, authors exploring VR social skills training for non-clinical populations address peripheral research questions rather than testing interventions themselves. Villani and colleagues (2012) tested whether individuals could feel more presence in a VR environment than a real-life environment when undergoing an interview training. The results demonstrated that individuals self-reported more presence within the VR environment as well as higher anxiety. To further probe this finding, Kwon, Powell, and Chalmers (2013) demonstrated that avatar realism impacts perceived trainee presence but not anxiety within a VR interview training. Lastly, Felnhofer and colleagues (2014) investigated the relation between presence, anxiety, and heart rate in a public speaking task. Their results demonstrated that anxiety was negatively related to presence and heart rate was unrelated to presence. The authors

suggested that public speaking anxiety may cognitively remove individuals from their behaviors, resulting in less perceived presence when performing a VR public speaking task. Between these three studies, it appears that the presence and anxiety are important in a VR social skills training, yet much is still yet to be known about their dynamics.

Research Question 25: What is the relation between perceived realism, presence, and anxiety in a VR social skills training?

Additionally, Price and Anderson (2012) noted the importance of outcome expectancy in training contexts. The authors tested this notion through analyzing the impact of trainees' outcome expectancy upon reductions to public speaking anxiety after a VR social skills training. The findings supported their notion. Individuals with positive outcome expectancy had larger reductions to their public speaking anxiety, but no public speaking performance measures were recorded. Nevertheless, these authors demonstrated that outcome expectancies are important for VR social skills training.

Research Question 26: Do outcome expectancies impact VR social skills training outcomes?

Much like research upon individuals with other psychiatric disorders, authors appear reluctant to propose concerns of VR social skills trainings for non-clinical populations, but future research should still understand the potential drawbacks of this application of the technology.

Overall Considerations for VR Social Skill Training

While each application of VR social skill training demonstrates particular considerations, certain factors are relevant for all applications. These factors should be considered the most important of all within VR social skills training applications, as authors often consider their

effects universal. Further, many of these research questions should not be answered through inferences gathered within a particular domain, and authors should consider each application together. Therefore, below, the general benefits of VR social skills trainings are noted, followed by the general concerns, and ending with general considerations for future research and practice.

General Benefits of VR Social Skills Training

In most VR social skills trainings, authors propose certain mechanisms cause the VR training to be particularly effective benefits beyond typical social skill trainings. These general benefits – not particular to any domain – are collected below and categorized by benefits which (a) reduce the fear of judgment, (b) increase excitement, and (c) increase functionality.

Reduced Fear of Judgment

In real-life trainings, including those for social skills, trainees are required to perform tasks under the supervision of a trainer. Some studies have noted that trainees may be self-conscious while performing these behaviors, and they may endure anxiety from making mistakes (Birk & Mahalik, 1996; Bowman & Roberts, 1979; Mauzey et al., 2001). This anxiety can also worsen training outcomes. Alternatively, when using VR, trainees may be less fearful of trainer reactions (Cobb et al., 2002; Parsons & Mitchell, 2002; Jung et al., 2006). In a VR environment, trainees are removed from a real-life trainer, as all their behaviors are performed through an electronic medium. Authors have argued that this added social distance may reduce anxiety and improve training outcomes (Cobb et al., 2002; Irish, 2013; Wann & Mon-Williams, 1996). In fact, some VR trainings may completely eliminate any perceived judgment and anxiety, as a VR training may be programmed to be completely automated. This would result in trainees' actions

to be completely unobserved by humans. Despite the widespread assumption that a VR training may reduce perceptions of trainer judgment, no study has actually empirically tested the notion.

Authors often claim that reduced judgment perceptions are responsible for VR social skill training success, and these authors place particular efforts towards reducing trainees' feelings of judgments. If this notion is demonstrated to be untrue, then their efforts are meaningless. More importantly, however, authors would be allocating their efforts away from more fruitful methods to increase VR training effectiveness. Therefore, demonstrating the validity of this claim is pivotal for future VR training research, especially social skill training research.

Research Question 28: Do trainees within a VR training experience less fear of trainer judgment than individual within a typical training?

Further, while it has been proposed that trainees are less fearful of trainer judgment within VR environments (Cobb et al., 2002; Irish, 2013; Jung et al., 2006; Parsons & Mitchell, 2002), the best method for trainees to interact with VR environments is unclear. Some authors have proposed that trainer interaction is still needed in a VR environment, such as through an avatar; however, others have proposed that trainer interaction should never occur within the VR environment, as this environment should be seen as a safe location. Yet, even others have noted that trainer interaction should not occur until after the trainee feels completely comfortable using the program. The ideal extent of trainer interaction is still largely unknown, and future research should investigate the optimal extent that a trainer should be incorporated into a VR training.

Research Question 29: Should the trainer interact with the trainee within the VR environment, or should the VR environment be seen as a completely "safe" location?

Increased Excitement

Many authors have proposed that the presentation of multiple, different environments and scenarios may cause repeated iterations of the VR training to remain exciting (Biocca & Levy, 2013; Regian et al., 1992; Steuer, 1992), whereas repeating experiences and dialogue in familiar settings may become boring. For example, a trainee may become bored practicing conversation skills with a trainer. In a VR environment, however, a trainee may practice their conversation skills with a trainer, during an interview, on a blind date, or any other social interaction. Many authors propose that trainee excitement may serve as a mediator between the application of advanced training technologies and positive outcomes (Biocca & Levy, 2013; Regian et al., 1992; Steuer, 1992). While research has shown that trainees generally enjoy VR (Irish, 2013; Parsons & Mitchell, 2002), no study has explicitly demonstrated enjoyment as a mediator between VR applications and training outcomes. It is possible that trainees enjoy VR, but the environment may simply serve as a distraction which reduces training effectiveness. Therefore, two research questions should be considered: (a) does presenting multiple VR environments increase the effectiveness of a VR training and (b) does trainee excitement mediate this effect?

Research Question 30: Does a changing VR environment and/or scenario increase improve trainee outcomes?

Research Question 31: Does a changing VR environment and/or scenario cause greater training effectiveness through the mediator of trainee excitement?

Increased Functionality

Across most trainings, trainees are expected to interact with a trainer to develop certain skills (Cobb et al., 2002; Irish, 2013; Jung et al., 2006; Parsons & Mitchell, 2002). While the training may be tiring for the trainee, it also prompts fatigue within the trainer (Bölte, 2002;

Gupta et al., 2002; Pop et al., 2013). This is especially true for social skills trainings. During many social skills trainings, the trainer is expected to display certain emotional states. As previous research has demonstrated, the forced presentation of certain emotional states can cause emotional exhaustion and burnout (Ashforth & Humphrey, 1993; Brotheridge & Grandey, 2002), and this exhaustion may reduce trainer efficacy and training outcomes.

Alternatively, VR trainings allow trainers to interact with trainees through digital avatars, and these avatars may present desired emotional states. The performance of behaviors through avatars eliminates most fatigue, and this is especially true for the display of emotion during social skills trainings. Once again, although authors have proposed this factor for VR social skill training success, no empirical studies have actually demonstrated that VR reduces trainer fatigue. More importantly, however, no study has demonstrated that reductions to trainer fatigue prompt social skill training success. Future research should probe these two research questions.

Research Question 32: Do VR trainings lessen trainer fatigue effects?

Research Question 33: Do reductions to trainer fatigue improve training outcomes?

Additionally, social skills trainings often require trainees to identify an array of emotions within others and/or interact with an individual demonstrating an array of emotions; however, some authors have noted that trainers may be unable to accurately portray emotions themselves (Ku et al., 2005; 2007), and other research has demonstrated that trainer expressiveness significantly impacts training success (Towler, 2009; Towler & Dipboye, 2001). It is difficult to portray authentic emotions, as decades of research upon Duchenne smiles have demonstrated (Krumhuber & Manstead, 2009). If a trainer is unable to authentically demonstrate particular emotions, then the trainee may not receive the full instructional potential of a social skills

training. For this reason, VR environments may be ideal for the training of emotional perception and skills. A VR training could present avatars with accurate facial expressions, and trainers could prompt the expression of these emotions at appropriate moments within the VR training. Research is needed, however, to support this notion.

Research Question 34: Does the ability for VR social skills trainings to accurately present emotional cues result in greater transfer of training?

In addition to trainer effects, other functional aspects of VR have been assumed to benefit VR social skills trainings. Notably, social interactions are often spontaneous and fast-paced (Schaffer, 1996; Schneider, 2009). This may cause practice to be difficult, as trainees may be unable to slow-down the process and consider the idiosyncrasies of social interactions. Authors have repeatedly noted that individuals rarely say their intentions, and individuals must fill-in-the-gaps to truly understand the meaning of an individuals' statements (Irish, 2013; Ozonoff & Miller, 1995). If an individual has deficient social skills, they may not recognize others' implicit meanings within their words.

In a typical social skills training, trainees are rarely able to explicitly pause an interaction and consider the multiple cues within the scenario and the proper course of action amongst multiple alternatives. In a VR environment, however, this is possible. Users may be able to pause or slow down their interactions with an avatar to consider the dynamics of an interaction. Whereas this may be awkward in a real-life scenario, a digital avatar would not have a negative reaction to any needed time. This would allow the trainee to fully consider the unspoken cues of the situation. Then, once they become more confident in their social skills, they may advance their social skills training at a life-like speed. Once again, this benefit has not been empirically studied, but future research should certainly test this notion.

Research Question 35: Does the ability to slow-down and/or stop a VR social skills training provide benefits to the transfer of training?

Together, the three categories of (a) reduced fear of judgment, (b) increased excitement, and (c) increased functionality constitute the proposed general benefits of VR social skills training. In addition to general benefits, the general concerns should also be noted.

Potential Overall Concerns

While the current state of VR social skills training scholarship poses many advantages for the technology, other aspects are less beneficial. Most notably, much of VR social skill training is focused on developing individual skills, such as recognizing others' point-of-view, rather than achieving integrated social skills, such as performing well in an interview (Irish, 2013). While it is recognized that many VR applications should focus upon developing basic social skills, an understanding of VR social skills training is incomplete without an investigation of more complex social skills. As Strickland, Coles, and Southern (2013) note in regards to creating a VR intervention to aid individuals with ASD in developing interview skills, "it was important to be concerned not only with teaching the appropriate verbal and nonverbal skills ... but with supporting an understanding of the reasons for these behaviors" (p. 2473). If VR social skill trainings only develop individual skills, then trainees may be unaware of the underlying importance or overarching goal of these behaviors. This may preclude trainees from successfully integrating their developed skills and achieving more complex social outcomes. Although many authors consider the study of VR as emergent, several foundational aspects of the technology have been discovered and more advanced applications should be currently sought.

Research Question 27: Does a well-constructed VR social skills training effectively train integrated social skills?

Furthermore, several authors have assumed that VR can provide meaningful improvements upon *all* previous efforts in social skill trainings; however, this notion should be reconsidered. Instead, authors should explicitly question which aspects VR can improve. As Park and colleagues (2011) discovered, a VR training may improve the development of certain social skills trainings, such as conversational skills, but detract from other outcomes, such as nonverbal cue development. Perhaps an overarching theory could direct authors towards effective applications and away from ineffective applications.

Research Question 36: For which social skills training applications may VR be particularly effective and which applications may VR be detrimental?

In creating these specialized social skills trainings, some final considerations should be made. Particularly, several aspects of VR have been proposed to be beneficial across the field of research; however, they may actually pose negative training outcomes. One of these is increases to trainee excitement. As mentioned within most of the domains above, authors proposes that more excited trainees result in better training outcomes; however, scholarship upon seductive details would argue otherwise (Harp & Mayer, 1998; Garner et al., 1989). Seductive details are interesting but irrelevant aspects of a training meant to increase trainee enjoyment, such as pictures within a textbook or (possibly) VR in a social skills training. Authors have repeatedly demonstrated that these seductive details negatively impact learning, and the same is likely true for the development of social skills within a VR training. Therefore, it is strongly encouraged for future research to determine whether VR is an actual added benefit to social skills trainings or whether it only serves as a seductive detail.

Research Question 37: Is VR a seductive detail in social skills trainings?

Further, a benefit of VR social skill training is a reduction to trainee fear of judgment and subsequent anxiety. It should be considered, however, whether a VR environment reduces fear of judgment too much. That is, it is possible that individuals within a VR social skill training may be focused upon completing the assigned tasks rather than completing them well (Parsons, 2005). This would result in reduced training effort, and likely reduced transfer of training.

Research Question 38: Does VR social skills training reduce trainee motivation compared to a traditional training?

Integrating Future Studies

Lastly, each domain of VR social skills training research applies its own perspective. For instance, research upon individuals with ASD largely applies trainings derived from theory-based therapies, whereas research upon individuals with schizophrenia largely applies theoretical models. Scholars should apply perspectives which are not typical for their domain to provide incremental inferences to their own research. More importantly, authors should also combine multiple perspectives to create integrated VR social skill training studies. For instance, it may be extremely beneficial for authors to create a theory-based training for individuals with ASD which incorporates a model popular within the schizophrenia social skills training scholarship.

Research Question 39: Do theoretical perspectives from a certain domain of VR social skills training benefit other domains?

Research Question 40: Does integrating perspectives from multiple domains of VR social skill trainings provide greater trainee benefits?

Conclusion

The current article noted that the current research on VR social skills trainings is disjointed, and authors tend to focus on their own research domains (ASD, schizophrenia, other psychiatric disorders, non-clinical populations). To rectify this concern, an overview was provided of each research domain, followed by an integrative discussion. The review demonstrated that, in each domain, very different theoretical perspectives are taken, several research questions are shared, and certain unique research questions are also evident. It is suggested that authors should seek answers to the integrative research questions presented within the current article, as they are among the most influential and may address concerns across the study of VR social skills trainings.

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Appendix C

Additional Material

Initially, my dissertation focused on the development of four separate outcomes; however, through multiple revisions, three of the outcomes were removed from the primary document. For this reason, they are now included in a final appendix – Appendix C.

Applications of CBIs

With the commonly applied technologies in CBIs reviewed, the current paper also reviews the common applications of CBIs and proposes a multidimensional taxonomy of CBI outcomes to differentiate the effect of CBT technologies in these various applications. Next, the study categorizes the outcomes on a single dimension – the amount of working memory required to develop the outcome.

To begin, this study adopts a four dimensional taxonomy of CBI applications separated by the outcome developed. The four dimensions are cognitive, physical, social, and emotional outcomes. These four dimensions were based upon previous intervention outcome typologies (Bloom, 1956; Byun, Kim, & Duffey, 2012; Ford, Kraiger, & Merritt, 2009; Kraiger, Ford, & Salas, 1993). Particularly, Kraiger, Ford, and Salas's (1993) training typology, which has been supported in numerous meta-analyses and reviews (Ford, Kraiger, & Merritt, 2009), included the three categories of cognitive outcomes, skill-based outcomes, and affective outcomes. Within the current work, cognitive and skill-based outcomes are both included within the dimension of cognitive outcomes, and affective outcomes are included within the dimension of emotional outcomes. Alternatively, Byun, Kim, and Duffey (2012) provide a taxonomy of collaborative learning outcomes consisting of cognitive, social, and emotional outcomes. These dimensions were directly incorporated within the current study. Also, Bloom (1956) proposed an educational objective taxonomy consisting of cognitive, psychomotor, and affective outcomes, whereas the cognitive outcome dimension consists of several sub-dimensions. This study incorporated each of these dimensions, placing psychomotor within physical outcomes and affective within emotional outcomes. Lastly, several other typologies were adapted (Anderson et al., 2001), and individual dimensions were added if they were present within VR intervention

scholarship but not within any existing typology. Table 1 lists each dimension and respective sub-dimensions adopted from the previous taxonomies.

The most working memory intensive outcomes are cognitive outcomes (Mayer & Moreno, 1998). Cognitive outcomes involve the incorporation of new information to memory, and they often require the conscious encoding of informational material (Jonassen & Land, 2012; McLean & Hitch, 1999). Likely the most working-memory taxing cognitive outcome is learning declarative knowledge – the direct interpretation and encoding of facts. To incorporate declarative knowledge to memory, the learner must often consciously repeat information in their conscious thoughts to commit it to memory, also called mental rehearsal, which requires continuous use of working memory resources (Davis & Yi, 2004; Yi & Davis, 2003; Squire, 1992). Alternatively, skills and abilities likely require less working memory (Dienes, 2012; Kolb, 2014). Skills and abilities, while requiring conscious thought to initiate development, are gradually developed through subconscious processes and automation that inherently involve a reduction to working memory taxation in favor of autonomic processes (Davis & Yi, 2004; Marcus et al., 2013). While requiring working memory to initially develop, skills and abilities may eventually become less thoughtful processes. Together, cognitive outcomes are assumed to be the most working-memory-intensive outcomes, with basic cognitive outcomes requiring more working memory than skills and abilities

Next, social outcomes require less working memory than cognitive outcomes to developed (Bora et al., 2006; Mueser & Bellack, 1998). Social skills, such as public speaking or interview skills, require several subconscious processes which are specified by several theories and models (i.e. Theory of Mind, social skills model, and others; Frith, 2004; Frith & Happé, 1994; Mueser & Bellack, 1998). Many authors have also demonstrated that social skills can be

developed (Michelson et al., 2013; Strickland, Coles, & Southern, 2013; White et al., 2013). For example, some companies have created computer software which can improve individuals' interview skills, even those on the autism spectrum (Strickland, Coles, & Southern, 2013). Further, the current study separates two types of social outcomes based upon the believed required amount of working memory to develop. Basic social outcomes involve particular aspects of social functioning, such as eye contact and notions of personal space. When developing these outcomes, the learner must consciously remember to perform or not perform a certain behavior, forcing them to allocate their working memory resources to mental rehearsal (Ozonoff & Miller, 1995; Riggio, 1986). Alternatively, integrated social outcomes involve multiple basic social outcomes to perform integrated social skills, such as public speaking and interviewing. Like skills and abilities for cognitive outcomes, integrated social outcomes involve subconscious automation (Ayoub, Vallotton, & Mastergeorge, 2011; Mueser & Bellack, 1998). Therefore, social outcomes are believed to require less working memory than cognitive outcomes, and basic social outcomes require the most working memory, of all social outcomes, whereas complex social outcomes require the least.

