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Identifying the effects of human factors and training methods on a weld training program

by

Alex Preston Byrd

A dissertation submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Major: Agricultural Education

Program of Study Committee:
Ryan G. Anderson, Major Professor
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Iowa State University
Ames, Iowa
2014

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DEDICATION

This dissertation is dedicated to my grandmother and my great-uncle. For always being there to lend an ear and teaching me many things about life. If it were not for their inspiration to pursue my dreams this dissertation would not have been possible.

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ABSTRACT

The purpose of this research was to enhance the welding training programs in technical colleges, post-secondary institutions, and industry to prepare certified welders. This dissertation contains three papers: (1) a study describing the ability of dexterity to predict future performance in beginning welders, (2) a study identifying the ability of virtual reality welding simulation to reduce the amount of anxiety experienced by beginning welders when completing test welds, and (3) a descriptive study assessing the ability of virtual reality welding simulations to evaluate seasoned welders.

With a high demand for certified welders, training programs need efficient methods of preparing certified welders. It was concluded that all welding training participants experienced anxiety during test welds. In addition, the more a participant used the virtual reality welding simulator, the more the participant experienced anxiety during completion of test welds. This implies that a virtual reality integrated welding training program will reduce anxiety better than a 100% virtual reality training program.

The use of virtual reality welding simulations may lead to heightened interest in welding among members of the gaming generation, which could lead to influx of individuals wanting to become welders. With increased numbers of potential welding trainees also comes an increase in cost of training (Mavrikios, Karabatsou, Fragos, & Chryssolouris, 2006). This increase in training cost has led welding training programs to look for criteria by which to select trainees. Dexterity has been documented as a needed skill among certified welders (Giachino & Weeks, 1985). Using the Complete

Minnesota Dexterity Test, dexterity could predict future performance for simple welds (2F – horizontal fillet weld and 1G – flat groove weld). This implies that training programs that prepare trainees to become certified in the 2F and 1G weld types can use dexterity as a criterion for selecting potential trainees.

Industry must also create a more efficient method of evaluating seasoned welders. The third article of the dissertation concluded that virtual reality welding simulations can distinguish between novice and seasoned welders. The conclusions from the three articles can be used to modify and improve welding training programs in technical colleges, four-year institutions, and industry to prepare certified welders.

CHAPTER 1: GENERAL INTRODUCTION

In this chapter, the background for this study is established, followed by a statement of the problem being studied. The purpose and objectives of the study are also provided. The organization of this dissertation is described along with assumptions and limitations of the study. Finally, key terms used in the study are defined.

Background

Welding has continued to grow in importance since the Industrial Revolution (White, Reiners, Prachyabrued, Borst, & Chambers, 2010). "Thanks to a global boom in industrial manufacturing, skilled welders are in greater demand than ever" (Brat, 2006, p. 1). Today's construction practices demands high quality workers with the ability to join metals when creating most structures; this demand has made welding a highly sought after trade (White et al., 2010). According to the U.S. Department of Labor Bureau of Labor Statistics (2013), the number of jobs for welders is expected to increase 15% between 2010 and 2020, which is more than the average for all other occupations reported. Therefore, it is important to train qualified welders (Byrd & Anderson, 2012). With such a great need for these skilled laborers, finding quicker and more efficient ways to train new welders while maintaining a high level of quality has become a necessity (Byrd & Anderson, 2012).

Virtual Reality

Since welding's inception, training programs have been continually modified to better prepare welders. Currently, the use of integrating virtual welding simulations has become popular to training programs (Mavrikios, Karabatsou, Fragos, & Chryssolouris,

2006). Virtual reality simulations have been used to train pilots, surgeons, and welders (Byrd & Anderson, 2012). One study looked at integrating virtual reality training methods into a welding program to determine the transferability of skills from virtual reality simulations to actual welding work (Stone, Watts, & Zhong, 2011). Stone et al. (2011) found that those who trained with a virtual reality-integrated program had superior training outcomes than those who trained traditionally. Other studies have shown that the integration of virtual reality simulation had a positive effect on trainees' ability to learn the skills necessary for their profession (Seymour et al., 2002; Stone et al., 2011).

Anxiety

One aspect of welding training programs that previous studies have not examined is the cognitive obstacles trainees encounter during training programs (Byrd & Anderson, 2012). Mavrikios, Karabatsou, Fragos, and Chryssolouris (2006) postulated that hands-on welding practice can be dangerous, which may lead to anxiety. Wallach, Safir, and Bar-Zvi (2009) stated that a social phobia, such as anxiety, can affect school performance, ability to create social networks, and work performance. Anxiety in the workplace has steadily increased, which can impair attention and motor coordination (Haslam, Atkinson, Brown, & Haslam, 2005). Therefore, finding a training method or strategy to reduce the effect that anxiety has on trainees may reduce the amount of time needed to train qualified welders (Byrd & Anderson, 2012). Powers and Emmelkamp (2008) found that virtual reality had a large effect on overcoming anxiety disorders. The

question is, would virtual reality be used to overcome anxiety, can virtual reality reduce anxiety in beginning welders in welding training programs?

Dexterity

Many occupations have tried to predict students' ability and future performance before admitting them into a training program. The tests typically used to predict future performance analyze cognitive ability, psychomotor skills, and perception (Brown & Ghiselli, 1951; Ganksy et al., 2004; Gettman et al., 2003; Hitchings & Moore, 1991; Levine, Spector, Menon, & Narayanan, 1996). Gansky et al. (2004) found that manual dexterity predicted the future performance of dental students in subsequent preclinical restorative courses. According to Campbell (2007), dexterity is the skill of using one's hands and body, which addresses the quickness or the coordination of sight and other senses with muscles. Dexterity has been validated in predicting performance in jobs that require routine assembly and packaging as opposed to jobs that require higher order abilities (Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969).