After social outcomes, emotional outcomes require even less working memory to develop (Wolfe & Bell, 2004). Emotional outcomes also vary greatly, but they include individuals' emotion-related abilities and emotions themselves. In the current work, emotion-related abilities are conceptualized as the ability model of emotional intelligence (EI) which consists of perceiving emotions, using emotions to facilitate thinking, understanding emotions, and managing emotions (Daus & Ashkanasy, 2005; Mayer & Salovey, 2007; Mayer, Salovey, & Caruso, 2008). Some authors have proposed that EI can be developed akin to other abilities, and the current study takes this same perspective. EI is believed to be developed initially through

little conscious thought but quickly and completely shifting to subconscious processes and automation, as authors have demonstrated that EI is possible to be developed (Morris, Öhman, & Dolan, 1998; Slaski & Cartwright, 2003). Alternatively, emotions, whether short-term or long-term, are autonomic processes which do not require working memory to alter (Greenberg & Watson, 2006; Raio et al., 2012). For these reasons, emotional outcomes are believed to require less working memory to develop than social outcomes, and emotions-related abilities are expected to require more working memory than emotions to alter.

Lastly, physical outcomes, such as psychomotor skills and strength, require very little, if any, working memory to develop. These outcomes are simply developed through repeated action, whether developing psychomotor abilities or strength, which are largely autonomous. Physical outcomes are believed to require the least amount of working memory to develop.

Together, cognitive outcomes require the most working memory to develop, followed by social, emotional, and physical outcomes. A visual representation of the working memory required by these multiple outcomes is presented in Figure 1. In the figure, the four domains overlap, as the current understanding does not expect the each outcome to have clear boundaries of working memory requirements. With the outcomes' impact on working memory noted, an integration of theory and context is provided below to identify conditions of task-technology “match” along with an explication of mechanism and boundary conditions.

A Meta-Analysis on Virtual Reality Interventions

Virtual Reality (VR)

A common definition for virtual reality (VR) is the computer-generated simulation of a three-dimensional environment with interactive capabilities (Dictionary.com, 2014). While this

definition is concise, its application for the purposes of classification causes some uncertainties. For example, does a first-person perspective video constitute VR? It is the presentation of a three-dimensional environment, but users are unable to interact with their surroundings. This precluded first-person perspective videos from consideration as VR. Then, what if a feature is added that allows users to go forward and backwards (i.e. rewind and fast-forward) within the first-person perspective video? This is the presentation of a three-dimensional environment with user input, albeit limited, but many scholars would not consider this true VR (Burdea & Coiffet, 2003; Rheingold, 1991; Steuer, 1992). To better understand the nuances of defining a VR experience, a brief overview of VR systems is necessary.

A VR system is the device which presents a VR environment, and it is composed of computer hardware and software (Vince, 1995). Computer hardware are the physical devices which present the virtual environment and receive user input, and can range widely in nature. A standard monitor, mouse, and keyboard are the most often used hardware in VR applications. The monitor presents the virtual environment, whereas the mouse and keyboard receive user input. This setup is preferred by many practitioners and researchers (Kalawsky, 1993; Pimentel, 2000; Vince, 1995); it allows a VR environment to be presented without the necessity to purchase specialized hardware, as almost every computer-user has access to a computer monitor, mouse, and keyboard. Despite the widespread availability of this VR hardware, more advanced computer hardware is also commonly used for VR applications. Head-mounted displays (HMDs) are becoming an increasingly popular hardware to present VR environments (Mon-Williams, Warm, & Rushton, 1993; Robinett & Rolland, 1992; Shibata, 2002; Ward et al., 1992).

A HMD presents a digital display overtop the user's eyes, completely encapsulating their field-of-view. Most HMDs track the user's head movements and align the presentation of the

VR with the user's point-of-view. Also, advanced hardware has been used to record user inputs, such as motion-sensor remotes and floor-pads (Gallo, De Pietro, & Marra, 2008; McArthur, Castellucci, & MacKenzie, 2009; Wingrave et al., 2010). Motion-sensor remotes can track users' hand movements, and floor-pads can track user's feet movements. This allows avatars to mimic users' bodily positioning. Together, this technology can provide intense feelings of immersion and presence which have been argued to result in important user outcomes (Krijn et al., 2004; Sanchez-Vives & Slater, 2005; Schuemie et al., 2001; Slater, 1999); however, this hardware is completely useless without adequate software.

Computer software is completely digital, created through computer coding languages, and is often synonymous with computer program. Software receives signals from the input hardware, such as keyboard and mouse, and presents information through the output hardware, such as a monitor; however, the various forms of recognized inputs and produced outputs are endless. This makes broad overviews of computer software difficult to perform, and authors often analyze individual properties of a particular type of computer software (Kapp, 2012; Zichermann & Cunningham, 2011). For this reason, the current study is solely interested in software relevant for VR purposes, which also exists in a multitude of forms.

Many popular programs present VR environments. For instance, most modern video games constitute VR. World of Warcraft places users in a complete VR fantasy world, and users control an avatar through first- or third-person perspective. Call of Duty provides a first-person perspective of an array of wartime situations, and users are expected to fight through their VR warzones. Also, organizations are applying VR intervention programs at an increasing rate. Hospitals and the military, for example, commonly use HMDs to train the required skills and abilities of diverse professions from surgeons and soldiers (Barrett, 2014; Blum et al., 2009;

Brandom, 2014; Bymer, 2012; Ilie et al., 2004; Mayton, 2014; Rhienmora et al., 2010; Sielhorst et al., 2004; Smith, 2014), and the HMDs present a first-person perspective of a realistic scenario. While these examples certainly constitute VR, applications of limited VR environments are likewise popular. For example, several roller-coaster simulations meant to be used in conjunction with a HMD have been created (VirtualDutchmen.com, 2014). The user can experience a lifelike rollercoaster experience with the HMDs tracking their point-of-view, but no other input is allowed. Similarly, 360-degree movies to be watched through HMDs are growing in popularity (BrandSumo.com, 2014, ConditionOne.com, 2014, Kolor.com, 2014), and likewise only allow point-of-view changes as input. This limited VR experience harks to the initial question of the current section: what constitutes VR?

This study utilizes the same operational definition listed above: virtual reality (VR) is the computer-generated simulation of a three-dimensional environment with interactive capabilities; however, an additional element is added to this definition: the necessity to specifically interact with the digital environment, whether through point-of-view movement or manipulating virtual objects. Through allowing users to interact with the digital environment, a software more effectively presents the feeling of “being there,” as opposed to a first-person video, for example, which is solely limited to a visual presentation of a three-dimensional environment. Therefore, *the current study uses the following operational definition for VR: the computer-generated simulation of a three-dimensional environment which allows users to interact with the digital environment, among other possible interactive capabilities.*

Furthermore, it should be noted that VR is separate from serious games. Serious games are computer programs which present elements typical of video games, such as conflict and mystery, for an educational objective (Landers & Callan, 2011; Wainer & Ingersoll, 2011;

Wilson et al., 2009). These serious games may or may not present a VR environment. For example, a serious game could assist “trainees” typing abilities through awarding points for the speedy input of presented text, and trainees could only advance to the next level after accumulating a certain number of points. When typing the text, the screen would simply change the color of the letters as they are typed, and nothing else is presented to the trainee. This would not constitute a VR environment, as an immersive three-dimensional environment is not presented. Alternatively, a serious game could present a first-person view of a realistic work environment and trainees must compete against each other to complete certain tasks the quickest. This would constitute a VR environment with gamification elements. These two examples demonstrate that gamification elements do not necessarily create a VR intervention.

Also, VR does not cause an intervention to necessarily incorporate gamification elements. A VR intervention may simply present a VR environment that is completely identical to a real-life situation. For example, several authors have tested VR interventions that allow surgeons to perform surgeries that are identical to a real-life experience (Grantcharov et al., 2004; Seymour et al., 2002; Westwood, 1998). These VR interventions do not incorporate any gamification element, but simply allow trainees to practice skills within safe environments. Therefore, while it is expected that gamification elements could certainly strengthen outcomes of VR intervention, these attributes themselves do not create a VR environment.

While this is the predominant view of the serious games and VR distinction, it is recognized that some authors consider the two as synonymous (Sitzmann, 2011; Tennyson & Jorczak, 2008). For this reason, the meta-analysis described below includes gamification elements within VR intervention. This ensures that any incorporated gamification elements are tested and allows for an alternative question to be addressed: ***Do authors who study VR***

intervention include gamification elements within their programs to an extent that the two concepts have become synonymous?

With a basic definition of VR provided, the following section provides a brief review of VR interventions before presenting hypotheses relevant to the current study.

VR Interventions

Recent technological advancements have facilitated the study of interventions (De Leo et al., 2003; Lee et al., 2012; Mirelman et al., 2010; Psotka, 1995; Van Dongen et al., 2011; Wagner & Campbell, 1994). Originally, early computer-based interventions (CBI) largely provided textual information to trainees with limited interactivity (Kearsley & Hillelsohn, 1982; Mahoney & Lyday, 1984; Williams & Zahed, 1996). Like gaming, developments to technology have allowed CBI to evolve into a sophisticated presentation of intervention material through improved software. Today, even the most basic CBI involves the presentation of text, pictures, and videos often followed by a post-test (Borman, Benson, & Overman, 2009; Desai, Richards, & Eddy, 2000; Wallen & Mulloy, 2006). More advanced CBIs involve gamification-inspired attributes as well as adaptability which alters the intervention material based upon user input (Bedwell & Salas, 2010; Cuevas & Fiore, 2014; Hardin, Looney, & Fulley, 2014). For example, if a user incorrectly answers an item or indicates that they do not understand the material, then they can repeat the needed material. This causes the intervention software to “learn” which personal characteristics require further improvement. While these basic CBI programs result in adequate improvements to outcomes, it is often assumed that more technologically advanced intervention result in better outcomes. Possibly the most advanced CBI, to date, is VR interventions.

A VR intervention is a computer-administered intervention which material is presented through a virtual environment (Grantcharov et al., 2004; Seymour et al., 2002; Van der Meijden & Schijven, 2009). The material can either be relevant to the environment or irrelevant. When the material is relevant to the environment, the intervention material is integrated in the digital environment. For instance, using VR intervention to teach welding skills has recently garnered popularity (Choquet, 2008; Fast, Gifford, & Yancey, 2004; Mavrikios, Karabatsou, Fragos, & Chryssolouris, 2006; Wang, Nan, Chen, & Hu, 2006). When using a VR intervention to teach welding skills, the VR environment is often the welding context of interest, such as a building worksite, and users digitally weld two metal objects together. In this context, the intervention material is integrated into VR environment. Alternatively, intervention material is sometimes irrelevant to the VR environment. For instance, developers may create a VR intervention to teach basic math skills (Kaufmann & Schmalstieg, 2003; Vogel, Greenwood-Ericksen, Cannon-Bowers, & Bowers, 2006; Zyda, 2005). To make the intervention exciting, the skills may be taught in an unusual environment, such as outer space or on a safari in Africa. In this context, the intervention material is separate from the VR environment, but it is still an immersive VR experience. These examples demonstrate that any topic can be taught within a VR intervention, whether it naturally lends itself to the digital environment or not, due to the capabilities of VR systems. The wide-scale application possibilities of VR systems likely contributes to VR intervention popularity, and these factors also support the continued research into VR interventions.

Although VR intervention research only began recently, largely initiating at the turn of the millennium, the popularity of this scholarship has resulted in numerous noteworthy discoveries. Several authors have demonstrated the success of VR intervention within an array

of contexts. Among the most widespread applications is within the healthcare industry (Crecente, 2014; Gallagher & Cates, 2004; Newman, 2014; Stark, 2014). Scholars have repeatedly noted hospitals' effective adaptation of this technology to train doctors and surgeons (Blum et al., 2009; Ilie et al., 2004; Rhienmora et al., 2010; Sielhorst et al., 2004), as these individuals can test new methods in controlled, safe VR environments where life-saving skills can be acquired without life-threatening consequences. Also, the military regularly applies VR for an array of intervention purposes (Barrett, 2014; Brandom, 2014; Bymer, 2012; Mayton, 2014; Smith, 2014), including the development of aviation abilities (Duchowski et al., 2000; Jennings et al., 1998; Simons & Melzer, 2003), parachuting abilities (Hogue et al., 1998; 2001; 2004; 2007), and vehicle identification abilities (Hays & Vincenzi, 2000; Keebler et al., 2008; Keebler, Jentsch, & Schuster, 2014). Lastly, practitioners have applied HMDs for the development of welding abilities for production workers (Choquet, 2008; Fast, Gifford, & Yancey, 2004; Mavrikios, et al., 2006), firefighting skills for firefighters (Brown et al., 2005; Tate, Sibert, & King, 1997a; 1997b), experience in outer space for astronauts (Aoki et al., 2007; Homan & Got, 1996; Rönkkö et al., 2006), and various other occupations and tasks (Boud et al., 1999; Chua et al., 2003; Park, Jang, & Chai, 2006; Schwald & De Laval, 2003). These examples demonstrate the widespread impact of this technology across numerous organizations, and several authors have proposed that VR interventions with HMDs will become even more important for the future of interventions (Makuch, 2014; Shamoan, 2014).

Further, VR interventions have been used to improve an array of other personal outcomes. An extremely popular method of phobia and post-traumatic stress disorder (PTSD) therapy involves the presentation of fear-inducing stimuli in a digital environment (Choi et al., 2005; Opdyke, Williford, & North, 1995; Windich-Biermeier et al., 2007). Over time, phobic

individuals are meant to gradually approach the stimuli in the digital environment until the learner no longer exhibit signs of distress. Then, the previously phobic individuals are expected to approach their previously fear-inducing stimuli in real life to demonstrate a conquering of their phobia. Also, many authors have tested the efficacy of VR to improve physical rehabilitation outcomes (Rostami et al., 2011; Singh et al., 2013; Yen et al., 2011). Physical Rehabilitation programs are often long and boring, thereby reducing patient motivation. The reduced motivation can also worsen rehabilitation outcomes, as patients are less effortful in their exercises. VR, however, can provide added excitement to an otherwise boring rehabilitation program, and it can often be easily added. For example, many authors have tested the efficacy of VR to improve gait rehabilitation outcomes by adding a surround-screen display to a typical treadmill intervention. These authors' results demonstrate that VR is applicable to a wide array of outcomes. Together, VR interventions have been applied to almost every personal outcome possible.

Alternatively, several authors have also demonstrated the failure of VR interventions to produce successful trainee outcomes (Cameron & Dwyer, 2005; Ellis, Marcus, & Taylor, 2005; Fletcher & Tobias, 2006), prompting Cannon-Bowers & Bowers (2009) to recommend investigations into *why* researchers' simulations were or were not effective. Fletcher and Tobias (2006) noted that many VR interventions provide positive benefits to trainee reactions and perceptions, but they often struggle with actually providing adequate personal development. Similarly, several authors have tested interventions to improve the public speaking ability of individuals (Anderson et al., 2005; Harris Kemmerling, & North, 2002; Slater et al., 2006; Wallach, Safir, & Bar-Zvi, 2009). Although the majority of these studies have demonstrated a reduction to trainee public speaking anxiety, none of them have demonstrated success in

improving trainees' public speaking ability. Together, these results demonstrate a disparity within the intervention literature. Some authors posit that VR interventions necessarily lead to outcomes beyond comparable intervention, whereas other authors note significant concerns and lackluster results.

Some authors have made attempts to address this disparity. Johnson and colleagues (2011) propose, and others agree (Moskaliuk, Bertram, & Cress, 2013), that VR intervention research "has yet to be underpinned by a strong evidence base for its utility and effectiveness in developing skills for real-life procedures" (p. 614). The authors further propose that VR interventions are rarely based upon firm theory, and the validity of many VR interventions is not sufficiently tested. Within their study, Johnson and colleagues (2011) demonstrate an effective multiple phase procedure to create valid and successful VR interventions. It is agreed that a focus upon theory and validity testing can prompt more effective VR interventions, but the current study is not as condemning in regards to extant studies. Most authors who report tests of VR interventions are likely experienced within the field. Although they may not report extensive a priori testing or theoretical foundation for their VR interventions, they likely incorporate prior knowledge and scholarship. Due to this, it is not expected that the current disparity between VR intervention success and failure is due to poor theoretical foundations, although it may account for some lackluster findings.

Alternatively, Tichon (2007) proposes that some VR intervention studies suffer from poor performance measures. If a study is unable to accurately measure the skills and abilities of interest, then it is unsurprising that results may indicate the VR intervention as ineffective. It is expected that poor measurement impacts some lackluster results, but it is unlikely that poor outcome measurement is the cause of most VR intervention result discrepancies. Once again,

VR intervention authors usually have extensive educational backgrounds, and most reporting of VR interventions is subject to peer review. Although some poor study designs are published, it is unlikely that an extreme number are successful.

Within the current study, an alternative perspective is provided. Authors have noted that VR interventions are applied to a wide array of contexts (Johnson et al., 2011), and authors are continuously seeking new contexts to apply VR technology. It is possible that certain applications are less suitable for VR interventions than others, as predicted by intervention-technology fit theory. Intervention-technology fit theory proposes that technologies which demand working memory should be paired with applications which require little working memory. In the case of VR, which requires users' working memory resources, it may produce lackluster results when paired with applications which also require working memory resources, such as learning declarative knowledge, but provide beneficial results when paired with applications which do not require working memory resources, such as skills and abilities. It is possible, if not probable, that differential VR success occurs due to its interaction with the application. Therefore, rather than the deficiencies of authors' study designs, the non-significant results of many VR intervention studies may be due to the application itself, and a more thorough understanding of these interactive effects is important and will help us better design effective interventions.

Additionally, the VR system itself, as suggested by others (Hays & Vincenzi, 2000; Howard, Under Review), may impact the efficacy of a VR intervention. Not all VR systems are the same, and they likely demonstrate varying effects upon the participant. These effects may provide benefits or detriments to the trainee. Also, the trainee population likely impacts the VR intervention success, as some individuals may be better equipped to deal with VR interventions

than others. Together, specific hypotheses and research questions are provided below about the impact of VR intervention applications, systems, and trainee populations.

Research Questions and Hypotheses

In the current section, research questions and hypotheses relevant to the intervention application are presented. This is followed by research questions and hypotheses relevant to the VR system and the participant population.

Research Questions and Hypothesis on VR Intervention Applications and Outcomes

VR Interventions for Social Outcomes

VR interventions for social outcomes is defined as the application of VR systems to improve individuals' interpersonal functioning, and successful interpersonal functioning involves the performance of several related social skills and abilities. While the performance of these social skills and abilities requires certain knowledge, authors have demonstrated that their success is largely independent from cognitive ability (Hartog, Van Praag, & Van Der Sluis, 2010; Mayer et al., 2001; Moran, Kornhaber, & Gardner, 2006; Salovey & Mayer, 1989). For this reason, social outcomes are considered a separate dimension relative to cognitive outcomes, as others have likewise done (Bar-On & Parker, 2000; Mayer, Caruso, & Salovey, 1999; Mayer & Salovey, 1993; Schmidt, 2002). Furthermore, employee proficiency in these social skills and abilities are becoming more important, as organizations are becoming increasingly reliant on employee interpersonal abilities (Ashforth & Humphrey, 1993; Brotheridge & Grandey, 2002; Diefendorff et al., 2011; Grandey et al., 2012). As several authors have noted, the United States is shifting towards a customer service economy (Chi et al., 2011; Fuchs, 1968; Gershuny & Miles, 1983; Iversen & Wren, 1988; Metcalfe & Miles, 2000), forcing employees to develop, at a

minimum, satisfactory customer relations for organizations to succeed (Bono & Vey, 2005; Grandey, 2000; Morris & Feldman, 1996). Also, workplaces are becoming more focused upon teamwork (Alper, Tjosvold, & Law, 2000; Ancona & Caldwell, 1992; Shin & Choi, 2010; Sung & Choi, 2012). No longer are employees expected to complete tasks alone. Instead, employees must work together to combine their KSAOs and produce a product that is beyond any sole individuals' effort, and these employees' social skills become a foundation for success (Collins & Clark, 2003; Morgeson, Reider, & Campion, 2005; Sundstrom, Meuse, & Futrell, 1990). For these reasons, social skills have become extremely important for modern organizations, and several authors have proposed methods to improve employees' social skills.

Several authors have posed traditional interventions for enhancing social outcomes, and many of these are focused upon teamwork and leadership applications (Barling, Weber, & Kelloway, 1996; Morey et al., 2002; Shapiro et al., 2004; Skarlicki & Latham, 1997). Team members and leaders are required to motivate and interact with others, and effective interactions require superb social skills (Bass, 1985; Hoegl & Gemuenden, 2001; Jones & George, 1998; Stogdill, 1974; Yukl & Van Fleet, 1992). When developing these social skills, trainees are often placed into artificial team or leader positions (Barling, Weber, & Kelloway, 1996; Eppich et al., 2011; Ford, 2014; Shapiro et al., 2004). The trainee is asked to complete certain tasks in conjunction with others, and their performance is subsequently rated with feedback provided for improvement. Most often, this teamwork or leadership development occurs through role-plays or simulations (Avolio, Waldman, & Winstein, 1988; Beaubien & Baker, 2004; Raybourn et al., 2005; Shapiro et al., 2004). Both role-plays and simulations often involve trainee interactions with actors and/or trainers. While this method has proven effective, several aspects may cause VR interventions to be more effective at developing social skills.

VR interventions pose several advantages that typical interventions cannot for social outcome development. Particularly, typical interventions often rely on role-plays with a trainer (Bellack, Hersen, & Lamparski, 1979; Bellack et al., 1990; Glueckauf & Quittner, 1992; Lane & Rollnick, 2007), such as a practice interview. In this situation, outcome success is largely reliant on the trainer to portray an accurate emotional state to the trainee's actions, but some trainers may not possess this ability. The inability of the trainer to demonstrate accurate emotional states has been demonstrated to result in diminished intervention outcomes (Burke & Hutchins, 2007; Towler, 2009; Towler & Dipboye, 2001). In a VR intervention, however, an avatar can be programmed to portray any emotion, removing any requirements upon trainer acting ability. This allows each trainee to experience an identical and effective intervention experience, which may result in better intervention outcomes.

Relatedly, more so than many other intervention applications, interventions for social outcomes include ample trainer-trainee interactions (Bellack, Hersen, & Lamparski, 1979; Bellack et al., 1990; Glueckauf & Quittner, 1992; Lane & Rollnick, 2007). It is possible, if not probable, that the trainer may experience fatigue effects due to continuous emotional expression. Individuals undergoing later interventions may experience burnout and lackluster trainers with the inability to continuously demonstrate various emotions. Interventions with a fatigued trainer, akin to interventions with an unexpressive trainer, may result in worse intervention outcomes. Of course, an avatar trainer within a VR environment does not experience fatigue effects, and trainees will always receive the same quality intervention. This may ultimately result in better intervention outcomes.

Further, some populations have systematic impairments to their interpersonal functioning, such as individuals with autism spectrum disorder (ASD) and schizophrenia

(Endicott & Spitzer, 1978; Gottesman, 1991; Jordan, 2004; Kay, Flszbein, & Opfer, 1987; Lord & Bishop, 2010; Lord et al., 2013; Wing, 1996). These impairments prevent these individuals from regular functioning lives, resulting in an array of negative personal outcomes (Faris & Dunham, 1939; Jones et al., 1994; Kaufman et al., 1997; Robins & Guze, 1970). For this reasons, authors have sought effective interventions that could improve the social functioning of these individuals (Bauminger, 2002; Bellini et al., 2007; Ozonoff & Miller, 1995; Tse et al., 2007), and VR interventions have been proposed as a recent possibility (Parsons & Mitchell, 2002; Standen & Brown, 2005). Preliminary research has demonstrated that some applications appear effective (Irish, 2013; Kandaloft et al., 2013; Wainer & Ingersoll, 2011). Although organizational researchers often study general employee populations, recent research has directed an interest into these specialized populations. Several authors have noted the importance of incorporating these specialized populations into modern workplaces, noting several advantages for employees, organizations, and society (Johnson & Joshi, 2014; Neely & Hunter, 2014).

Lastly, social outcomes require less working memory to develop than cognitive outcomes, and VR interventions may utilize this unused working memory. Therefore, organizational practitioners and researchers should be interested in the impact of VR social outcome interventions for their effect on specialized and general employee populations, and it is expected that VR interventions are effective at developing individuals' social outcomes.

Hypothesis 2a: Compared to traditional methods, VR is more effective at developing individuals' social outcomes.

Furthermore, the current study distinguishes two types of social outcomes. The first are basic, behavioral social outcomes. These outcomes involve proficiency in a single social act,

such as maintaining eye contact or finding an appropriate seat within a café. While social outcomes may require less working memory to develop than cognitive outcomes, overall, it is expected that VR will demonstrate lackluster results in developing basic social outcomes due to their reliance on working memory.

Hypothesis 2b: Compared to traditional methods, VR is less effective at developing individuals' basic social outcomes

The other type of social outcomes are complex, integrated social outcomes. These involve proficiency within a variety of basic social outcomes. For example, competence within a job interview involves the ability to maintain eye contact, carry-on a conversation, and self-present positively. Each of these basic social skills can be developed individually or together in a VR intervention. It is expected that VR interventions are effective at developing these more integrated social outcomes. Integrated social outcomes, while requiring working memory to initially develop, gradually become more reliant on autonomic processes, thereby increasing the effectiveness of VR interventions.

Hypothesis 2c: Compared to traditional methods, VR is more effective at developing individuals' integrated social outcomes.

Together, when considering social outcomes, basic social outcomes require more working memory to develop than integrated social outcomes. For this reason, it is predicted that VR will demonstrate greater ability to develop integrative social outcomes than basic social outcomes.

Hypothesis 2d: VR demonstrates increasing effectiveness to develop the following outcomes as they are ordered: basic social outcomes and integrative social outcomes.

VR Interventions for Emotional Outcomes

Emotions. Another VR application is VR interventions for emotional outcomes, and it is divided into two primary sub-dimensions. The first sub-dimension is the application of VR systems to improve individuals' emotional and motivational states, and the second is the application of VR systems to improve individuals' Emotional Intelligence (EI). Several authors have noted the importance of altering individuals' emotional and motivational states through interventions, suggesting that performance is a combination of ability and motivation. Whereas many of the intervention applications mentioned above affect the former, ability, those impacting emotional and motivational states impact the latter, motivation.

One such emotional and motivational state is affect or mood. Much has been written about the importance of affect, as employee performance is greatly susceptible to momentary impacts on affect (George & Zhou, 2007; Pelled & Xin, 1999; Tsai, Chen, & Liu, 2007). Most often, scholars alter organizational factors to improve the affect of individuals, and little effort is placed on interventions to directly improve the affect of individuals; however, VR interventions pose great possibilities to directly improve trainee affect.

Within a VR environment, trainees affect may be easily impacted, and several authors have demonstrated the efficacy of VR to aid relaxation techniques (Plante et al., 2006; Riva et al., 2007). Most often, when aiding relaxations techniques, the VR system displays a tranquil outdoor scene and sometimes provides relaxation instruction. Users are meant to become immersed within the environment and disengaged from the stresses of reality. In these instances, VR utilizes individuals' attention and the working memory to focus on the digital environment, which is possible due to the little working memory required by the outcome itself. Thereby,

these processes improves affect, and it is expected that VR interventions are effective at improving trainees' affect.

Further, the current study separates two types of affect. The first is short-term affect, also called mood. It is expected that VR interventions will have a weak effect on mood, as this short-term affect is fleeting and less impacted by outside interventions. Therefore, it is predicted that VR will be equal to traditional methods in improving mood, as all interventions have a generally lackluster effect.

Hypothesis 3a: Traditional methods and VR are relatively equal at improving trainees' mood.

The other type of affect in this context is long-term affect, also called emotions. It is expected that VR interventions will have a strong effect on emotions, as this long-term effect is lasting and more effected by outside interventions. Therefore, it is predicted that VR will be better than traditional methods at improving emotions, as interventions can demonstrate a differential impact on emotions.

Hypothesis 3b: Compared to traditional methods, VR is more effective at improving emotions.

A closely related phenomenon to emotions, but not an emotion itself, is pain. Pain is the outcome of physical discomfort caused by illness or injury, and research has demonstrated that physical pain activates the same regions of the brain as "emotional pain" (Kross et al., 2011). Many authors have used VR to reduce feelings of pain when undergoing physically challenging procedures, such as surgery. Due to the immersive nature of VR, many authors have used the technology to reduce patients' feelings of pain (Hoffman et al., 1999, 2001, 2004, 2008). Also,

due to the nature of VR to utilize individuals' working memory, it may have a beneficial effect on reducing pain. Through distracting individuals' cognitive resources, VR may focus thoughts away from the painful sensations – thereby reducing feelings of pain. Therefore, it is expected that VR is effective at reducing pain.

Hypothesis 3c: Compared to traditional methods, VR is more effective at reducing pain.

Additionally, craving is another phenomenon which is similar but not an emotion. A craving is a biological indication that an individuals' biological systems desire a certain substance (Robinson & Berridge, 1993). Like emotions, cravings do not require working memory to alter. Instead, cravings are autonomic processes. According to intervention-technology fit theory, VR should effectively alter individuals' cravings, as it can utilize working memory which is not required by the specific outcome of interest. An example would be a VR program designed to reduce or even elicit smoking cravings.

Hypothesis 3d: Compared to traditional methods, VR is more effective at altering cravings.

Authors have noted the importance to alter individuals' attitudes towards specific targets through interventions (Ekström, Widström, & Nissen, 2005; Parker, Moore, & Neimeyer, 1998; Salas, Ford, & Kraiger, 1993), whereas attitudes are feelings, beliefs, and perceptions about a physical entity or concept. Although several attitudes may be altered through organizational interventions, the most studied is likely attitudes towards safety (Cox & Cox, 1991; Rundmo, 2000; Rundmo & Hale, 2003; Wichman & Ball, 1983). Employee safety is considered a primary outcome for many organizations (Brown & Holmes, 1986; Huang et al., 2006; Probst & Brubaker, 2001), even more so than performance, and safety incidents are often caused by

employee error (Colla et al., 2005; Dedobbeleer & Béland, 1991; Glendon & Stanton, 2000; Vredenburg, 2002); however, this employee error is not simply carelessness (O'Toole, 2002). Safety scholars pose that employees exist within a complex organizational system, and safety incidents which arise from employee error are due to an array of factors (Brown & Holmes, 1986; Colla et al., 2005; Dedobbeleer & Béland, 1991; Probst & Brubaker, 2001). Recent scholars have pointed towards organizational-level causes of safety incidents, and noted that organizations have an extreme impact upon employees' safety perceptions (Flin et al., 2000; Neat, Griffin, & Hart, 2000; Zohar, 1980, 2000). Employees a part of organizations with little focus upon safety also incur little focus upon safety themselves, resulting in an increased amount of safety incidents. While many scholars have attempted to address organizational climates to improve safety outcomes, others have directly addressed employees' attitudes towards safety through interventions.

Several interventions exist to alter trainee attitudes, especially attitudes towards safety. Most of these interventions treat attitudes towards safety as a peripheral outcome (Kraiger, Ford, & Salas, 1993). For example, behavioral modeling interventions require a trainee to observe coworkers performing certain tasks, and the coworkers instruct trainees upon proper task performance. Often, the intervention procedure involves a large focus on safety, and the coworkers are meant to consistent reinforce the importance of safety within the organization. Through this method, trainees perceive a strong organizational norm for safety through coworkers' reinforcement, and this improves the trainee's attitudes towards safety (Gore, 2002; Latham & Saari, 1979). Interventions such as these may be particularly effective within a VR environment, as the organization can ensure the trainee observes these reinforcements through preprogrammed avatars, but few authors have actually proposed VR interventions which impact

attitudes. Further, intervention-technology fir theory would predict that VR would be effective at altering attitudes, as attitudes require little working memory to develop. Together, it is expected that trainees will demonstrate positive changes to their attitudes within certain VR interventions.

Hypothesis 3e: Compared to traditional methods, VR is more effective at improving trainees' attitudes.

Similarly, the current study is interested in VR's effect on altering attitudes about oneself, labeled self-perceptions. Like attitudes, it is expected that VR will effectively alter self-perceptions, due to the outcomes' minimal need for working memory to alter.

Hypothesis 3f: Compared to traditional methods, VR is more effective at altering trainees' self-perceptions

Improving trainee motivation is often desired within organizations (Lawler, 1969; Nohria, Groysberg, & Lee, 2008; Rousseau, 1977). As mentioned, performance is a combination of ability and motivation. Whereas affect and attitudes may prompt motivation, some authors have devised interventions to directly improve motivation (Hennessey & Zbikowski, 1993; Kolb, 1965; McClelland, 1972). Many of these interventions specifically target achievement motivation, which is an individuals' need for success and excellence (Aronoff & Litwin, 1971; Kolb, 1965; McClelland, 1972). Authors believe that employees with high achievement motivation will strive for personal success which positively impact organizational success. Interventions for achievement motivation vary widely. Some prompt trainees to take greater risks, believing that those who do not achieve are self-handicappers (Ryals, 1975). Others specially choose trainees with above average abilities, such as high IQ, and demonstrate that the

trainees are underachievers due to their low motivation. Then, the trainees are provided information about their potential for success and advice to achieve this success (Kolb, 1965; Rootes, 1974). Few authors have noted the potential for VR interventions to develop trainee motivation. Within the current study, this application of VR interventions are studied in an exploratory manner, but it is nevertheless expected to be effective due to the minimal amount of working memory required to alter motivation.