The welding literature has indicated that welders need manual dexterity, good eyesight, and good hand-eye coordination (Giachino & Weeks, 1985). Giachino and Weeks (1985) suggested that welders needed to be able to concentrate on detailed work, be free of disabilities that would prevent working in awkward positions, and be able to lift up to 100 pounds. To evaluate various criteria, welding training programs have employed tests that evaluate mechanical ability, ability to judge shapes and sizes, ability to remember designs, and manual dexterity when selecting apprentices (Fleming, 1937), but have not extensively evaluated the predictive ability of individual factors for future

performance. If a dexterity test that replicates the psychomotor skills necessary for welding were implemented in a training program, would dexterity be able to predict the future performance of the trainees?

Assessing Existing Skill via Virtual Reality Simulations

Trainees have shown the ability to learn basic psychomotor skills necessary to perform job-related tasks within technical fields through the integration of virtual environments (Manca, 2013). According to Manca (2013), training with virtual environments increased memory retention and reduced human error in trainees; this is because the trainees can perfect their skills and gain a deeper understanding of the work environment before actually being put into a real-life job situation. Virtual reality environments work well when trainees are learning skills for the first time, but can they be used to evaluate a person's ability after training as a means of continual education within technical fields?

The virtual reality simulation offers potential as an evaluation tool because every interaction within the simulated environment can be monitored and recorded to facilitate assessment (Mantovani, Castelnuovo, Gaggioli, & Riva, 2003). According to Gaba (2004), simulations can be used with both young and old. Virtual reality simulations have been focused primarily to train novices and interns, but currently virtual reality has been utilized for continuous training and evaluation of experienced workers (Gaba, 2004). Gaba (2004) stated that aviation simulations are applied regularly to practicing clinicians individually and in groups regardless of their seniority. Cosman, Cregan, Martin, and Cartmill (2002) stated that virtual reality simulations could play a role in

continuing medical education and recertification. Within the welding industry, can virtual reality simulations be used as valid instruments for evaluating seasoned welders?

Problem Statement

The current shortage and predicted increased demand for skilled welders now and in the near future, has created the need for educators to revise programs to meet the evolving needs of the industry (Pate, Warnick, & Meyers, 2012). Altering the learning environment in which welders learn the basic psychomotor skills of welding has been accomplished with the incorporation of virtual welding simulations (Byrd & Anderson, 2012). However, no research has ascertained the effect of virtual welding simulations on a welder's anxiety level. Dexterity is another essential trait for a welder, but no research has empirically tested the effect of dexterity on weld quality. As individuals progress from novice to seasoned welder, how are evaluations of performance monitored? Research has not yet ascertained the ability and usefulness of virtual reality simulations for continuing education and evaluation of seasoned welders.

Purpose and Objectives

The purpose of this study was to evaluate if dexterity can predict future performance, the effect of virtual reality simulations on anxiety in a welding program, and the ability of virtual reality simulations to assess existing skills of a welder. This study is also meant to describe the relationships among these three purposes and their effect on a welding training program. Thus, the following objectives were used to guide this study:

1. Examine dexterity's utility in predicting the ability of beginning welders to become certified.
2. Explore the relationship between integrating a virtual reality welding simulator and its effects on anxiety when learning to weld.
3. Describe the ability of a virtual reality welding simulator as an evaluation tool of existing skill in welders.

Dissertation Organization

This dissertation is organized into six chapters. Chapter one is a general introduction to the study. Chapter two is a literature review of the guiding theoretical framework, anxiety, dexterity, and virtual reality simulations used in welding training programs. Chapter three is a research article that examines the ability of dexterity to be used as an indicator of future performance in beginning welders. The fourth chapter is a research article that reports the effects of incorporating virtual reality on a welder's anxiety during a welding training program. Chapter five is a research article that reports how virtual reality can be used in the assessment of existing skills of welders. Chapter six presents general conclusions and recommendations based on the findings.

Assumptions

Several assumptions were made during this study:

- It was assumed that random assignment of treatment groups would control for extraneous circumstances such as some participants having more knowledge of welding theory.

- It was also assumed that the maturity level of the participants would not affect their ability to learn how to weld correctly.
- The conditions, in which the participants worked, mainly the temperature, were expected to affect their physical stamina and mental ability to weld, which was factored into the design. The temperature during the research study averaged in the low 90's. To keep the virtual reality simulators working correctly an air-conditioned room was built to control temperature. This allowed participants to be in an air-conditioned environment while immersed in virtual reality. However, learning with the traditional welding methods participants were exposed to the heat. All participants did complete test welds outside of the air-conditioned environment. Differences were accounted for when completing statistical analyses.
- It was assumed that the participants would follow the instruction to not consume caffeine before arriving at the experiment site; caffeine would affect the participants' mental capacity.

Limitations

Several limitations of this study were noted:

- This study took place during summer session at Iowa State University. Initially, industry representatives were supposed to recruit individuals for this study, but due to the lack of support participant numbers were limited for each segment of the study, although the minimum requirements were met.

- The instruction given in the traditional welding portion of training was overseen by a certified welding instructor (CWI), researchers were not involved in the traditional training methods.
- The testing protocol had to be modified because of malfunctions with the virtual welding simulation equipment. One virtual reality simulator had to be serviced and took two hours to complete. This required researchers to rotate participants differently between the virtual reality environment to the traditional training method during that time period. Participants did however maintain the proper time protocols according to their training group.
- Testing for two segments had to be conducted twice, at the participants' willingness, due to the wrong size base material provided for the certification weldment process. Participants were contacted and were given the option to retest with the correct base material within seven days.

Definitions

Key terms used in the study are listed below with their contextual definitions.

1. **1G:** A weld made on a groove joint in the flat welding position (Bowditch, Bowditch, & Bowditch, 2010).
2. **2F:** A fillet weld made in the horizontal position (Bowditch et al., 2010).
3. **3F:** A fillet weld made in the vertical position (Bowditch et al., 2010).
4. **3G:** A weld made on a groove joint in the vertical position (Bowditch et al., 2010).