Hypothesis 3g: Compared to traditional methods, VR is more effective at improving motivation.

Therapy Outcomes. The current study is interested in the application of VR to reduce phobias and PTSD. Phobias involve great and persistent fear of objects or situations, which is disproportionate to the danger posed (Clark & Wells, 1995; Etkin & Wagner, 2007; Rapee & Heimberg, 1997). Phobic individuals incur severe and negative reactions to their phobias, often taking extreme lengths to avoid the fear-inducing stimuli, which causes great burden to the phobic individuals. Alternatively, PTSD is similar to a phobia. PTSD is an extreme fear induced by a terrifying event, and can be considered a conditioned response to a stimuli. Often, military veterans develop PTSD, disallowing them from living a normal life when returning home from military duty.

Both of these conditions often require clinical interventions to address. Many innovative therapies have been applied to address phobias and PTSD, and many authors have tested the efficacy of VR to reduce phobias and PTSD (Harris, Kemmerling, & North, 2002; McLay et al., 2011; Reger et al., 2011). In fact, using VR to reduce phobias may be the most popular application of VR interventions. Authors have demonstrated that VR may allow individuals with phobias and PTSD to approach their fear-inducing stimuli, such as spiders or battle, in a safe

digital environment. Then, then they are ready, they can transition into approaching their fear-inducing stimuli in a naturalistic environment. Further, according to the proposed intervention-technology fit theory, VR should effectively reduce phobias and PTSD, as they do not require working memory to alter. Instead, they are autonomic processes. As predicted by theory, VR should be effective at reducing phobias and PTSD.

Hypothesis 3h: Compared to traditional methods, VR is more effective at reducing phobias.

Hypothesis 3i: Compared to traditional methods, VR is more effective at reducing PTSD.

Emotional Abilities. Additionally, a second dimension of VR interventions for emotional outcomes exists. Some VR interventions prompt trainees to understand their emotional processes and identify moments that their emotions may become detrimental (Arora et al., 2011). Other VR interventions instruct individuals on methods to perceive and understand others' emotions (Ververidis & Kotropoulos, 2006). Although these articles may not precisely label these abilities as such, it can easily be interpreted that these applications are essentially VR interventions to develop Emotional Intelligence (EI). EI is the ability to recognize and use emotions within oneself as well as others. Since the initial specifications of EI, authors have repeatedly debated upon the nature of the construct, resulting in multiple theoretical models to define the construct (Brackett & Mayer, 2003; Goleman, 2006; Mayer & Salovey, 1993, 2007). Within the current study, Mayer and Salovey's (1993, 2007) EI conceptualization is applied. Although multiple conceptualizations of EI exist, Mayer and Salovey's (1993, 2007) model is amongst the most scientifically valid. Several studies have supported multiple aspect of the model's validity.

Mayer and Salovey's (1993, 2007) EI conceptualization consists of the four dimensions of perceiving emotions, using emotions to facilitate thought, understanding emotions, and managing emotions. The first dimension, perceiving emotions, relates to identifying emotions within oneself as well as others. The second, facilitating thought, involves the ability to generate emotions to communicate feelings and aid other cognitive processes. The third dimension, understanding emotions, is the ability to understand emotional information and its impact upon others. The fourth and final dimension, managing emotions, includes the ability to modify the emotions of oneself and others. Using this model, several scholars have noted the importance of EI to the workplace, posing that an Emotionally Intelligent work force is an effective workforce (Mayer et al., 2001; Mayer, Salovey, & Caruso, 2008; Salovey & Mayer, 1989; Salovey, Mayer, & Caruso, 2002). Further, the importance of EI may be particularly true for particular occupations. Authors have noted that the ability to control and regulate emotions may be important for the military, customer service, and others (Ashforth & Humphrey, 1993; Brotheridge & Grandey, 2002; Diefendorff et al., 2011; Grandey et al., 2012; Mayer et al., 2001; Mayer, Salovey, & Caruso, 2008; Salovey & Mayer, 1989; Salovey, Mayer, & Caruso, 2002). Also, authors have proposed that EI may be beneficial for all organizations through preparing employees for performance within emergency situations (Beroggi, Waisel, & Wallace, 1995; De Leo et al., 2003; Gamberini et al., 2003).

Currently, some authors have demonstrated success through developing EI in a traditional intervention (Cherniss & Adler, 2000; Slaski & Cartwright, 2003), and the same is true for the development of EI within VR interventions (Popovic et al., 2009; Stetz et al., 2006; Tworus, Szymanska, & Ilnicki, 2010). These authors often focus on the ability to perceive emotions, as avatars display certain emotional expressions and trainees are meant to identify these

expressions. Trainees are provided feedback upon their performance, which has been demonstrated to be effective in developing emotional recognition (Ververidis & Kotropoulos, 2006; Zhang et al., 2009). Much like social outcome development, the use of avatars to demonstrate facial expressions may allow VR intervention for EI to be more effective than traditional interventions, as the intervention does not rely on the expressiveness of trainers. While the development of other dimensions of EI within VR interventions is less popular, some studies have nevertheless demonstrated initial success (Stetz et al., 2006; Tworus, Szymanska, & Inicki, 2010). Lastly, EI likely requires little working memory to develop, and intervention-technology fit theory would predict that VR would be effective in developing EI. Together, EI is important for organizational settings and scholars have investigated the potential for VR to train these abilities. It is expected that VR interventions are effective at developing EI and respective sub-dimensions.

Hypothesis 3j: Compared to traditional methods, VR is more effective at developing the ability to perceive emotions.

Hypothesis 3k: Compared to traditional methods, VR is more effective at developing the ability to use emotions to facilitate thought.

Hypothesis 3l: Compared to traditional methods, VR is more effective at developing the ability to understand emotions.

Hypothesis 3m: Compared to traditional methods, VR is more effective at developing the ability to manage emotions.

Hypothesis 3n: Compared to traditional methods, VR is more effective at developing Overall EI.

Although several emotional outcomes were noted, the current study only draws a distinction between the ability of VR to develop emotions and emotion-related abilities, with the latter requiring more working memory. For this reason, VR is expected to have greater effects on emotion development than emotion-related ability development.

Hypothesis 3o: VR demonstrates increasing effectiveness to develop the following outcomes as they are ordered: emotion-related abilities and emotions.

VR Interventions for Physical Outcomes

The last primary application of VR interventions focuses on physical outcomes. VR interventions for physical outcomes is defined as the application of VR systems to improve trainees' physical capabilities, most often focused upon developing muscle strength or psychomotor skills (Boian et al., 2002; Jack et al., 2001; Merians et al., 2002; Saposnik et al., 2010). Although many organizations do not require interventions for physical outcomes, it is extremely important to certain occupations, particularly the military (Hoffman et al., 1999; Knapik, 1989), firefighters (Cady et al., 1979; Rhea, Alvar, & Gray, 2004), and police officers (Arvey et al., 1992; Ash, Slora, & Britton, 1990). These occupations rely on the physical abilities of employees for their performance and safety. For this reason, effective physical outcome interventions could greatly aid employee outcomes within these specific applications, and several attempts have been made to create such interventions.

Currently, most physical outcome interventions are based upon validated Kinesiology principals (Baechle & Earle, 2008; Liu & Latham, 2009; Nelson et al., 1994; Ramsay et al., 1990). A multitude of authors have demonstrated the necessary conditions of muscle and psychomotor development, noting that trainees need sufficient nutrition (Fiatarone et al., 1994;

Hughes et al., 2001; Matson-Koffman et al., 2005) and a research-based workout regimen (Latham et al., 2003; Marcinik et al., 1991; Tsutsumi et al., 1997). While these interventions provide ample opportunity for physical development, certain concerns exist. Particularly, interventions are often physically demanding with little focus upon cognitive components (Aniansson & Gustafsson, 1981; Fitzgerald et al., 2003; Thomis et al., 1998). This may cause trainees to become bored or solely focus upon the difficult nature of the intervention (Anshel, 1991; Kraemer & Fleck, 2007; Kraemer & Knuttgen, 2003; Rooks, Silverman, & Kantrowitz, 2002; Treuth et al., 1998), potentially resulting in reductions to trainee motivation and, in some cases, increases to trainee withdrawal (Faigenbaum et al., 1996; Fatouros et al., 2005; Kraemer & Fleck, 2007; Kraemer & Knuttgen, 2003; Vuori et al., 1994). Therefore, the maximum potential of these interventions may not be realized due to trainee disengagement.

Some efforts have likewise been made towards developing effective VR interventions for physical skills (Jack et al., 2001; Merians et al., 2002; Saposnik et al., 2010). Within these studies, trainees regularly view a VR environment upon a digital display, and alternative hardware simultaneously tracks certain muscle movements (Bisson et al., 2007; Rizzo & Kim, 2005; Sveistrup et al., 2003). Within the VR environment, the trainee is instructed to move these certain muscles, and visual feedback is given on trainee performance. This visual feedback can be lifelike and display the movements of a realistic virtual avatar. Alternatively, the visual feedback can also be unrealistic and present the movements of a fantastical avatar or something else altogether. Together, the VR intervention allows trainees to work out their bodies, prompting muscle growth, in an exciting environment. Unlike prior physical outcome interventions which often suffered from poor trainee motivation due to boring elements, VR interventions for physical outcomes do not pose such a problem.

Additionally, studies focused upon VR interventions for physical outcomes are often directed towards individuals with impairments and physical disabilities (Lam et al., 2006; Wade & Winstein, 2011; Weiss, Naveh, & Katz, 2003), such as individuals recovering from stroke (Sisto, Forrest, & Glendinning, 2002; Subramanian et al., 2013; Trotti et al., 2009). These individuals often endure difficulties functioning in day-to-day life due to their muscle impairments. In these instances, the goal of the VR intervention is to allow trainees to retain regular functioning lives. Although these interventions are often developed and tested within the fields of Human Factors and Healthcare, they should pose an interest to organizational researchers. Recent scholars have noted the importance of inclusive organizations (Sabat et al., 2014; Santuzzi et al., 2014; Wax, 2014), posing that increasing the potential employee pool results in greater selection outcomes (Arthur, 2001; Breugh, 2008; Breugh & Starke, 2000; Hughes & Rog, 2008). Organizations with the possibility to attract individuals with physical disabilities could result in great benefits to productivity, as they would be able to apply their skills and abilities within a conducive environment, and the availability of VR physical outcome interventions may attract these individuals. Therefore, organizational researchers should also take note of methods to allow disadvantaged employees to regain functionality, and subsequently take an interest within VR interventions for physical outcomes.

Further, physical abilities require little, if any, working memory to develop. Based on intervention-technology fit theory, VR would not encumber working memory that would otherwise need to be used for outcome development, thereby improving outcomes. Together, whether for rehabilitation purposes or otherwise, VR interventions for physical outcomes are increasingly sophisticated and often rely on specialized hardware. Due to these technological improvements, authors have noted success in developing physical outcomes within VR

environments. It is expected that VR interventions are effective at developing individuals' physical outcomes. Also, to obtain a more specific understanding of VR interventions for physical outcomes, VR interventions for muscle strength and psychomotor skills are analyzed separately.

Hypothesis 4a: Compared to traditional methods, VR is more effective at developing trainees' physical outcomes.

Hypothesis 4b: Compared to traditional methods, VR is more effective at developing trainees' muscle strength.

Hypothesis 4c: Compared to traditional methods, VR is more effective at developing trainees' psychomotor skills.

The current study did not make a distinction between the working memory required to develop muscle strength and psychomotor skills. For this reason, no predictions are made about the differential effectiveness of VR to develop these outcomes.

VR Interventions for Other Outcomes

In addition to the outcomes specified by previous taxonomies and theory, VR has been applied to develop lesser-researched outcomes. Notably, several authors have tested the efficacy of VR to develop cognitive abilities which are unrelated to knowledge, especially in aging populations (Cherniack, 2011; Optale et al., 2010). These cognitive abilities do not involve the incorporation of information to memory, which is why it was not included in the cognitive outcome dimension. Instead, it involves quickness of thought, thinking logically, and using novel methods to solve problems. In general, developing these abilities solely involves

subconscious processes rather than mental rehearsal. For this reason, it is expected that VR will effectively develop fluid intelligence.

Hypothesis 5a: Compared to traditional methods, VR is more effective at developing other cognitive abilities.

In addition to general mental abilities, a specific mental ability is often studied in a VR context – Spatial abilities. Spatial abilities involve the capability to understand and remember spatial relations among objects (Bock & Kolakowski, 1973; Linn & Petersen, 1985; Lohman, 1979; Williams & Meck, 1991). This ability is used within navigation, movement, and the manipulation of objects (Gaulin & FitzGerald, 1986; Hier & Crowley, 1982; Just & Carpenter, 1985; McGlone & Davidson, 1973). Few organizational researchers have demonstrated interest within spatial ability, but the inherent properties of VR has seemingly prompted scholars to investigate the potential of the technology to develop this ability (Burdea & Coiffet, 2003; Cruz-Neira et al., 1993; Seymour et al., 2002; Steuer, 1992). In fact, VR interventions for special knowledge may be the only intervention outcome which is currently investigated within a VR environment more often than a real-life environment (Bliss, Tidwell, & Guest, 1997; Caglio et al., 2009; Cánovas et al., 2011; Cohen & Hegarty, 2014).

Studies investigating the potential of VR to develop spatial ability are often straightforward (Diaz & Sims, 2003; Foreman et al., 2003; Grewe et al., 2014; Giudice et al., 2010). Trainees experience a VR environment, and they are asked to search for specific objects. Then, they are asked to search for specific objects while timed, either within a VR or real-life environment, which provides a intervention outcome measure. VR provides a unique opportunity to develop spatial abilities, as it can provide a completely immersive experience which seems realistic to the trainee. Whereas trainees would previously have limited

opportunities to develop spatial abilities, VR interventions may allow trainees to perform an array of exciting tasks to develop this skill. Also, spatial ability development is often considered an autonomic process which does not require extensive working memory, and intervention-technology fit theory would predict that VR would be apt at developing spatial abilities.

Therefore, it is expected that VR interventions positively affects spatial abilities.

Hypothesis 5b: Compared to traditional methods, VR is more effective at developing spatial abilities.

Lastly, it is recognized that some outcomes may not be included in the above typology. For this reason, an “other” category will be a catch-all for all other outcomes. No predictions are made about the effectiveness of VR to develop these other outcomes, but they will be incorporated into the current meta-analysis and their implications will be discussed in the context of intervention-technology fit theory

Due to the large amount of hypotheses about the differential effectiveness of VR in various applications, Table 1 presents a representation of these predictions. Additionally, the current study proposed differential working memory required by the four primary dimensions: cognitive, social, emotional, and physical outcomes. For this reason, it is expected that VR will demonstrate an increasing effect on its ability to develop these outcomes.

Hypothesis 5c: VR demonstrates increasing effectiveness to develop the following outcomes as they are ordered: cognitive outcomes, social outcomes, emotional outcomes, and physical outcomes.

Other VR Intervention Application Research Questions

Using this typology, the current study analyses the applications of all identified research upon VR interventions. In addition to drawing inferences about the efficacy of current VR intervention applications, this study also draws inferences about the current scholarship upon VR interventions. The first research question regards the most popular research applications. As noted above, VR has been applied to improve an array of trainee attributes. It may be beneficial to researchers and practitioners to understand which applications are the most popular. This could direct researchers to address research questions within the less-popular applications, as well as provide guidance to practitioners to applications with a theoretically-sound basis.

Research Question 1: What are the current applications of VR interventions in research?

Research Questions and Hypotheses on the VR system

As mentioned, VR exists in several forms based upon the VR system. VR systems are composed of two aspects, the hardware and software. Applied hardware can greatly alter users' VR experience. A VR intervention through a HMD presents a different experience than one through a computer monitor, as the former provides a more immersive and futuristic experience (Mon-Williams, Warm, & Rushton, 1993; Robinett & Rolland, 1992; Shibata, 2002; Ward et al., 1992). Also, applied software can similarly alter the experience. Certain software features can cause the trainee to be more motivated and interested within the VR intervention (Barrett, 2014; Blum et al., 2009; Brandom, 2014; Bymer, 2012; Ilie et al., 2004; Mayton, 2014; Rhienmora et al., 2010; Sielhorst et al., 2004; Smith, 2014). Together, these two factors can cause VR to differ greatly from application to application, and these varying experiences may also result in varied application effectiveness.

As mentioned, several recent developments have altered VR hardware. Originally, VR interventions were exclusively presented through computer monitors. Then, certain technologies were created to present an innovative VR experience, such as surround-screen displays. Today, HMD are the most cutting-edge development within VR hardware. Research upon these incremental developments has largely posed that advancements to technology improve desired outcomes (Cruz-Neira, Sandin, & Defanti, 1993; Cruz-Neira et al., 1992; DeFanti et al., 2009; Das et al., 1993; Demiralp et al., 2006). In regards to HMDs, it is largely expected that the increased immersive capabilities of these devices result in greater intervention outcomes. When using a HMD, trainees are completely immersed and focused within the intervention environment, and several authors have proposed that this immersion relates to greater intervention outcomes; however, this notion has rarely been tested. To date, only Howard (Under Review) has demonstrated a difference between a traditional CBI via monitor and an intervention via HMD. The authors' series of studies demonstrates significantly lower transfer of training for the HMD conditions which use VR software compared to intervention via monitor which use non-immersive programs. While this article certainly provided information on the capabilities of HMDs, it is not conclusive. Multiple types of HMDs interventions exist, and the author's results may be due to the context, such as the sample of software applied. Unfortunately, no other author has made a direct comparison between these two devices, and limited alternative information is available. Nevertheless, it is expected that the more advanced and immersive hardware, HMDs for example, will result in better intervention outcomes.