5. **Anxiety:** A feeling of uneasy suspense; the tense, unsettling anticipation of a threatening but vague event; a negative effect (Rachman, 2004).
6. **Certified welding instructor (CWI):** A person qualified to determine whether a weldment meets the acceptance criteria of a specific code or standard; capitalized, a certification given by the American Welding Society (American Welding Society, 2007).
7. **Dexterity:** The skill of using one's hands and body, which addresses the quickness or the coordination of sight and other senses with muscles (Campbell, 2007).
8. **Electrode:** Filler material that is used in many electrical arc welding processes where the electrical arc is produced, melting the electrode and becoming part of the weld (Bowditch et al., 2010).
9. **Fillet weld:** A weld performed at the inside corner of two pieces of material that creates an approximately right (90°) angle (Bowditch et al., 2010).
10. **Fine motor skills:** The use of smaller muscles to move within a limited area to perform precise and accurate movements (Cratty, 1973; Singer, 1980, 1982).
11. **Gas metal arc welding (GMAW):** An electrical arc welding process that uses a continuously fed consumable electrode and a shielding gas, also referred to as metal inert gas welding (Bowditch et al., 2010).
12. **Groove weld:** A weld created by fusing two pieces of material that has had material removed for a V, U, or J profile at the edges to be joined (Bowditch et al., 2010).

13. **Gross motor skills:** Skills related to use of the whole body and larger muscles to perform large movements with less precision (Cratty, 1973; Singer, 1980, 1982).
14. **Personal protective equipment (PPE):** Safety equipment worn for protection against safety hazards in the workplace (Koel, Mazur, Moniz, & Radcliff, 2013). For welding, the PPE consists of safety glasses, welding helmet, gauntlet gloves, welding jacket, long sleeve shirt, pants, and closed-toed shoes.
15. **Shielding gas:** A gas, usually inert, which is used to shield the weld area and prevent contamination from the air (Bowditch et al., 2010).
16. **Shielded metal arc welding (SMAW):** An electrical arc welding process that heats a base material to fusion temperature with an electric arc created between a covered electrode and base material (Bowditch et al., 2010).
17. **Virtual reality (VR):** An artificial environment experienced through sensory stimuli provided by a computer and in which a person's actions partially determine what happens in the environment (Virtual Reality, n.d.).
18. **VRTEX 360®:** The virtual reality welding simulation machine marketed by Lincoln Electric that puts students into a simulated welding environment to learn how to weld (Lincoln Electric, 2013).
19. **Weld:** The blending of two or more metals or nonmetals by heating them until they melt and flow together (Bowditch et al., 2010).
20. **Welding:** The process of making a weld on a joint (Bowditch et al., 2010).
21. **Weldment:** An assembly of parts joined by welding (Bowditch et al., 2010).

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CHAPTER 2: LITERATURE REVIEW

Introduction

Welding training is an essential part of the welding industry as it is the gateway to becoming a certified welder. Successful completion of a welding training program provides an individual with the tools and skills necessary to become an integral part of the welding workforce. This chapter will set the stage for the three journal articles that follow by providing an outline of the overarching theoretical framework of this dissertation. The following sections will then provide background on dexterity, anxiety, and evaluating the existing skills of current welders.

Theoretical Framework

The theory of individual differences in task and contextual performance guided this study (Motowidlo, Borman, & Schmit, 1997). Motowidlo et al. (1997) described job performance as behavioral, episodic, evaluative, and multidimensional. Job performance has been further defined as an aggregated value of behavioral episodes that add value to an organization (Motowidlo et al., 1997). The theory of individual differences uses the distinction between task and contextual performance to identify and define behavioral episodes to describe performance (Motowidlo et al., 1997). In the welding industry, welds are completed one at a time, which would be a behavioral episode. The aggregate of the behavioral episodes would be the completed welded product. For this study, objective one will be addressed by examining cognitive ability, dexterity, and how that affects task skill and task performance. Objective two will examine personality variables, anxiety, and how anxiety affects task skill, habits, and

performance. Objective three will be examining existing welding skill or task skill and task performance.

Motowidlo et al. (1997) posited that behavior, performance, and results differ in nature; behavior is defined as what people do at work. Performance is a behavior, but performance has an evaluative element that can have a positive or negative effect on an individual or organization's efficiency; the result is either a state or a condition that contributes or detracts from the organization's goals (Motowidlo et al., 1997). Individuals' contributions to an organization come through their results; hence, results are considered in evaluating an individual's performance (Motowidlo et al., 1997). In the welding industry, the performance that is being evaluated is the ability to accurately join two pieces of metal as described on a work order.

Performance behavior is also described as episodic; this relates to the periods during the workday in which an individual performs a task that contributes to the organization's goals. During the workday, a welder is not constantly welding. Between episodes of welding, the welder will be cleaning and preparing the material for the next weld. The level of contribution to organizational goals from performance behaviors varies in value, from a slight impact to an extreme impact in either a positive or negative direction (Motowidlo et al., 1997). A welder that performs well will create a positive impact on the organization, whereas a welder that performs poorly will create a negative impact. The multidimensionality of performance means that other characteristics of an individual, such as personality and intelligence, play a role in that individual's

performance behavior; behavioral performance can be divided into two types, task and contextual (Motowidlo et al., 1997). See Figure 2.1.

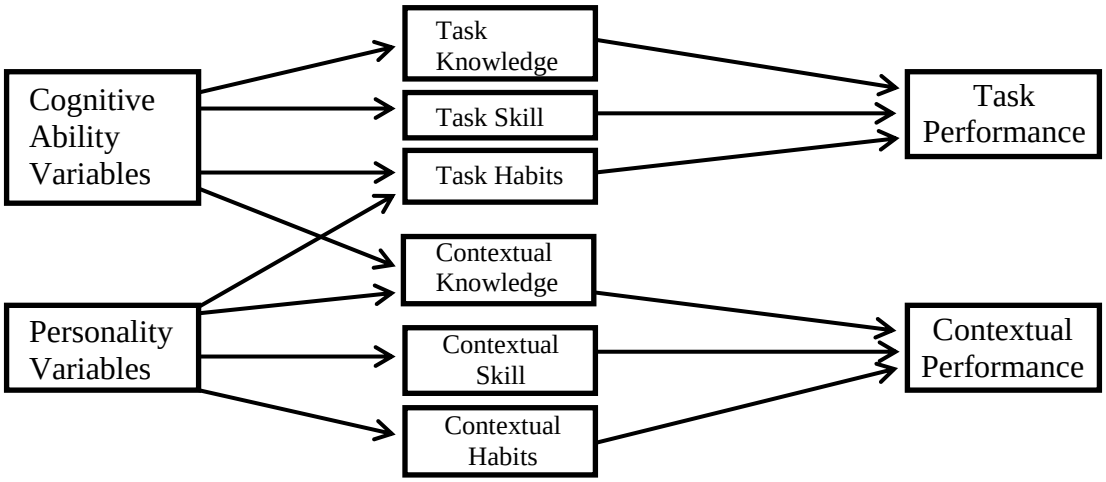

Figure 2.1. A theory of individual differences in task and contextual performance. Adapted from "A theory of Individual Differences in Task and Contextual Performance," by S. Motowidlo, W. Borman, and M. Schmit, 1997, *Human Performance, 10*(2), p. 79. Copyright 1997 by Lawrence Erlbaum Associates, Inc.