Hypothesis 6a: VR interventions which apply more advanced hardware, such as HMD, will be more effective than VR interventions which apply less advanced hardware, such as a monitor.

Additionally, other various forms of hardware can be utilized during a VR intervention in conjunction with the VR system. For example, several authors have applied motion-sensor remotes and floor-pads to track users' hand and feet movements (Gallo, De Pietro, & Marra, 2008; McArthur, Castellucci, & MacKenzie, 2009; Wingrave et al., 2010). When applying alternative hardware, certain aspects of the intervention can be specifically targeted, allowing for a more nuanced intervention regimen. For this reason, it is expected that integrating this alternative hardware will improve the transfer of training from a VR intervention.

Hypothesis 6b: VR interventions which apply alternative hardware in conjunction with the VR system will be more effective than those which do not.

Alternatively, software is the second component of a VR system. Software is completely digital, created through computer coding languages, and is often synonymous with computer program. It is difficult to quantify the whether a certain software is more advanced than other. Although a certain software may have lifelike graphics, the functionality of the program may be basic. For example, a VR software may present a completely realistic depiction of a single room, but it may not allow users to interact with the room whatsoever. Alternatively, a different VR software may present a basic depiction of an entire world, and users may interact with all aspects of this world. In this example, it is impossible to determine which program is more advanced, and this is common with other software comparison examples.

Within the current study, it is assumed that more recent articles apply more advanced VR software. Developments to software are made over time, and software manufacturers adapt best-practices when constructing their software. This dispersion of information allows programmers to develop more advanced VR software. Although it is recognized that alternative time-related factors may cause VR interventions to produce improved intervention outcomes, such as

developments within theory, it is still believed that developments to VR software play a large role in any potential improvements. Therefore, it is expected that time demonstrates a relationship to VR intervention effectiveness, with more recent VR interventions producing greater intervention outcomes.

Hypothesis 7a: Recent VR interventions are more effective than older VR interventions.

Also, as mentioned above, intervention material may or may not be incorporated into the VR environment. When the material is incorporated, the intervention environment is often the intervention itself. For example, a VR intervention for welding may instruct trainees to weld within a virtual environment. When the material is not incorporated, the intervention environment only supports the intervention. For example, a VR intervention for math skills may teach the information within a space environment to improve trainee attitudes. While the VR environment is meant to increase trainee interest, the VR environment may be distracting. Trainees may become preoccupied with elements unrelated to the intervention. Therefore, it is expected that VR interventions with material integrated into the VR environment are more effective than those not integrated.

Hypothesis 7b: VR interventions integrated within the VR environment are more effective than those not integrated.

Further, while VR does not necessarily cause an intervention to include gamification elements, many studies nevertheless incorporate gamification elements within VR interventions (Deterding et al., 2011; Kapp, 2012; Zichermann & Cunningham, 2011). Gamification is application of video-game elements to the workplace, and this may include the application of

video-game elements to interventions (Deterding et al., 2011; Kapp, 2012; Zichermann & Cunningham, 2011). Within current study, gamification also describes serious-games. Possibly the most popular typology of gamification elements was created by Bedwell and colleagues (2012). This typology presents nineteen different elements which may relate to intervention outcomes, including challenge, conflict, and fantasy. In the current study, each individual gamification element is not of interest. Instead, the general impact of gamification elements upon VR interventions are recorded, and it is predicted that any included gamification elements result in greater intervention outcomes.

Hypothesis 7c: Gamification elements result in greater trainee outcomes within VR interventions.

Lastly, two research questions are posed in regards to VR system factors. The first is related to gamification elements. In the introduction of this study, it was noted above that gamification elements may be incorporated into VR interventions to an extent that the two terms are repetitive. In the current study, this notion is tested.

Research Question 2: Do all simulations include gamification elements?

Also, VR environments can be single-user environments (SUE) or multi-user environments (MUE). Scholars have supported the use of SUE or MUE for several non-intervention applications, but this research question has rarely been posed within intervention research. Within the current study, the efficacy of SUE or MUE are compared with no a priori hypothesis.

Research Question 3: Are SUE or MUE VR interventions more effective?

Research Questions and Hypotheses on the Participant Population

In addition to VR elements, several attributes of participants may affect the transfer of training from VR intervention. Notably, VR interventions are often performed upon special populations. These special populations often suffer from a debilitating condition that prevents regular functioning in day-to-day life. For instance, certain stroke survivors lose complete functioning of their appendages, preventing them from performing many basic tasks. Also, individuals with autism spectrum disorder (ASD) are unable to accurately detect and understand certain social cues, causing great difficulty in interpersonal interactions. For examples such as these, authors have developed VR interventions to train basic skills, ranging from the control of particular muscles to the identification of certain facial expressions.

It is believed that interventions for these special populations will be effective. VR interventions for general populations must consider a wide array of people, including general and special populations. Alternatively, a VR intervention for a specialized population only needs to focus on a relatively homogeneous population, as each person of interest possesses a special characteristics. Therefore, VR interventions for these populations can be catered for certain types of people, and it is predicted that a VR intervention upon a special population will be more effective than a VR intervention upon the general population.

Hypothesis 8: VR interventions with samples from specialized populations result in better intervention outcomes than VR intervention with samples from general populations.

Research Questions and Hypotheses on the Study Design

Although not mentioned above, it is also important to consider the design of VR intervention studies, particularly the measurement of intervention effectiveness. To analyze the

measurement of intervention effectiveness, Kirkpatrick's (1975, 1979) four levels of training outcomes is applied. Kirkpatrick (1975, 1979) proposed that training effectiveness can be evaluated on four attributes: trainee reaction, learning, behavior, and results.

First, reactions describe trainees' responses towards the intervention itself, such as affect (i.e. pleased or displeased) and utility judgments towards the intervention. This category is regarded as the lowest level of intervention effectiveness. Trainees may perceive positive affect or utility for an intervention, but it may not actually improve employee performance. Also, the opposite is true, whereas trainees may negatively perceive an intervention but it is actually effective. To measure reactions, trainees are directly queried about their opinions through Likert-scaled items. Further, it should be noted that the measurement of reactions is different than affective outcomes. Affective outcomes describe applications of the intervention, such as improving motivation and attitudes towards particular objects or concepts (i.e. safety). Kirkpatrick (1975, 1979) describes trainee reactions towards the intervention itself, and is regarded as the first level of intervention effectiveness measurement.

Second, the measurement of learning describes the demonstration of an understanding of principles, facts, skills, and abilities. This level of intervention measurement can be gauged through immediate or delayed self-report, multiple-choice questions, and free-recall. It can also be gauged through immediate or delayed demonstration of behaviors, skills, or abilities. Due to the various possibilities of learning measurement, this level can be gauged for any VR intervention application. For example, if a VR intervention is meant to train welding abilities, then a learning measurement would be a demonstration of that skill before and after the intervention.

Third, the measurement of behavior describes the application of learned principals on the job. This level of intervention measurement must be measured through naturalistic behavioral observations. If a trainee demonstrates an application of learned principals on the job, then the intervention was successful at the behavior-level of intervention measurement. If the trainee does not demonstrate an application of learned principles on the job, then the intervention was unsuccessful at this level.

Fourth, the measurement of results describes the impact upon desired ends, including reductions to costs, turnover, absenteeism, and grievances and/or increases to quality, quantity, or morale. Like all other measurement levels, results can gauge any VR intervention application.

Together, these four levels describe the possible methods to gauge intervention effectiveness, and much has been written about these four levels. Most importantly, the level of measurement may greatly impact the perceived success of an intervention. Generally, the first level, reactions, demonstrates the greatest relationship with an intervention, and each progressive level demonstrates a smaller relationship. For this reason, it is expected that VR interventions which measure lower-level intervention outcomes will demonstrate greater success than those which measured higher-level intervention outcomes.

Hypothesis 9: VR interventions have a greater impact upon lower-level intervention outcomes than higher-level intervention outcomes.

In total, thirty-nine hypothesis and three research questions are presented. To test these within a single study would be difficult, if not impossible. Instead, these ideas are addressed through meta-analysis.

Meta-analysis is the quantitative combination of previous study results. Through performing a meta-analysis, the multiple studies can be quantitatively combined to provide overall inferences and draw meaningful conclusions about the accumulation of research. Most importantly the properties of these studies can be compared to determine which attributes lead to successful VR interventions which will better inform application and practice. In doing so, this would address each of the research questions and hypotheses listed above.

Meta-Analytic Methods

Given the current state of VR interventions, the field of study is extremely expansive, ranging from workplace-related skills development to physical patient rehabilitation. At the same time, however, the field is also extremely disjointed. Many authors seem to draw from VR intervention scholarship within their relevant field, but largely ignore other research domains. For this reason, a meta-analysis study is conducted in an attempt to summarize extant findings and provide clarity to the entire field of VR intervention research. Meta-analysis is a statistical method which combines the collective results of several studies to identify consistent patterns as well as disagreements within a particular research question or hypothesis. With this method, authors can clearly understand trends within the literature and receive guidance upon future research directions, as needed within the field of VR intervention research.

Social Outcomes

Basic Social Outcomes. Effect sizes were coded on whether the intervention developed individual social skills, such as eye contact.

Integrated Social Outcomes. Effect sizes were coded on whether the intervention developed integrated social skills which require multiple basic social skills together, such as job interview success or public speaking.

Emotional Outcomes

Mood. Effect sizes were coded on whether the intervention altered short term affect.

Emotions. Effect sizes were coded on whether the intervention altered long term affect.

Pain. Effect sizes were coded on whether the intervention altered perceptions of pain. This was one of the two outcomes which could be included even if authors' did not measure the outcome after the VR intervention. Whereas other outcomes, such as declarative knowledge, must have been measured completely after the VR intervention, pain could have been assessed while undergoing the VR intervention.

Craving. Effect sizes were coded on whether the intervention reduced cravings for certain substances.

Self-Perceptions. Effect sizes were coded on whether the intervention altered feelings about themselves.

Attitudes. Effect sizes were coded on whether the intervention altered feelings about objects or concepts.

Motivation. Effect sizes were coded on whether the intervention altered focus upon a goal.

Phobia. Effect sizes were coded on whether the intervention reduced phobias towards certain objects or concepts.

PTSD. Effect sizes were coded on whether the intervention reduced the symptoms of Post-Traumatic Stress Disorder.

Emotional Intelligence. Effect sizes were coded on whether the intervention developed any of the four categories listed below.

Perceive Emotions. Effect sizes were coded on whether the intervention increased the ability to recognize others' emotions.

Using Emotions to Facilitate Thought. Effect sizes were coded on whether the intervention increased the ability to use emotions to decide the best course of action.

Understanding Emotions. Effect sizes were coded on whether the intervention increased the ability to understand felt emotions.

Manage Emotions. Effect sizes were coded on whether the intervention increased the ability to manage felt emotions.

Physical Outcomes.

Muscle Strength. Effect sizes were coded on whether the intervention developed physical muscle abilities.

Psychomotor Skills. Effect sizes were coded on whether the intervention developed hand-eye coordination.

Other.

Fluid Intelligence. Effect sizes were coded on whether the intervention developed the quickness of thought and other aspects of fluid intelligence,

Spatial Abilities. Effect sizes were coded on whether the intervention developed abilities to perceive objects' locations and the relative distance between objects.

Biological Markers. Effect sizes were coded on whether the intervention altered biological markers, such as blood pressure and neurological activity. Like pain, this was the other outcome which could be included even if authors' did not measure the outcome after the VR intervention, and biological markers could have been assessed while undergoing the VR intervention.

Other. Any effect size not able to be categorized into the categories listed above was categorized as other.

Outcome Level.

After the effect size was categorized into an outcome category listed above, it was also coded on its outcome level. The four outcome levels were adapted from the previously noted popular training outcome taxonomy (Kirkpatrick, 1975; 1979).

Reactions. Effect sizes were coded on whether the outcome was measured through asking participants whether they thought the intervention was effective.

Learning. Effect sizes were coded on whether the outcome was measured through measures and tests which were not self-reported perceptions of intervention effectiveness or behavioral methods.

Behavior. Effect sizes were coded on whether the outcome was measured through gauging changes in daily behaviors.

Results. Effect sizes were coded on whether the outcome was measured through distal outcomes, such as perceptions that the intervention positively impacted quality of life.

Study Coding

Each study was coded on the following variables to test for any moderating effects.

Hardware

Output Hardware

Head-Mounted Display. Articles were coded on whether the intervention used a HMD.

Computer Monitor. Articles were coded on whether the intervention used a computer monitor.

Other. Articles were coded on whether the intervention used a different display technology.

Input Hardware

Other Input Hardware. Articles were coded on whether the intervention used a specialized input hardware, which anything other than a keyboard, mouse, or joystick.

Software

Integrated. Articles were coded on whether the intervention used intervention material integrated in the digital environment.

Game Elements. Articles were coded on whether the intervention included popular video game elements.

Multi-User. Articles were coded on whether the intervention allowed multiple people to interact in the digital environment simultaneously.

Participant Population

Specialized Population. Articles were coded on whether the intervention used a specialized participant population, such as individuals with phobias.

Workplace. Articles were coded on whether the intervention occurred within the workplace. Classrooms were not considered a workplace environment; however, interventions to develop medical and surgical abilities were considered workplace-related, as they often occurred with students during their medical residence.

Child. Articles were coded on whether the intervention used a child sample.

Type of Control Group. Articles were coded on whether they included a wait-list control group or a control group which received a comparable intervention.

Causes.

Although not outcomes, effect sizes were coded on the categories below (but not included within primary analyses) if they gauged a hypothesized cause of VR intervention success.

Working Memory. Effect sizes were coded on whether the outcome was a measure of working memory.

Cognitive Engagement. Effect sizes were coded on whether the outcome was a measure of cognitive engagement.

Intervention Motivation. Effect sizes were coded on whether the outcome was a measure of intervention motivation.

Reduced Feelings of Judgement. Effect sizes were coded on whether the outcome was a measure of feelings of judgement.

Excitement. Effect sizes were coded on whether the outcome was a measure trainee excitement.

Presence. Effect sizes were coded on whether the outcome was a measure of presence.

Cybersickness. Effect sizes were coded on whether the outcome was a measure of cybersickness.

Other. Effect sizes were coded on whether the outcome measured a hypothesized cause of VR intervention success and not included into one of the categories above.

Results

Primary Research Questions about Outcome Effectiveness

To determine the effect of VR, all results are presented as the standard difference of the means (d) between the VR group (treatment group) and the comparison group. Table 3 presents these effects, as calculated by a fixed effects model, separated by outcome and without any corrections. Table 4 presents these effects, as calculated by a random effects model, separated by outcome and without any corrections. Table 5 presents these effects, as calculated by a random effects model, separated by outcome, without any corrections, and only including studies which the control group received an alternative intervention.

For the results below, only the random effects model is reported (Table 5). In some instances, the fixed effects model may be more appropriate than the random effects model when the effects sizes can be considered homogeneous, often indicated by a Q statistic. Borenstein, Hedges, and Rothstein (2007) note, however, that the random effects model reverts to a fixed effects model when homogeneity is large, eliminating the need to apply a fixed effects model.

These findings have prompted several authors to note the superiority of random effects beyond fixed effects calculations for meta-analyses in most situations (Murphy, 2015). Therefore, only a random effects model is discussed in the results.

Also, only statistics which were calculated through alternative intervention group comparisons are reported. Few studies used control groups which did not receive an alternative intervention. It is possible that these few studies were clustered within particular outcomes, altering the interpretation of results. Therefore, only results calculated through alternative intervention group comparisons are discussed in the results.

When considering all outcomes together, VR has a positive impact on intervention effectiveness, as the VR groups demonstrated a significantly larger overall effect than the comparison groups ($d = .309$; 95% C.I. = .200 - .417; $p < .001$). Further, each of the primary subgroups also demonstrated a positive effect of VR. The positive effect of cognitive outcomes was small to moderate ($d = .367$; 95% C.I. = .165 - .568; $p < .001$); the positive effect of social outcomes was small ($d = .143$; 95% C.I. = -.411 - .697; $p > .10$); the positive effect of emotional outcomes was small ($d = .171$; 95% C.I. = .030 - .312; $p < .005$); the positive effect of physical outcomes was small to moderate ($d = .340$; 95% C.I. = .141 - .540; $p < .001$); and the positive effect of other outcomes was moderate ($d = .449$; 95% C.I. = .187 - .710; $p < .001$). Overall, the confidence intervals for each of the five subgroup outcomes overlapped, but the order of the subgroups from smallest to largest is: social outcomes, emotional outcomes, physical outcomes, cognitive outcomes, and other outcomes. These results partially support Hypothesis 5c, the ordering of the primary subgroups, except cognitive outcomes is out-of-place. It was predicted to demonstrate the lowest effect size, but it was the second largest.