Task Performance

Task performance comprises two types of tasks. The first involves the transformation of raw materials into a finished product or service (Motowidlo et al., 1997). Welders that transform raw materials would be those who work on assembly lines fabricating parts or whole products. The second type involves service and maintenance of the technical core by helping to restock raw materials, move products, plan, and supervise or coordinate the first type of task performance. Welders that work at repairing faulty production welds fall into this category, so that the welders involved with the transformation of raw materials can continue production. Therefore, task

performance directly relates to an organization's technical core by creating products or maintaining and servicing the technical core (Motowidlo et al., 1997).

Contextual Performance

Contextual performance maintains the broader organizational, social, and psychological environmental goals in which the technical core operates (Motowidlo et al., 1997). Contextual performance includes activities such as helping and cooperating with others, following rules and procedures, abiding by organizational objectives, showing enthusiasm, and volunteering for tasks outside one's normal job (Motowidlo et al., 1997). Contextual performance deals with personality, morals, and beliefs within a person and how they affect the social and psychological climate within an organization (Motowidlo et al., 1997). In the welding industry, welders may work individually or in groups to assemble products. The ability of the welders to cooperate with each other can hinder the welders' capability to assemble products efficiently.

Individual Differences in Task and Contextual Performance

Task and contextual performance uses individual characteristics as antecedents of performance (Motowidlo et al., 1997). The theory of individual differences in task and contextual performance begins with two groups of basic tendencies: cognitive ability and personality (Motowidlo et al., 1997). Prior learning experiences combined with basic tendencies lead to variability in a person's character. The variability in character determines how the individual adapts to situations and how the adaptation affects the individual's job performance (Motowidlo et al., 1997). Intervening variables that can change due to a person's basic tendencies include knowledge, skills, and work habits

(Motowidlo et al., 1997). The individuals that choose to become welders come from various backgrounds with different experiences and values. Those individuals who are exposed to welding at a young age may know more than individuals that enter a welding training program with no prior experience.

Knowledge

Task knowledge, skill, and habits affect task performance by increasing the number of people's behavioral episodes that positively contribute to an organization's technical core (Motowidlo et al., 1997). Motowidlo et al. (1997) suggested that task knowledge is largely affected by a person's cognitive ability, which allows for a higher rate of retention and mastery of procedures, principles, and facts. Industry welders that are able to retain the procedural knowledge of setting up a weldment and a welding machine correctly may be more apt to produce increased numbers of positive behavioral episodes. Contextual knowledge, skill, and habits increase the likelihood that people will have behavioral episodes that positively affect the psychological climate as well as the social and organizational network in which the technical core is embedded (Motowidlo et al., 1997). An individual's personality characteristics also affect contextual knowledge, which determines how the person will act in various situations (Motowidlo et al., 1997). A welder's personal morals and values may dictate how the individual reacts to various situations that might be encountered in the welding industry.

Skill

Task skill is the ability to use technical information, handle information, make judgments, solve problems, and perform technical skills related to an organization's core

technical functions (Motowidlo et al., 1997). A task skill involves the application of task knowledge to perform the required actions quickly, smoothly, and without error (Motowidlo et al., 1997). Likewise, contextual skill is a person's ability to carry out actions that are effective for handling various situations (Motowidlo et al., 1997). Based on Motowidlo et al. (1997), contextual skills include helping and coordinating with others, following rules and procedures, supporting and endorsing the organization's objectives, and volunteering.

Work Habits

Motowidlo et al. (1997) defined work habits as patterns of behavior learned over time that can contribute or impede the execution of organizational goals. Furthermore, work habits are formed through the interaction of basic tendencies and environmental influences and include motivational characteristics such as taking a shortcut to finish a task or completing the task in a proper manner, choosing how much effort to put forth, and procrastination (Motowidlo et al., 1997). Contextual work habits influence how a person handles various situations by either approaching or avoiding them or manages conflict in a way that can positively or negatively affect the psychological climate (Motowidlo et al., 1997). Task work habits influence a person's ability to complete task-related responsibilities such as how to use technical information, perform procedures, and make decisions that might facilitate or interfere with a task (Motowidlo et al., 1997).

For this study, task performance and the associated indicators will be examined. The prediction of future performance will be examined based on an individual's dexterity. In this framework, dexterity will be part of the cognitive ability variable

because it is an ability that a person has that could affect how well a task is performed. Cognitive ability variables affect how well an individual can perform task skills, which in turn affects overall task performance. Secondly, anxiety will be studied in beginning welders. Specifically, how anxiety affects a beginning welder's ability to learn how to weld. Anxiety in this framework will be considered a personality variable because it is a variable that could affect task and contextual performances. As a personality variable, it will affect the work habits of an individual either positively or negatively. Finally, the use of virtual reality to evaluate a seasoned welder will be examined. The variables to be examined when evaluating a seasoned welder include cognitive ability variables, task skill, task knowledge, and overall task performance.

Dexterity

According to Campbell (1977), dexterity is the skill of using one's hands and body that addresses the quickness or coordination of sight and other senses with muscles. Dexterity can be broken into several categories, such as manual and finger dexterity, but the focus of this paper is manual dexterity. Schmidt and Lee (2011) defined manual dexterity as the underlying ability to complete tasks that require the manipulation of an object primarily with the use of arms and hands. Many occupations require manual dexterity during routine work, including dentistry, surgery, and welding (Fleming, 1937; Gansky et al., 2004; Giachino & Weeks, 1985; Hitchings & Moore, 1991; Levine, Spector, Menon, & Narayanan, 1996). Understanding that manual dexterity pertains to the manipulation of an object using the arms and hands, researchers have further dissected dexterity and classified the movements as motor skills.

Motor skills relate to tasks that require the performer to move accurately with strength and/or power in various combinations (Cratty, 1973). As a motor skill, use of the arms and hands can be classified into two different categories: fine and gross motor skills. Fine motor skills have been defined by several researchers, but the commonality in the definitions is the use of smaller muscles to move within a limited area to perform precise and accurate movements (Cratty, 1973; Singer, 1980, 1982). Gross motor skills relate to use of the whole body and the larger muscles to perform big movements that require less precision (Cratty, 1973; Singer, 1980, 1982). The process of welding incorporates both fine and gross motor skills. As a welder maintains work and travel angles, the individual is utilizing fine motor skills. The utilization of gross motor skills are seen when maintaining travel speed and arc length during the welding process.

To fully understand the interaction between gross and fine motor skills, researchers have categorized movements into four types created in relation to the movement of the body and environment. These four types were originally identified by Fitts and later modified by Merrill (Singer, 1980). Singer (1980) described the four types as follows: Type-I tasks are performed when the body and environment are at rest and stable, such as threading a needle; type-II tasks involve the body at rest and the environment in motion, such as aiming a gun at a duck; type-III tasks, such as throwing a baseball, have the body in motion and the environment at rest; and type-IV tasks such as a quarterback passing a football while on the run have both the body and the environment in motion. In the occupation of welding, the welder can be stationary or in

motion while the environment is at rest. Thus, type-I and type-III tasks will be examined in discussing how dexterity affects welding.

Another way to classify the movements of a welder is by motor behavior. Schmidt and Lee (2011) described the movements of motor behavior on a continuum of discrete, serial, and continuous. Discrete movements have a recognizable beginning and end, which resemble throwing an object or striking a match. Serial tasks are strung together such as playing the piano or assembly line tasks. Continuous movements have no recognizable beginning or end; an example would be a person swimming (Schmidt & Lee, 2011). See Figure 2.2.

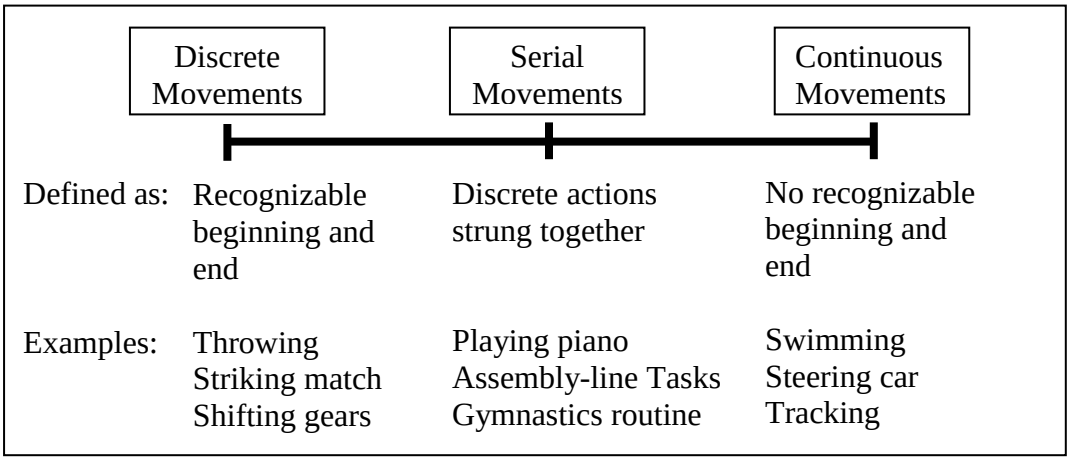

Figure 2.2. The discrete/serial/continuous classification for motor behavior. Reprinted, with permission, from R.A. Schmidt and T.D. Lee, 2011, *Motor control and learning: A behavioral emphasis*, 5th ed. (Champaign, IL: Human Kinetics), 22.

The classification of motor skills along this continuum facilitates understanding how motor skills are related to the educational field; educators refer to these skills as psychomotor skills (Singer, 1980). With welding in mind, this task has a recognizable beginning and end; thus, it falls into the discrete movement category (Singer, 1980). This leads to the next question: Is welding a skill or an ability?

Ability versus Skill

The term skill has several connotations, but to understand the concept, it must be distinguished from the notion of ability (Schmidt & Lee, 2011; Singer, 1980). Schmidt and Lee (2011) defined ability as a relatively stable trait that is non-modifiable by practice and is the support structure of skills. A skill, on the other hand, is specific to a given task and is learned through practice. With regard to welding, this paper considers dexterity as a skill that can be improved with practice.

Welding Defined

Welding is a "joining process that produces coalescence of materials by heating them to the welding temperature, with or without the application of pressure or by the application of pressure alone, and with or without the use of filler metal" (Jeffus & Bower, 2010a, p. 4). In other words, welding is the fusion of two pieces of material by heating the materials to the point of melting and flowing together (Cary & Helzer, 2005; Jeffus, 2012; Jeffus & Bower, 2010a). Welding is a specialized task that usually requires training and certification of abilities before a welder can work in industry (Cary & Helzer, 2005; Jeffus, 2012; Jeffus & Bower, 2010a).

Dexterity in Welding

Dexterity is a physical attribute that industries look for in a potential welding employee. Jeffus and Bower (2010a) stated that a young person planning a career in welding should possess good eyesight, manual dexterity, and good hand-eye coordination, as well as an understanding of welding. Jeffus (2012) emphasized that welding requires a high degree of hand-eye coordination. Cary and Helzer (2005)

provided a detailed list of requirements for a person in the welding profession. This list includes spatial aptitude, form perfection, finger dexterity, and manual dexterity as the most significant required fundamentals (Cary & Helzer, 2005). Cary and Helzer (2005) also listed physical demands that pertain to dexterity; a few of these demands are climbing, handling, fingering or feeling, reaching, kneeling, and crouching.