When analyzing the further sub-dimensions within each subgroup, greater variation can be seen. Within cognitive outcomes, declarative knowledge outcomes demonstrated a small positive effect ($d = .125$; 95% C.I. = $-.089 - .338$; $p > .10$); knowledge organization outcomes demonstrated an extremely large positive effect, but it only consisted of a single effect size ($d = 1.765$; 95% C.I. = $1.158 - 2.372$; $p < .001$); skill-based outcomes demonstrated a moderate to large positive effect ($d = .643$; 95% C.I. = $.310 - .975$; $p < .001$); and wayfinding outcomes demonstrated a moderate negative effect ($d = -.592$; 95% C.I. = $-1.275 - .090$; $p > .10$). When comparing cognitive outcomes, none of the confidence intervals overlapped, and the order of the sub-dimensions from smallest to largest is: wayfinding outcomes, declarative knowledge outcomes, skill-based outcomes, and knowledge organization outcomes.

When further inspecting the cognitive outcome results, Hypothesis 1c (knowledge organization) is not supported, although the results reflect a single effect size and further research is certainly needed. Hypotheses 1e (skill-based outcomes) and 1f (wayfinding) are certainly supported, whereas Hypothesis 1d (cognitive strategies) could not be tested due to a dearth of studies. Alternatively, the results are less clear towards Hypothesis 1b (declarative knowledge). The effect size ($d = .125$) suggests that VR is more effective than alternative interventions when developing declarative knowledge outcomes, but this figure is much smaller than the other positive effects on skill-based outcomes ($d = .643$) and knowledge organization outcomes ($d = 1.765$). For this reason, Hypothesis 1b is partially supported. Although VR has a positive effect on declarative knowledge outcomes, it is not as strong as the other effects. Further, Hypotheses 1a and 1f were supported. VR was more effective than alternative interventions in developing cognitive outcomes (Hypothesis 1a), and the rank order of the outcomes in their effectiveness was close to predictions (Hypothesis 1f).

Very few studies investigated VR for social outcome development, although several authors have suggested a need for this research. Hypothesis 2b (basic social outcomes) could not be investigated due to the dearth of studies. Hypothesis 2a (social outcomes) 2c (integrated social outcomes) were not supported. Although the effect for both was positive, it was very small and not statistically significant ($d = .143$; 95% C.I. = $-.411 - .697$; $p > .10$). It should also be noted that this effect size is a reflection of only four studies, and future research is certainly needed within this domain. Hypothesis 2d could not be tested.

Next, many authors have investigated the efficacy of VR to improve emotional outcomes. Within this subgroup, three further subgroups were noted. VR demonstrated a positive, small effect on altering emotional and motivational states ($d = .239$; 95% C.I. = $.057 - .421$; $p < .05$) and a positive, small to moderate effect on altering emotional intelligence ($d = .308$; 95% C.I. = $-.032 - .648$; $p < .10$), but the latter effect was not statistically significant due to the small number of studies included in the calculation (two). Alternatively, VR demonstrated a null effect on altering therapy outcomes ($d = -.023$; 95% C.I. = $-.134 - .088$; $p > .10$). The null effect cannot be explained by a dearth of studies, as it was calculated with 43 different articles, reflecting 331 individual effect sizes and 1435 participants.

Within each of the three subgroups, further sub-dimensions can be analyzed. In the emotional and motivational states subgroup, the sub-dimensions demonstrated noteworthy variation in effect sizes. Motivation outcomes demonstrated the smallest and only negative effect ($d = -.284$; 95% C.I. = $-.998 - .430$; $p > .10$), but this was only calculated with two effect sizes from a single study. Mood outcomes were the next smallest effect ($d = .179$; 95% C.I. = $-.088 - .446$; $p > .10$), closely followed by emotion outcomes ($d = .242$; 95% C.I. = $-.054 - .539$; $p > .10$). Pain ($d = .324$; 95% C.I. = $.006 - .641$; $p < .05$), craving ($d = .381$; 95% C.I. = $-.867 -$

1.628; $p < .10$), and self-perception ($d = .461$; 95% C.I. = .030 - .892; $p < .05$) outcomes each demonstrated positive, small to moderate effects. Lastly, an effect size could not be calculated for alterations to attitudes due to the dearth of research. These results supported Hypotheses 3a (Mood), 3b (Emotion), 3c (Pain), 3d (Craving), 3f (self-perceptions), but failed to support Hypothesis 3g (motivation). Hypothesis 3e (attitudes) could not be tested. Therefore, in the following order, VR demonstrates an increasing improvement beyond alternative treatments for the outcomes within the emotional and motivational states subgroup: motivation, mood, emotion, pain, craving, and self-perception outcomes.

The therapy outcome subgroup also demonstrated a variation in its two sub-dimensions. Phobia outcomes did not demonstrate a difference between the VR and control group ($d = -.004$; 95% C.I. = $-.163 - .156$; $p > .10$), whereas PTSD outcomes demonstrated a moderate difference between the VR and alternative intervention group ($d = .581$; 95% C.I. = $.061 - 1.102$; $p < .05$). These results support Hypothesis 3i (PTSD), but fail to support Hypothesis 3h (phobia). Therefore, VR appears to be more effective than alternative interventions when targeting reduction of PTSD, but equal when addressing phobias.

Little can be said about the emotional intelligence subgroup, as it was only represented by one of four possible sub-dimensions: managing emotions. Even so, managing was only represented in two studies, and a small to moderate overall effect was still observed ($d = .308$; 95% C.I. = $-.032 - .648$; $p < .10$). These results partially support Hypothesis 3m (managing emotions), but Hypotheses 3j (perceive emotions), 3k (using emotions to facilitate thought), 3l (understanding emotions), and 3n (EI) could not be tested.

Additionally, applying VR to improve physical outcomes was another popular objective of authors. Within this subgroup, the two sub-dimensions demonstrated similar results.

Developing muscle strength demonstrated a moderate effect ($d = .412$; 95% C.I. = .174 - .649; $p < .001$), whereas developing psychomotor skills demonstrated a small to moderate effect ($d = .307$; 95% C.I. = .079 - .535; $p < .01$). These results support Hypotheses 4a (physical outcomes), 4b (muscle strength), and 4c (psychomotor skills). VR interventions are more effective than alternative interventions at developing muscle strength than psychomotor skills.

Lastly, four sub-dimensions were categorized in the subgroup of other outcomes. Biological markers did not demonstrate a significant difference from alternative interventions ($d = -.043$; 95% C.I. = $-.267 - .182$; $p > .10$). Other cognitive abilities demonstrated a large effect ($d = .752$; 95% C.I. = $.444 - 1.060$; $p < .001$) and spatial abilities demonstrated a very large effect ($d = 1.118$; 95% C.I. = $.156 - 2.080$; $p < .05$), demonstrating a great improvement beyond alternative interventions. Lastly, VR interventions were more effective than alternative interventions in developing all other outcomes ($d = .478$; 95% C.I. = $-.150 - 1.106$; $p > .10$). These results support Hypotheses 5a (cognitive abilities) and 5b (spatial abilities). In order, VR demonstrated an increasing effect on biological markers, cognitive abilities, spatial abilities, and other outcomes.

Alternative Research Questions

Several other alternative research questions and hypotheses were proposed in the current study, and these research questions are largely unrelated to the efficacy of VR for certain outcomes. Research Question 1 speculated about the most popular applications of VR for intervention purposes. As apparent from Table 4, which includes studies with no intervention and alternative intervention control groups, the most popular specific applications (with their respective number of articles) were skills-based outcomes (42), phobias (37), mood (33), declarative knowledge (22), psychomotor skills (19), emotions (18), other (17), biological

markers (15), and pain (14). In these applications, it is apparent that the three most popular types of VR interventions are for educational/workplace (skills-based outcomes and declarative knowledge), therapy (phobias, mood, emotions), and rehabilitation purposes (psychomotor skills and biological markers); however, other applications can be seen throughout the literature (pain and other).

Next, the current study proposed several effects related to the software, hardware, and participant population. To test these effects, effect sizes were calculated for each level of the aspects of interest using all recorded effect sizes. To determine the relative effectiveness for each level of the aspects of interest, the confidence intervals of the effects are compared. These results are presented in Table 6. Also, meta-regressions was performed to further test for the significance of the aspects of interest. A separate meta-regression was performed for each aspect, included in Table 7, as well as a final meta-regression which analyzes each aspect together, included in Table 8.

Hypothesis 6a proposed that more advanced hardware, such as HMDs, would produce greater VR outcomes. When analyzing the effect sizes, VR demonstrates a stronger effect beyond alternative interventions when HMDs ($d = .450$; 95% *C.I.* = .272 - .628) or other output hardware ($d = .572$; 95% *C.I.* = .049 - 1.094) are used instead of monitors ($d = .297$; 95% *C.I.* = .180 - .414); however, all of the confidence intervals overlapped, and HMD and other output hardware cannot be considered more or less effective than monitors when analyzing the confidence intervals. When analyzing the meta-regression of output type alone, none of the coefficients are significant and all confidence intervals contain zero. On the other hand, when considering the overall meta-regression, the coefficients for the type of output comparing monitor-HMD ($\beta = .335$; *S.E.* = .142; 95% *C.I.* = .056 - .614) and monitor-other ($\beta = .446$; *S.E.* =

.220; 95% *C.I.* = .016 - .887) are significant. Together, it is possible that HMDs and other specialized displays are more effective than computer monitors for VR interventions, but further investigation is needed to understand their differences.

Hypothesis 6b proposed that interventions which applied specialized input hardware, aside from a keyboard, mouse, and/or joystick, would have more effective outcomes than those which did not. The effect sizes slightly differed between studies which used standard input hardware ($d = .362$; 95% *C.I.* = .237 - .487) and specialized input hardware ($d = .435$; 95% *C.I.* = .275 - .595), but their confidence intervals overlapped. The respective meta-regression coefficient comparing studies which did and did not use specialized input hardware did not reach significance in either of the meta-regressions. Therefore, specialized input hardware does not seem to improve VR outcomes.

Hypothesis 7a predicted that more recent VR interventions would be more effective than older VR interventions. Due to the continuous nature of the variable, the effect of year could only be tested in a meta-regression. The respective coefficient for year did not reach significance in either meta-regression, indicating that VR interventions have not been getting more effective over time.

Hypothesis 7b predicted that VR interventions with the material integrated into the environment were more effective than those without integrated material. This prediction was not supported. The confidence intervals for not integrated ($d = .566$; 95% *C.I.* = .124 - 1.009) and integrated ($d = .381$; 95% *C.I.* = .277 - .485) VR interventions overlapped, and the respective coefficients in the two meta-regressions were not significant.

Hypothesis 7c predicted that VR interventions with game elements would be more effective than those without game elements. The confidence intervals for VR interventions with game elements ($d = .623$; 95% *C.I.* = .427 - .819) and those without game elements ($d = .325$; 95% *C.I.* = .212 - .439) barely overlapped. When analyzing the meta-regression with each aspect included separately, the coefficient comparing VR interventions with and without game elements was significant ($\beta = .301$; *S.E.* = .123; 95% *C.I.* = .066 - .549). When analyzing each aspect together, the coefficient was no longer significant. Overall, it appears that game elements may somewhat improve VR intervention effectiveness.

Relatedly, Research Question 2 asked whether all VR interventions contained game elements. This was certainly found to not be true, as 150 articles reported on VR interventions which did not contain game elements, and 38 articles reported on VR interventions which did contain game elements. While 80% of these studies did not include game elements, there is still an obvious interest in game elements.

Research Question 3 asked whether single-user environments (SUE) or multi-user environments (MUE) were more effective. Almost no difference was seen between the two, as the confidence for SUE ($d = .393$; 95% *C.I.* = .286 - .500) and MUE ($d = .366$; 95% *C.I.* = .061 - .670) largely overlapped. Also, the respective coefficients in both meta-regressions were not significant, indicating no difference between VR interventions which use SUE or MUE.

Hypothesis 8 predicted that VR interventions which focus on specialized populations are more effective than those which focus on general populations. To test this, three comparisons were made. The first compared specialized samples and non-specialized samples. A specialized sample was any sample collected due to a specific attribute, such as stroke survivors or mentally handicapped individuals. No differences were seen in effects for these two samples, as the

confidence intervals for general samples ($d = .444$; 95% *C.I.* = .274 - .613) and specialized samples ($d = .344$; 95% *C.I.* = .227 - .461) overlapped. The respective coefficients in the meta-regressions were not statistically significant, indicating that VR interventions focusing on specialized samples were not more effective than those focused on general samples. The second comparison compared workplace VR interventions and non-workplace VR interventions. The confidence intervals of workplace VR interventions ($d = .444$; 95% *C.I.* = .274 - .613) and non-workplace VR interventions ($d = .344$; 95% *C.I.* = .245 - .443) overlapped, and the coefficient for the meta-regression with the single aspect alone was not significant. Nevertheless, the meta-regression with all aspects together indicated that the comparison between workplace and non-workplace VR interventions was significant ($\beta = .704$; *S.E.* = .209; 95% *C.I.* = .294 - 1.114), but more research is needed to definitively support this claim. The last comparison compared child and adult samples. The confidence interval between the child ($d = .679$; 95% *C.I.* = .430 - .928) and adult ($d = .326$; 95% *C.I.* = .217 - .434) samples barely overlapped, and the meta-regression with all aspects together indicated that the comparison was not significant; however, the meta-regression with all aspects separated indicated that the comparison was significant ($d = .358$; 95% *C.I.* = .087 - .629). Once again, a significant difference may exist between the child and adult samples when applying VR interventions, but more research is certainly needed.

Hypothesis 9 predicted that lower-order outcomes would demonstrate larger effects than higher-order outcomes. The confidence intervals for the four levels of outcomes largely overlapped, except for reactions ($d = -.249$; 95% *C.I.* = -.732 - .235) and learning ($d = .386$; 95% *C.I.* = .285 - .488). When analyzing the meta-regressions, none of the coefficients indicated a significant difference between the four levels of outcomes.

Discussion

Discussion of Primary Findings

The current study focused on a new theory of intervention-technology fit, which proposes: For a CBI to be effective, the technology should present as realistic and/or entertaining of an experience as possible without burdening the trainees' working memory resources necessary to develop the outcome of interest. In other words, outcomes which require little (much) working memory to develop should be paired with technologies which require much (little) working memory to maximize intervention outcomes, and the benefits of the technology should only be viewed in-addition-to the requirements of the outcome itself.

To test this theory, the current study conducted a meta-analysis on VR interventions across a multitude of outcomes. In regards to the four overall subgroups of outcomes, not accounting for other, the results were somewhat in alignment to the proposed theory. The theory predicted that cognitive, social, emotional, and physical outcomes would demonstrate an increasing effect, in that order. The results demonstrated an increasing effect in the following order: social outcomes, emotional outcomes, physical outcomes, and other outcomes. Three of the four outcomes were in alignment with theory, whereas cognitive outcomes was not. From these results, the proposed theory may not be apt at describing the task and technology match for all VR interventions.

When analyzing the specific outcome sub-dimensions, the proposed theory describes some results better than others. Particularly, the ordering of cognitive outcomes aligned with predictions. The smallest effect sizes were for wayfinding and declarative knowledge, which both require extensive working memory to develop. Skill-based outcomes demonstrated significantly larger effects. Knowledge organization demonstrated larger effects, too, but it will not be considered as it was represented by a single effect size. Then, when including the two

other mental outcomes categorized in the other category, other cognitive abilities and spatial abilities demonstrated even stronger effects than skill-based outcomes. These two outcomes do not require the commitment of knowledge to memory, although they require the development of mental abilities, resulting in a smaller demand on working memory. Together, the proposed theory, intervention-technology fit theory accurately predicts the effects of technology on developing mental outcomes.

Alternatively, the theory could not be tested for social outcome development, as authors have only analyzed a small amount of integrated social outcomes and no basic social outcomes. Similarly, the theory predicted the same effects for the physical outcomes of muscle strength and psychomotor skills, and the results do not support or deny the theory.

In regards to emotional outcomes, however, some results were discrepant with the proposed theory. Of the three subgroups in emotional outcomes, emotional intelligence demonstrated the strongest effect, although it was only represented by two studies and seven effect sizes. Emotional and motivational states demonstrated the next highest, which was extremely close to emotional intelligence. Lastly, therapy outcomes demonstrated an extremely small effect size, with VR interventions not demonstrating a significant improvement beyond alternative interventions. These results go against intervention-technology fit theory.

When further analyzing the sub-dimensions in these subgroups, the theory does not provide any support for the ordering for the specific emotional and motivational state outcomes; however, some notes should be made about these outcomes. First, motivation demonstrated a strong negative effect. When investigating the three motivation studies, the negative effect may be due to study design rather than a reflection of true outcomes. In the studies, the control group underwent an intervention and the VR group underwent the same intervention along with a VR

intervention. Then, subsequent motivation towards a task was gauged by the word count provided in a writing prompt. In these studies, the VR group may have demonstrated less motivation because they were tired from the extra intervention, rather than VR itself reducing motivation outcomes.

Second, pain demonstrated the largest difference between VR interventions and alternative interventions in the emotional and motivational states subgroup. This finding may have arose due to pain being most often gauged during the intervention process, whereas other outcomes (asides biological markers) must have been gauged after the intervention. Thus, the effect for VR interventions on pain may not be more noteworthy than its effect on other emotional and motivational states.