Dexterity plays a vital role during the welding process as the welder tries to maintain all the correct parameters to ensure a proper weld is achieved. The parameters a welder is required to maintain during the welding process include arc length, weld position, travel angle, work angle, and travel speed (Jeffus, 2012; Jeffus & Bower, 2010b). These parameters are crucial for the welder to correctly weld two pieces of material together. In the process of shielded metal arc welding (SMAW), also known as arc or stick welding, these parameters are always in a state of flux (Jeffus, 2012) because the welding electrode used is consumed as the weld is performed (Jeffus, 2012). This requires the welder to maintain the correct position, angles, and travel speed while slowly feeding the electrode downward to maintain the correct arc length. Another aspect of welding that increases the need for manual dexterity is the use of weave patterns. Manipulation of the electrode, or weaving, can help control penetration, width, porosity, undercut, and slag inclusion (Jeffus, 2012; Jeffus & Bower, 2010b).

Understanding that welders must be dexterous to weld correctly may encourage a researcher to hypothesize that if a person has a high level of dexterity then that person should be able to weld and vice versa. If researchers examine the variables a welder must address, they can understand how dexterity affects a person's ability to weld. The

first variable is body type. Whether a person is tall, short, slender, obese, young, or old all play a role in the amount of dexterity a person may possess. Tremblay, Wong, Sanderson, and Cote (2003) stated that older age is accompanied by a decline in manual dexterity. Buffington, MacMurdo, and Ryan (2006) indicated that body position (kneeling, sitting, and standing bent at the waist) affected manual dexterity in a study of anesthesiologists. Being tall or short can hinder a welder's ability to position themselves correctly to the weld area, which in turn creates stress in the welder's dexterous movements as a result of having to bend over, kneel, or stand on a ladder. Obesity results in lower dexterous abilities than normal-weight children (D'Hondt, Deforche, Bourdeaudhuij, & Lenoir, 2009). Other physical impairments such as broken bones, physical barriers, pulled muscles, and pinched nerves will hinder an individual's level of dexterity. The amount of dexterous movement a person can endure is another factor that can affect the ability to weld. A person who has full range of motion and fluid movement of the arms and hands may have a better chance to complete a weld correctly than a person who has limited range of motion and sluggish movements of the arms and hands.

Using the proper protective equipment (PPE) specified for welding can also impede a welder's dexterity. The PPE a welder uses can include welding helmets, hearing protection, respirator, leather gauntlet gloves, leather jacket, leather pants, and spats (shoe protectors) (Jeffus & Bower, 2010a). However, the weight of leather jackets and pants, for example, may be burdensome after a short time, which may lead to welder fatigue and a loss of dexterity. Wearing all of the PPE listed can result in restrictions in

body motor function, which may lead to decreased dexterity. One example of a loss of dexterity involves the leather gauntlet gloves. When leather gloves are exposed to heat, the leather dries up and the material hardens. The part of the gloves typically exposed to welding heat is the fingers because welders come in contact with hot weldments. Stiffness in the glove's fingers can compromise a welder's ability to grasp the electrode holder to maintain all the correct angles for welding.

Dexterity as an Indicator of Future Performance

One factor studied to examine the ability to predict future performance is dexterity. Dexterity has been validated in predicting performance in jobs that require routine assembly, coil winding, and packaging, in contrast to jobs that require higher order abilities (Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969). Gansky et al. (2004) found that future performance could be predicted by analyzing dental students' dexterity in preclinical restorative courses. Many occupational fields have tried to predict a student's ability for future performance before admission to a training program. The typical tests used to predict future performance analyze cognitive ability, psychomotor skills, and perception (Brown & Ghiselli, 1951; Gettman et al., 2003; Hitchings & Moore, 1991; Levine et al., 1996). Dental and surgical training programs have conducted studies to examine the effectiveness of aptitude tests to predict future performance. Gettman et al. (2003) indicated that the measures of innate ability accurately predicted the future performance of 65% of laparoscopic surgeons.

The welding literature argues that welders should possess manual dexterity, good eyesight, and good hand-eye coordination (Giachino & Weeks, 1985). Giachino and

Weeks (1985) also stated that welders need the ability to concentrate on detailed work and must be free of disabilities that prevent working in awkward positions. Fleming (1937) indicated that welding training programs have employed aptitude tests that evaluate mechanical ability, ability to judge shapes and sizes, ability to remember designs, and manual dexterity, but have not extensively evaluated the predictive ability of individual factors regarding future performance.

Mansell (1969) argued that technical teachers are mostly concerned with trainee knowledge and dexterity. Mansell (1969) postulated that teaching dexterity of a skill requires that the skill first be analyzed. Mansell (1969) posited that every skill has sub-skills that must also be known in order to understand the dexterous ability needed to perform the skill. Using dexterity and trainability testing techniques requires the test to be designed around a particular job (Hitchings & Moore, 1991). If a dexterity test that replicates the psychomotor skills necessary for welding were implemented in a training program, would the test be able to predict the future performance of trainees?

Anxiety

Rachman (2004) defined anxiety as the tense and unsettling anticipation of a vague yet threatening event that has a negative effect on a person. Anxiety is a negative affect that is closely related to fear, which has led to both words being used interchangeably (Barlow, 1988; Goodwin, 1986; Rachman, 2004). Both terms refer to a combination of tension and unpleasant anticipation, but distinctions can be made between causes, duration, and maintenance of fear and anxiety (Rachman, 2004). The term fear is used to describe a reaction to a specific, perceived danger or identifiable

threat (Rachman, 2004). Fear reactions are intense and usually recede once the danger is removed (Rachman, 2004). In contrast, anxiety is described as a heightened vigilance rather than an emergency reaction causing an uneasy tension where the cause is not always identified (Rachman, 2004).

When a person experiences anxiety, it comprises several components and is more of a process than a categorical event that occurs or does not occur (Rachman, 2004). To help explain the different components a person experiences with anxiety, Rachman (2004) put them into a model. See Figure 2.3.

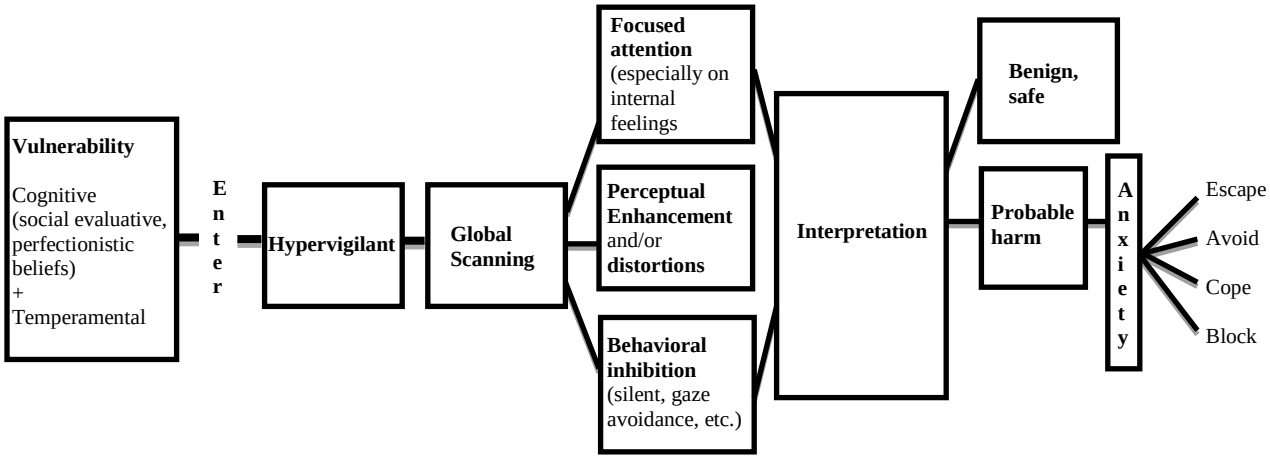

Figure 2.3. A model of anxiety. From *Anxiety* (p. 5), by S. Rachman, 2004, New York, NY: Taylor & Francis, Inc. Copyright 2004 by Psychology Press, Ltd. Reprinted with permission.

Vulnerability relates to a person's susceptibility to anxiety and the degree of susceptibility varies from person to person (Rachman, 2004). Temperamental vulnerabilities are experiential and biological in nature, things not controlled by one's mind (Rachman, 2004). Cognitive vulnerabilities are shaped from past experiences and present beliefs, things that are controlled by one's mind (Rachman, 2004). A person's

susceptibility to anxiety is put to the test once the person enters a new or unfamiliar environment. Upon entering an environment, a person predisposed to anxiety becomes hypervigilant (Rachman, 2004). This is evidenced by global scanning, where a person experiences rapid eye movement throughout the visual field (Rachman, 2004). With global scanning, a person will first broaden his or her attention to detect any threats; if a threat is found, the person's attention will narrow as the threat is processed (Rachman, 2004). Once a person overcomes his or her anxiety disorder, hypervigilance usually is not found (Rachman, 2004). In the welding industry, hypervigilance could be seen when trainees are initially brought into the training facility because the place is unfamiliar to them. This may be caused by seeing the actual production floor where a welder might be working. When an individual observes the production process several threats might be discovered.

Focused attention refers to people who are hypervigilant and globally scan their environment; when they find a threat, they focus all their attention solely on the threat and appear inattentive to everything else around them (Rachman, 2004). Perceptual enhancement or distortion relates to people who have extreme cases of anxiety; if they leave a familiar place, they become fixated on globally scanning for threats, to the point that it is all they do (Rachman, 2004). When a person enters an environment and detects a threat but decides to seek safety to avoid the threat, the action is referred to as behavioral inhibition (Rachman, 2004). The information gathered from global scanning and focusing attention on a threat is used to determine whether the threat is benign or harmful (Rachman, 2004). Rachman (2004) posited that misinterpretations have two

dimensions where the probability or seriousness of an event occurring is exaggerated. When being introduced to the production floor, an individual without prior experience could misinterpret potential threats.

Rachman (2004) stated that if a threat were benign no anxiety would occur. If a threat is perceived as harmful, a person will attempt to reduce the effects of his or her anxiety (Rachman, 2004). There are four common ways a person can reduce the effect of anxiety, which include escape, avoid, cope, and block (Rachman, 2004). For example, once a person experiences anxiety, to reduce the effect, that person will escape as quickly as possible (Rachman, 2004). If the experience occurs at the same place several times, the person will begin to avoid the place (Rachman, 2004). To cope with not being able to go to the place, an individual might ask someone else to go there or to accompany the anxious person (Rachman, 2004). Responses to perceived threats in the welding industry might include escape and avoidance, where an individual would leave the welding environment to reduce the effect of anxiety.

Social Anxiety

The terms social anxiety and social phobia are used interchangeably and are associated with social anxiety disorder (Barlow, 1988; Rachman, 2004). The essential feature of social anxiety is an intense and persistent fear of social or performance situations (Barlow, 1988; Goodwin, 1986; Rachman, 2004). The symptoms of social anxiety manifest in many forms because the anxiety is experienced in social situations (Barlow, 1988; Goodwin, 1986; Rachman, 2004). People who suffer from social anxiety

have an innate fear of possible scrutiny because they might behave in a manner that is embarrassing or unacceptable or they may perform ineptly (Rachman, 2004).

To explain social phobia further, it will be related to the model of anxiety. The vulnerability contains a predisposition to feel anxious in social situations (Rachman, 2004). Rachman (2004) stated that cognitive theorists have three beliefs about people who suffer from social anxiety: (1) they have perfectionist standards for social performance, (2) they hold false beliefs about social evaluation, and (3) they have negative views about the self. Another difference is a more direct focus, especially on internal feelings and their significance, including whether the emotional state is visible to others (Rachman, 2004).

A person suffering from social anxiety can misinterpret the emotional reactions of others as an indication that others are making them the center of attention in a criticizing fashion (Rachman, 2004). During the interpretation component, a person responds to threats as if the person sees that other people are judging him or her as inept or inadequate within the social situation (Rachman, 2004). If the person correctly interprets the emotional reaction as benign, a friendly or accepting feeling will occur and anxiety will subside (Rachman, 2004). If the reaction is interpreted as harmful, the person will have the feeling of being shunned or rejected (Rachman, 2004). The negative interpretation will cause the person to experience social anxiety, leading that person to escape, avoid, cope, or block the social interaction from recurring (Rachman, 2004).