Third, each of the other emotional and motivational state sub-dimensions demonstrated approximately equal effects. While intervention-technology fit theory accurately predicted this finding, the effect size of each of these outcomes is much smaller than many cognitive outcomes, which is against the proposed theory.

In regards to the next sub-dimension, therapy outcomes, VR interventions demonstrate a great disparity between reducing phobias and PTSD. VR interventions were not more effective than alternative interventions in reducing phobias, but demonstrated moderate effects beyond alternatives when reducing PTSD. More research is needed to understand this finding. A significantly smaller number of studies have applied VR interventions to reduce PTSD (five with alternative treatment groups) when compared to phobias (33 with alternative treatment groups), but most authors would consider five studies enough to calculate a meta-analytic effect. So, these results are likely not due to an insufficient number of studies. More pertinent to the current

study, however, is that intervention-technology fit theory does not explain the differences in the phobia and PTSD results.

The final emotional outcome subgroup, emotional intelligence, was only represented by one of its four possible sub-dimensions: managing emotions. For this reason, little can be said about comparisons within the construct. Nevertheless, the observed effect of VR interventions beyond alternative interventions was small to moderate for developing this outcome, which is contrary to intervention-technology fit theory.

The next primary subgroup is physical outcomes. Within this subgroup, the two sub-dimensions demonstrated similar results, with VR interventions being more effective than alternative interventions for developing muscle strength and psychomotor skills. This results is in agreement to the proposed theory; however, the effect sizes for these two outcomes was still smaller than cognitive outcomes, which is in disagreement to the theory.

Lastly, in the other subgroup, biological markers did not significantly differ between VR interventions and alternative interventions, whereas VR interventions demonstrated a moderate effect in developing other outcomes beyond alternative interventions.

Together, these results have several implications. First, task-technology fit theories (Dennis & Kinney; Dennis & Valacich, 1999; Mennecke, Valacich, & Wheeler, 2000; Suh, 1999; Valacich et al, 1994; Vessey, 1991; Vessey & Galletta, 1991) are warranted, as VR interventions demonstrated differential effectiveness across the multiple outcomes. As mentioned, most task-technology fit theories are often cited as justification for a well-performing technology, but true tests of the theories have yet to be performed. The current study demonstrated that, in an intervention context, VR demonstrates differential effectiveness which

is dependent upon the outcome. Nevertheless, while the global idea of task-technology fit theories is sound, the theories themselves still have many aspects which are not falsifiable. Particularly, no justification is given for conditions of task and technology match. For this reason, it is important to analyze the current results in the context of the provided theory.

Second, intervention-technology fit theory did not accurately predict the differential effects of the primary sub-dimensions, and it did not accurately predict the effects of social, emotional, and physical outcomes; however, it accurately predicted the effect of cognitive outcomes, even when two outcomes originally included in the other category were included. In creating the theory, it was mentioned that task-technology fit theories should be specific, which was the justification of creating a theory which was relevant to only an intervention context; however, this may have still been too broad. Instead, it may be best to solely consider the theory in an education and training context, as these contexts are most focused on cognitive outcomes. Also, it should be relatively unsurprising that the created theory is most apt for these contexts and outcomes, as the original theories that intervention-technology fit theory is based upon are almost all derived from education and training scholarship. Therefore, intervention-technology fit theory should be redefined to explicitly refer to cognitive outcome development, such as during employee training and development.

When rewriting the dissertation results for a publication, I anticipate framing the paper as an investigation into training-technology fit, which would provide a larger emphasis on cognitive outcomes which developing the theory. Then, for predictions, I would predict the following order for cognitive outcomes: wayfinding, declarative knowledge, knowledge organization, cognitive strategies, skills and abilities, spatial knowledge, and cognitive abilities. These predictions fit with the expected amount of working memory required to develop the outcome.

Also, as apparent from this list, I would move two variables from “other” to the cognitive outcome category. Then, I would also provide the results within other categories, noting that the theory was not created for the other outcomes, and therefore it should not and does not predict their order. Through this reframing, my eventual article would lead into my next implication.

When analyzing these cognitive outcomes, it is apparent that VR is most apt at developing skills and abilities, spatial abilities, and cognitive abilities. Currently, a large amount of research has investigated VR to develop skills and abilities. Likewise, the most popular practical applications of VR for cognitive outcomes are focused on skills and abilities, such as developing surgical skills and welding abilities. Much less research has targeted VR for cognitive ability development. Likely, the dearth of research is due to perceptions that cognitive abilities are relatively fixed; however, VR may provide a unique opportunity to improve these outcomes. Future research should take a great interest in applications of VR to develop these lesser-studied outcomes.

Alternatively, VR is least capable at developing declarative knowledge and spatial abilities. Surprisingly, a noteworthy amount of research has applied VR to develop declarative knowledge, often in educational settings. Researchers may want to allocate their efforts towards testing other computer programs, such as serious games, to develop these outcomes, as intervention-technology fit theory proposes that VR can never be effective at developing this outcome.

Fourth, authors should seek to create other theories which target specific outcome development, as specific theories may be more accurate in predicting outcomes. Particularly, intervention-technology fit theory was particularly poor at predicting emotional outcomes. A new theory and set of analyses should propose a new idea towards the differential effectiveness

of VR for emotional outcomes, particularly for therapy purposes. Nevertheless, it is believed that simply discovering the overall effects of VR interventions for these other outcomes could provide several benefits for research and practice, as noted below.

Further, authors should take great interest in VR interventions' lackluster ability to reduce phobias. Of all outcomes, the null difference between VR interventions and alternative interventions is likely the most surprising. Given that applying VR interventions for therapy phobias is amongst the most popular applications for VR altogether, it would be expected for authors to have small to moderate success in creating interventions which are superior to alternative – especially given the potential added cost of VR. A possible future study could investigate the cause of this effect by systematically analyzing the poor, moderate, and well performing VR interventions. Also, in the future, practitioners should heavily consider the continued application of VR interventions, and the lackluster effect of VR on therapy purposes may be the most unclear result of any outcome analyzed.

Another popular therapeutic application of VR is to reduce pain during surgery. The current meta-analysis demonstrated that VR was very effective at reducing pain, and this real-world application of VR is certainly merited. Further research in this area should continue.

Relatedly, VR was shown to be effective for physical outcome development. As demonstrated in Appendix A, many authors have expressed great interest in physical outcome development. These authors have used VR to improve motor control, balance, gait, and strength abilities. While the current study only divided outcomes into motor control and strength, future research could provide a more in-depth analysis of VR for more specific physical outcome development. As noted in Appendix A, several authors have already provided frameworks which could be used to guide future research in physical outcome development.

Fifth, several areas of VR intervention research are understudied. For instance, despite several authors noting the potential of VR to develop social outcomes, very few authors have tested the effectiveness of VR to actually develop these outcomes. Or, at least, they are not using a control group to test their programs. As included in Appendix B, an extensive amount of research has proposed theoretical dynamics which may occur when applying VR for social outcome development. So, it is surprising that VR is not being applied to develop these outcomes. Similarly, very little research has investigated the efficacy of VR to improve EI, although several authors have noted its potential. Future research could certainly benefit from extended investigations into these two areas.

In addition to the primary finding of VR interventions'; differential effectiveness across outcomes, the current study also investigated many alternative hypotheses and research questions. A discussion of these alternative analyses is presented below.

Discussion of Alternative Findings

The current study analyzed several additional research questions. Some of these were related to the hardware applied during the VR intervention. When analyzing the type of output hardware applied, differences can be seen in the relative effectiveness of computer monitors, HMDs, and other output hardware (such as surround-screen displays and 3D TVs). VR interventions using computer monitors demonstrated a small effect size beyond alternative interventions, whereas those that used HMDs and other output hardware demonstrated moderate effect sizes. Although these differences were not significant in all analyses, the three technologies likely demonstrate differential levels of effectiveness, with HMDs and other output technologies being more effective than computer monitors. Alternatively, when analyzing the

type of input hardware, little difference could be seen between VR interventions which use traditional

Some research questions were related to the type of software. Particularly, the current study was interested on whether instructional material which was integrated into the VR environment was more effective than material which was not integrated into the environment. No differences was seen between these two groups. Also, the current study was interested in the differences between VR interventions which use SUE or MUE. Once again, no differences were seen between these two groups. The current study also proposed that more recent VR interventions would be more effective than older VR interventions. This was not found, as there was no relationship between the year of the study and VR intervention effectiveness beyond alternative interventions. Lastly, the current study was interested in whether game elements improved VR intervention outcomes. Most results indicated that game elements improved outcomes, further supporting the recent movements in serious games and workplace gamification.

Other research questions were focused on the study design. Studies which contained a no-treatment control group demonstrated larger effects than studies which contained an alternative-treatment control group, and this finding was replicated across all tests of the hypothesis. Additionally, studies which applied the VR intervention in conjunction with another intervention did not demonstrate larger effects than studies which applied the VR intervention alone. Surprisingly, studies which focused on higher-order outcomes, such as learning and behavior, demonstrated larger effect sizes than studies which focused on lower-order outcomes, such as reactions. This result may be due to two possible reasons. First, the vast majority of studies only used learning outcomes to gauge VR intervention effectiveness. Twelve studies

used reactions, 185 used learning, 11 used behaviors, and seven used results. It is possible that the effect sizes for all outcomes other than learning are inaccurate due to their lower use.

Second, when reviewing the studies that used outcomes other than learning, it seems that better developed VR interventions were tested using higher-order outcomes. For instance, if an author was testing the first iteration of their VR intervention, they appear more likely to use reactions as an outcome, whereas they were more likely to use results if they were testing a refined version of their VR intervention. In these instances, the more refined versions are more likely to demonstrate improved effects beyond the early iterations, possibly explaining the surprising results in regards to outcome measurement. Together, several aspects of the study design greatly impact the apparent efficacy of the VR intervention, and authors should carefully consider their study design.

Lastly, the current study was also interested in aspects of the sample. First, it was hypothesized that VR interventions focusing on specialized samples would be more effective than those focused on general samples. This prediction was not supported, and no difference was observed between specialized and general samples. Differences were observed between child/adult samples and workplace/non-workplace samples, with child samples demonstrating greater effects of VR interventions when compared to adult samples and workplace samples demonstrating greater effects of VR interventions when compared to non-workplace samples. While hypotheses were presented towards the potential effectiveness of specialized samples demonstrating greater VR intervention effects, no such hypotheses were presented towards the effectiveness of child or workplace samples. Therefore, further research and theory construction is needed to explain this finding.

Together, these results have great implications for research design, practice, and theory. First, authors should heavily consider their research designs when testing VR interventions. Some of the largest observed effects were between different types of research designs, such as non-treatment and alternative treatment control groups. For authors to truly understand the impact of VR, they should carefully consider the research design within their studies as well as in their reviews of previous literature. Likewise, when reviewing previous studies, authors should remain aware of the differences between research designs and discuss study effects accordingly.

Second, these results may provide direct implications for current popular applications of VR interventions. Within the five primary subgroups, authors are performing extensive research within four. Sixty-one articles investigated cognitive outcomes, sixty five investigated emotional outcomes, twenty investigated physical outcomes, and 31 investigated other outcomes. These results support several practitioners who claim that VR is the future of organizational training, therapy interventions, and physical rehabilitation programs. Alternatively, only four articles investigated VR interventions for social outcome development. This is surprising, as a large number of authors have heavily supported the use of VR to develop the social abilities of individuals with ASD and schizophrenia.

Third, surprising results were discovered in regards to the samples of interest. No differences were observed between specialized and non-specialized samples. While many authors have suggested that the largest benefits of VR interventions may be their direct effect on certain individuals, such as those with ASD or schizophrenia, all individuals may receive the benefits of VR interventions. Alternatively, positive effects were seen for child samples beyond adult samples and workplace samples beyond non-workplace samples. The latter, workplace

samples, may receive benefits from the extra focus placed towards making a successful intervention. When making a VR intervention for the workplace, authors are often forced to consider organizational benefits and profits. When making a VR intervention for non-workplace settings, authors have more of an ability to test reiterations of an intervention until it is successful. Nevertheless, while this assumption is plausible, it is only an assumption. More tests are needed to determine the cause of differential results between workplace and non-workplace samples. In regards to child samples demonstrating more positive VR intervention effects than adult samples, it is possible that children are naturally excited by VR and allocate more efforts to VR interventions than adults; however, no firm suggestions are made for the cause of this result. Once again, more research is needed to definitively understand this cause.

Fourth, certain aspects of the VR system appear to impact VR intervention effectiveness. Particularly, likely the largest developmental focus of modern VR technology companies is the creation of new and immersive display systems. This interest is well warranted, as the meta-analysis demonstrated that these immersive displays are more effective than traditional monitors. Future research should investigate the precise reasons that these displays are more effective. Authors have proposed that presence and immersion may be the cause, but more empirical research is needed.

Limitations

As with all studies, some limitations should be noted. Certain limitations are relevant to meta-analyses in general. To obtain accurate meta-analytic estimates, a large number of studies are often needed. Unfortunately, many of the outcomes were represented by a small number of studies, such as two or three. While nothing can be done to correct for the small number of

existing studies, the current study noted when an effect was represented by a small number of studies and could not be considered representative of the outcome of interest.

Additionally, certain aspects of task-technology fit theories cannot be tested through meta-analyses, as a sufficient number of studies likely do not exist which investigate the aspect of interest. For instance, in accordance to the proposed theory, individuals with worse working memory would likely perform worse on VR interventions. It is unlikely that many authors have tested this notion, and alternative research methods are more appropriate for this research question.

Other limitations are specific to the current meta-analysis. Some authors would criticize the decision to not correct for unreliability. As mentioned, this decision was made for theoretical and practical reasons, and correcting for unreliability may obfuscate the true impact of VR across the outcomes. It is still believed that not correcting for reliability is the correct decision to best understand these results.

Additionally, a comment should be made about the decision to use studies with a relevant control group. If only studies were chosen without a control group, then the results could not be direct inferences about the efficacy of VR interventions to develop outcomes. Instead, these results may only reflect the malleability of a construct, and any intervention would demonstrate similar effects – whether VR or otherwise. When using studies with a control group, the results reflect the efficacy of VR interventions to develop constructs beyond relevant alternative interventions, which draws more accurate inferences towards the efficacy of VR interventions. It is possible, however, that the alternative interventions in certain outcomes were particularly (un)sophisticated when compared to others, thereby altering the apparent efficacy of VR interventions. This is not a large concern for outcomes with a large number of studies, but it

could have affected others with fewer representative studies. Nevertheless, it is believed that any bias from using studies with control groups is less than the bias from solely using studies without a control group.

Relatedly, task-technology fit theories often contain an implicit notion that the effectiveness of a certain technology for a task is compared to some standard set by similar alternatives. In the current study, the standard is different for each outcome and could only be obtained through analyzing relevant comparisons. Given that alternative treatment groups within studies are meant to allow such comparisons, the most appropriate method to test task-technology fit theories are to use alternative treatment groups.

Conclusion

The current study noted that current theories of task-technology fit are insufficient to understand the complexity of many applications of technology, and the theories are largely not falsifiable. For this reason, a new theory of task-technology fit was presented, entitled intervention-technology fit theory, which speculates that the effectiveness of a technology for intervention purposes is reliant on the amount of working memory that it requires and the amount of working memory required to develop the outcome of interest. To test this theory, a meta-analysis of VR interventions was performed with the goal of understanding the differential effectiveness of VR across outcomes of interest. The results supported intervention-technology fit theory for cognitive outcomes, but it demonstrated lackluster predictive ability for other outcomes of interest. Therefore, the proposed theory should be reconsidered, and possibly rewritten, to only apply to an educational or workplace setting where some form of knowledge acquisition is desired.

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Table 1c – Predicted Effects Across Outcomes

Primary Applications	First-Level Sub-dimensions	Second-Level Sub-dimensions	Predicated Effect of VR	Rank of Predicted VR Effectiveness Across Applications	Rank of Predicted VR Effectiveness within Sub-dimensions	
Cognitive Outcomes			Effective	4		
		Declarative Knowledge	Ineffective		3	
		Knowledge Organization	Ineffective		3	
		Cognitive Strategies	Effective		2	
		Skill-Based Outcomes	Effective		1	
Social Outcomes			Effective	3		
		Basic Social Outcomes	Ineffective		2	
		Integrated Social Outcomes	Effective		1	
Emotional Outcomes	Emotional and Motivational States		Effective	2		
			Effective		1	
		Mood	Effective		1	
		Emotions	Effective		1	
		Pain	Effective		1	
		Craving	Effective		1	
		Self-Perceptions	Effective		1	
		Attitudes	Effective		1	
		Motivation	Effective		1	
		Therapy Outcomes	Phobia		Effective	1
			PTSD		Effective	1
			Emotional Intelligence		Effective	2
			Perceiving Emotions		Effective	2
			Facilitating Thought		Effective	2
			Understanding Emotions		Effective	2
	Managing Emotions	Effective	2			
Physical Outcomes			Effective	1		
		Muscle Strength	Effective		1	
		Psychomotor Skills	Effective		1	
Other			Unknown	N/A		
		Biological Markers	Effective		N/A	
		Spatial Knowledge	Effective		1	
		Fluid Intelligence	Effective		1	
		Other	Unknown		N/A	

Table 2c – Impact of Technology

	Working Memory Requirement	Fidelity	Entertainment
Software			
Simulation	Low	Low	Low
Virtual Reality	High	High	High
Serious Game	Varies	Varies	High
Hardware – Output			
Monitor	Low	Low	Low
Immersive Display	High	High	High
Hardware – Input			
Keyboard & Mouse	Low	Low	Low
Specialized Input	High	High	High

Table 3c – Meta-Analysis Results with All Studies Included (Fixed Effects)

Primary Applications	# of Articles	k	n	d	S.E.	95% Confidence Interval	Hedges g	Z-value	p
All Outcomes Together	188	1246	8544	.306	.023	.262 - .350	.301	13.595	<.001
Cognitive Outcomes	67	242	3302	.284	.036	.215 - .354	.280	7.975	<.001
Declarative Knowledge	22	61	1929	.176	.044	.089 - .262	.174	3.970	<.001
Knowledge Organization	1	1	58	1.765	.310	1.158 - 2.372	1.741	5.702	<.001
Cognitive Strategies	0								
Skill-Based Outcomes	42	143	1456	.543	.061	.423 - .662	.526	8.910	<.001
Wayfinding	8	37	289	-.563	.129	-.816 - -.311	-.545	-4.378	<.001
Social Outcomes	4	10	132	.132	.178	-.217 - .482	.132	0.743	>.10
Basic Social Outcomes	0								
Integrated Social Outcomes	4	10	132	.132	.178	-.217 - .482	.132	0.743	>.10
Emotional Outcomes	85	567	3632	.263	.034	.196 - .330	.258	7.668	<.001
Emotional and Motivational States	61	228	2755	.342	.040	.264 - .420	.334	8.640	<.001
Mood	33	107	1566	.288	.052	.186 - .389	.280	5.540	<.001
Emotions	18	36	650	.346	.081	.188 - .505	.335	4.274	<.001
Pain	14	48	920	.485	.066	.356 - .614	.478	7.376	<.001
Craving	2	11	76	.464	.239	-.005 - .933	.451	1.941	<.10
Self-Perceptions	6	18	255	.289	.127	.040 - .539	.286	2.273	<.05
Attitudes	2	4	180	.296	.150	-.002 - .590	.293	1.972	<.05
Motivation	3	4	85	-.508	.223	-.945 - .071	-.486	-2.277	<.05
Therapy Outcomes	43	331	1435	.040	.055	-.068 - .148	.045	0.728	>.10
Phobia	37	312	1355	.008	.057	-.103 - .120	.013	.149	>.10
PTSD	6	19	80	.578	.234	.120 - 1.037	.536	2.472	<.05
Emotional Intelligence	3	8	157	.319	.167	-.008 - .646	.314	1.912	<.10
Percceiving Emotions	0								
Facilitating Thought	0								
Understanding Emotions	0								
Managing Emotions	3	8	157	.319	.167	-.008 - .646	.314	1.912	<.10
Physical Outcomes	22	204	882	.383	.071	.244 - .523	.375	5.391	<.001
Muscle Strength	10	36	479	.473	.095	.286 - .660	.463	4.964	<.001
Psychomotor Skills	19	168	755	.374	.076	.224 - .524	.366	4.890	<.001
Other	45	223	2282	.299	.043	.215 - .384	.297	6.927	<.001
Biological Markers	15	65	481	.101	.090	-.075 - .278	.102	1.123	>.10
Spatial Abilities	4	8	557	.324	.088	.153 - .496	.325	3.705	<.001
Other Cognitive Abilities	9	69	275	.735	.129	.483 - .987	.714	5.711	<.001
Other	17	81	971	.276	.067	.144 - .408	.275	4.108	<.001

Table 4c – Meta-Analysis Results with All Studies Included (Random Effects)

Primary Applications	# of Articles	k	n	d	S.E.	95% Confidence Interval	Hedges g	Z-value	p
All Outcomes Together	188	1246	8544	.390	.051	.289 - .490	.380	7.610	<.001
Cognitive Outcomes	67	242	3302	.459	.105	.253 - .665	.447	4.364	<.001
Declarative Knowledge	22	61	1929	.225	.136	-.041 - .490	.221	1.659	<.10
Knowledge Organization	1	1	58	1.765	.310	1.158 - 2.372	1.741	5.702	<.001
Cognitive Strategies	0								
Skill-Based Outcomes	42	143	1456	.684	.157	.376 - .993	.660	4.347	<.001
Wayfinding	8	37	289	-.428	.343	-1.100 - .244	-.413	-1.249	>.10
Social Outcomes	4	10	132	.130	.196	-.254 - .515	.130	.665	>.10
Basic Social Outcomes	0								
Integrated Social Outcomes	4	10	132	.130	.196	-.254 - .515	.130	.665	>.10
Emotional Outcomes	85	567	3632	.263	.065	.135 - .391	.257	4.024	<.001
Emotional and Motivational States	61	228	2755	.301	.077	.150 - .452	.293	3.915	<.001
Mood	33	107	1566	.246	.117	.016 - .475	.239	2.097	<.05
Emotions	18	36	650	.291	.141	.014 - .568	.281	2.058	<.05
Pain	14	48	920	.551	.139	.279 - .824	.539	3.964	<.001
Craving	2	11	76	.381	.636	-.867 - 1.628	.375	.598	<.10
Self-Perceptions	6	18	255	.302	.154	.000 - .603	.297	1.960	<.05
Attitudes	2	4	180	.296	.150	.002 - .590	.293	1.972	<.05
Motivation	3	4	85	-.467	.277	-1.011 - .076	-.444	-1.685	<.10
Therapy Outcomes	43	331	1435	.146	.087	-.025 - .316	.144	1.672	<.10
Phobia	37	312	1355	.107	.093	-.075 - .289	.107	1.149	>.10
PTSD	6	19	80	.578	.234	.120 - 1.037	.536	2.472	<.05
Emotional Intelligence	3	8	157	.319	.167	-.008 - .646	.314	1.912	<.10
Perceiving Emotions	0								
Facilitating Thought	0								
Understanding Emotions	0								
Managing Emotions	3	8	157	.319	.167	-.008 - .646	.314	1.912	<.10
Physical Outcomes	22	204	882	.369	.095	.183 - .554	.361	3.898	<.001
Muscle Strength	10	36	479	.458	.106	.251 - .665	.446	4.340	<.001
Psychomotor Skills	19	168	755	.354	.111	.135 - .572	.347	3.174	<.01
Other	45	223	2282	.481	.103	.279 - .683	.469	4.669	<.001
Biological Markers	15	65	481	.192	.140	-.082 - .465	.186	1.373	>.10
Spatial Abilities	4	8	557	1.118	.491	.156 - 2.080	1.098	2.277	<.05
Other Cognitive Abilities	9	69	275	.733	.137	.465 - 1.000	.712	5.367	<.001
Other	17	81	971	.452	.186	.087 - .817	.442	2.426	<.05

Table 5c – Meta-Analysis Results with Only Alternative Treatment Groups (Random Effects)

Primary Applications	# of Articles	k	n	d	S.E.	95% Confidence Interval	Hedges g	Z-value	p
All Outcomes Together	154	1043	7109	.309	.055	.200 - .417	.300	5.595	<.001
Cognitive Outcomes	61	212	3155	.367	.103	.165 - .568	.357	3.565	<.001
Declarative Knowledge	21	53	1845	.125	.109	-.089 - .338	.122	1.146	>.10
Knowledge Organization	1	1	58	1.765	.310	1.158 - 2.372	1.741	5.702	<.001
Cognitive Strategies		0							
Skill-Based Outcomes	38	136	1292	.643	.170	.310 - .975	.620	3.788	<.001
Wayfinding	7	22	266	-.592	.348	-1.275 - .090	-.570	-1.702	<.10
Social Outcomes	3	5	110	.143	.283	-.411 - .697	.143	.505	>.10
Basic Social Outcomes		0							
Integrated Social Outcomes	3	5	110	.143	.283	-.411 - .697	.143	.505	>.10
Emotional Outcomes	65	485	2854	.171	.072	.030 - .312	.167	2.374	<.05
Emotional and Motivational States	43	182	1973	.239	.093	.057 - .421	.232	2.572	<.05
Mood	26	94	1365	.179	.136	-.088 - .446	.175	1.316	>.10
Emotions	16	33	616	.242	.151	-.054 - .539	.235	1.603	>.10
Pain	8	23	622	.324	.162	.006 - .641	.319	1.996	<.05
Craving	2	11	76	.381	.636	-.867 - 1.628	.375	.598	<.10
Self-Perceptions	4	12	159	.461	.220	.030 - .892	.452	2.097	<.05
Attitudes		0							
Motivation	1	2	31	-.284	.364	-.998 - .430	-.277	-.780	>.10
Therapy Outcomes	38	295	1342	-.023	.057	-.134 - .088	-.019	-.404	>.10
Phobia	33	286	1280	-.004	.081	-.163 - .156	-.003	-.043	>.10
PTSD	5	17	62	.581	.266	.061 - 1.102	.535	2.188	<.05
Emotional Intelligence	2	7	146	.308	.173	-.032 - .648	.304	1.776	<.10
Perceiving Emotions		0							
Facilitating Thought		0							
Understanding Emotions		0							
Managing Emotions	2	7	146	.308	.173	-.032 - .648	.304	1.776	<.10
Physical Outcomes	20	178	757	.340	.102	.141 - .540	.333	3.343	<.001
Muscle Strength	9	30	386	.412	.121	.174 - .649	.401	3.400	<.001
Psychomotor Skills	17	148	630	.307	.116	.079 - .535	.301	2.637	<.01
Other	31	163	1698	.449	.134	.187 - .710	.438	3.359	<.001
Biological Markers	10	50	346	-.043	.115	-.267 - .182	-.040	-.374	>.10
Spatial Abilities	4	8	557	1.118	.491	.156 - 2.080	1.098	2.277	<.05
Other Cognitive Abilities	8	52	238	.752	.157	.444 - 1.060	.729	4.780	<.001
Other	9	53	558	.478	.321	-.150 - 1.106	.469	1.491	>.10

Table 6c – Effect of Moderator Variables on VR Effectiveness (Random Effects)

Variable	Effect Size (Confidence Interval)			
	No Treatment	Alternative Treatment		
1.) Type of Control Group	.696 (.480 - .912)	.309 (.200 - .417)		
2.) Level of Outcome	Reactions	Learning	Behaviors	Results
	-.249 (-.732 - .235)	.386 (.285 - .488)	.754 (.162 - 1.345)	.161 (-.200 - .521)
3.) Type of Output	Standard	HMD	Other	
	.297 (.180 - .414)	.450 (.272 - .628)	.572 (.049 - 1.094)	
4.) Type of Input	Standard	Specialized		
	.362 (.237 - .487)	.435 (.275 - .595)		
5.) Integration of Material	Not Integrated	Integrated		
	.566 (.124 - 1.009)	.381 (.277 - .485)		
6.) Game Elements	Not Included	Included		
	.325 (.212 - .439)	.623 (.427 - .819)		
7.) Number of Users	Single User Environment	Multi User Environment		
	.393 (.286 - .500)	.366 (.061 - .670)		
8.) Other Treatment	No Other Treatment	Other Treatment Applied		
	.428 (.272 - .584)	.352 (.224 - .480)		
9.) Specialized Sample	General Sample	Specialized Sample		
	.444 (.274 - .613)	.344 (.227 - .461)		
10.) Workplace Intervention	Not in Workplace	In Workplace		
	.344 (.245 - .443)	.691 (.296 - 1.087)		
11.) Child Sample	Not Child Sample	Child Sample		
	.326 (.217 - .434)	.679 (.430 - .928)		

Table 7c – Meta-Regression of Each Moderator Tested Individually

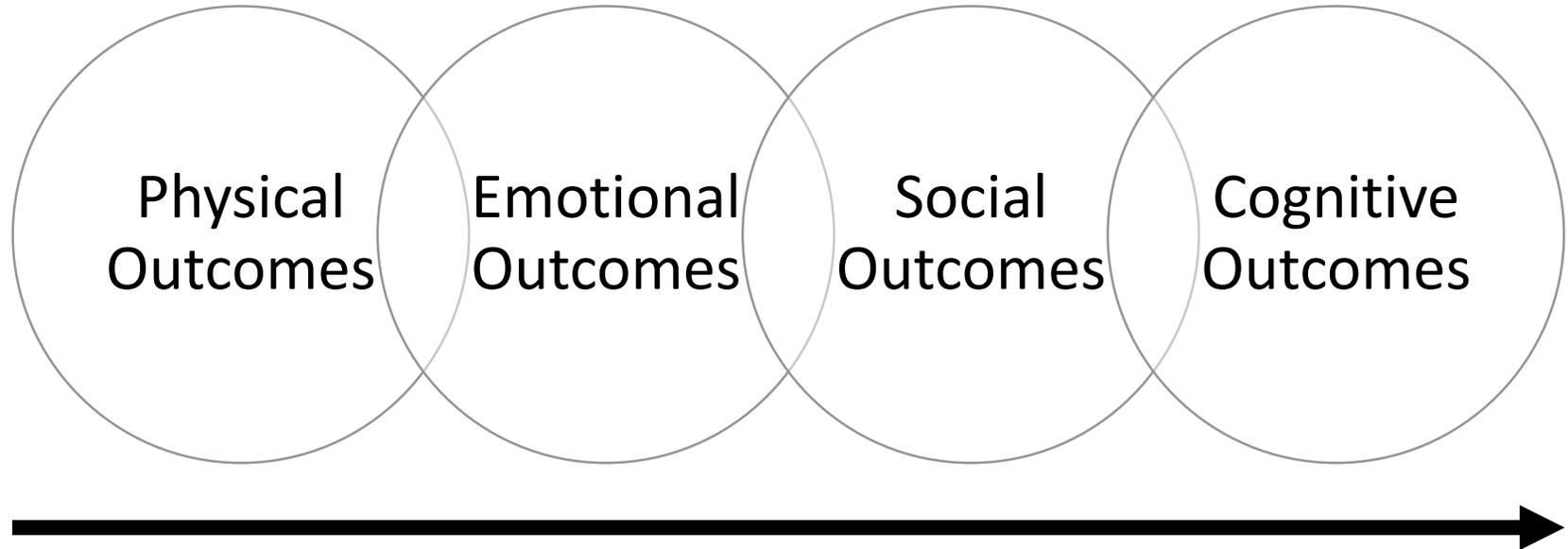
Variable	Coefficient	SE	CI	Z
1.) Type of Control Group	-.451***	.131	-.701 - -.195	-3.45
2.) Level of Outcome	.049	.451	-.835 - .933	.11
3a.) Type of Output (Standard – HMD)	.133	.110	-.083 - .348	1.21
3b.) Type of Output (Standard – Specialized)	.274	.200	-.119 - .666	1.37
4.) Type of Input	.102	.110	-.114 - .319	.90
5.) Integration of Material	-.193	.273	-.658 - .273	-.81
6.) Game Elements	.301*	.123	.066 - .549	2.49
7.) Number of Users	-.017	.188	-.387 - .353	-.09
8.) Other Treatment	-.091	.104	-.295 - .113	-.88
9.) Specialized Sample	-.061	.104	-.265 - .143	-.59
10.) Workplace Intervention	.277	.144	-.006 - .560	1.92
11.) Child Sample	.358**	.138	.087 - .629	2.59
12.) Year	.008	.011	-.0143 - .030	.69

Table 8c – Meta-Regression of Each Moderator Variable Tested Together

Variable	Coefficient	SE	CI	Z
1.) Type of Control Group	-.476**	.151	-.772 - -.180	-3.16
2.) Level of Outcome	-.172	.470	-1.093 - .749	-.37
3a.) Type of Output (Standard – HMD)	.335*	.142	.056 - .614	2.35
3b.) Type of Output (Standard – Specialized)	.446*	.220	.016 - .877	2.03
4.) Type of Input	.060	.143	-.220 - .341	.42
5.) Integration of Material	-.315	.261	-.827 - .197	-1.21
6.) Game Elements	.261	.150	-.053 - .575	1.63
7.) Number of Users	.107	.230	-.343 - .557	.47
8.) Other Treatment	-.196	.125	-.441 - .050	-1.56
9.) Specialized Sample	.078	.147	-.211 - .367	.053
10.) Workplace Intervention	.704***	.209	.294 – 1.114	3.37
11.) Child Sample	.260	.159	-.053 - .572	1.63
12.) Year	.023	.015	-.007 - .052	1.51

Figure 1c – Visual Representation of Outcomes of Interest

Amount of Working Memory Required to Improve Outcome



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Scholarly Achievements

As of November 2015, Matt C. Howard has published 10 articles in eight different academic journals, eight as the first-author and two as the second-author, and he has several other manuscripts with Revise and Resubmit decisions, under review, and in progress. He has presented 24 different conference papers at 10 different conferences, again with several other conference presentations under review. He is a current reviewer for five different journals and two conferences, and he has received several internal grants during his time at Penn State – for which he is very thankful. Also, he has taught an undergraduate course on leadership and a psychological research methods and statistics lab section, and he has served as a teaching assistant for many other interesting classes. Lastly, he has successfully completed several consulting projects. In conjunction with the I/O Department’s practicum program at Penn State, he completed paid projects with Oakley, PSEA, DDI, Johnson & Johnson, and several other companies. Working independently, he has also completed paid projects with Universium and Northeastern University. For further information, which includes a current contact email address, please visit MattCHoward.com.