Anxiety in the Workplace

Although most symptoms seen in those suffering from anxiety are negative, in the workplace, anxiety and stress can have positive results (Stein & Hollander, 2003). Stein and Hollander (2003) stated that a good argument could be made that some degree of stress and anxiety is always evident in the workplace and can be beneficial as a source of motivation. Stress and anxiety in the workplace, and the need to manage both, can be useful, but some people perceive themselves as suffering from stress and anxiety (Stein & Hollander, 2003).

Workers who suffer from anxiety and stress in the workplace can create problems for the rest of the organization (Pflanz & Heidel, 2003). Workers who suffer from stress and anxiety can exhibit poor job performance, job dissatisfaction, absenteeism, and interpersonal conflict (Pflanz & Heidel, 2003). Psychiatric illnesses affect 48% of Americans during their lifetime and nearly 30% of the U.S. population annually (Pflanz & Heidel, 2003). Pflanz and Heidel (2003) stated, "anxiety disorders cost industries $4.1 billion per year, 88 percent of it attributable to decreased productivity (Greenberg et al., 1999)" (p. 281).

Anxiety in Welding Training Programs

A welding environment potentially holds many triggers of anxiety, and most causes of anxiety stem from safety issues related to welding, including electrical shock, arc radiation, air contamination, fire, explosion, and compressed gases (Cary & Helzer, 2005; Jeffus, 2012). Electrical shock is a concern because of the voltage required for welding. With most alternating current (AC) sources, voltage use ranges between 115

and 460 volts, but fatalities can occur with equipment using less than 80 volts (Jeffus, 2012). Arc radiation is harmful because the welding arc emits ultra-violet (UV) rays (Cary & Helzer, 2005; Jeffus, 2012). These UV rays can cause flash burn to unprotected eyes and severe sunburn to skin exposed during welding (Cary & Helzer, 2005; Jeffus, 2012). Another concern for welders is the noise created by the welding process. The result of a welder exposed to the noise of a welder during an 8-hour workday is the main cause for frequent hearing loss in welders (Cudina & Prezelj, 2003).

Air contamination comes in two forms, particulate matter and gases, through the process of welding (Cary & Helzer, 2005). Air contamination can result from smoke or fumes rising from the welding operation (Cary & Helzer, 2005). The hazard is created by the metal being welded, chemical composition of the flux, and the length of time a welder is exposed to the fumes (Cary & Helzer, 2005). Fire and explosions are caused by welding in an area unsuitable for welding because sparks can travel up to 40 feet and come in contact with flammable substances (Cary & Helzer, 2005; Jeffus, 2012). Safety concerns with compressed gases revolve around the gas cylinders used to provide the shielding gas for various welding operations (Cary & Helzer, 2005; Jeffus, 2012). The major concern with gas cylinders is inadvertently breaking off the tank valve, allowing the cylinder to act as a rocket (Cary & Helzer, 2005).

With all the different types of safety issues related to the welding occupation, inexperienced individuals are likely to exhibit anxiety-related symptoms. Ursano, Fullerton, Wiesaeth, and Raphael (2007) postulated that inexperienced disaster volunteers might be at higher risk for acute effects of psychological discomfort than

experienced personnel. Understanding that inexperienced individuals may exhibit more symptoms of anxiety, it is imperative to examine methods of reducing anxiety within a training program. Reducing an individual's anxiety level may lead to increased levels of performance (Pflanz & Heidel, 2003). One suggested method to reduce anxiety in beginning welders is to integrate virtual reality simulations (Byrd & Anderson, 2012). Kunkler (2006) stated that the use of simulations provides a safe and realistic computer-based environment in which individuals can practice. The question becomes whether the introduction of virtual reality into a welding training program will lead to a reduction in anxiety exhibited by inexperienced individuals.

Evaluation of Seasoned Workers

According to de Freitas and Oliver (2006), the use of educational computer-based games has become popular in traditional teaching and learning practices. One should note that computer-based games and simulations are employed as supplements to and not replacements for traditional methods (de Freitas & Oliver, 2006). The popularity of computers is attributable to society's reliance on technology, which requires adults and children alike to use computers (Vogel et al., 2006). Vogel et al. (2006) found that educational institutions and several industry job-training programs have used computer-based programs to reduce training costs.

Within a technical field, simulations can be useful in training workers as they enhance retention of the basic skills needed to perform work tasks (Stone, McLaurin, Zhong, & Watts, 2013). Simulations offer immediate training opportunities and access to a wide variety of scenarios (Kunkler, 2006). Through repetition of a task, a worker's

ability to anticipate and recognize when situations can go awry is enhanced under both normal and stressful conditions (Stone et al., 2013). Stone et al. (2013) posited that training in a virtual reality environment can lead to increased memory retention, reduced human error, and a deeper understanding of the complexities of a work environment.

One field in the forefront of implementation of technology to teach students is the field of medicine. The medical field has used robotics and a variety of simulation devices to train practitioners for several decades (Kunkler, 2006), from the emergence of the Harvey mannequin in the 1980s to the two-dimensional models of the human body created by the Virtual Human Project in the 1990s (Kunkler, 2006). Simulations have been used to put theory into practice and to reinforce cognitive ability (Boyd & Murphrey, 2002). Other occupational fields that have used simulations to train students include medical and welding (Byrd & Anderson, 2012).

Stone et al. (2013) found that in a welding training program full or partial integration of virtual reality was appropriate, depending on the weld difficulty. Seymour (2002) found that medical residents who trained with a virtual reality surgical simulator to learn the skills for gallbladder surgery were 20% more efficient than those who trained traditionally. Although research has shown that virtual reality simulators can be used to increase efficiency in training individuals to perform work-related tasks, it is imperative that the simulators be able to measure individual abilities. Ota (1995) stated that a key aspect to accurately evaluate a person using virtual reality simulation is creating a rule-based analysis of the person's performance. Kunkler (2006) postulated that for the rule-based analysis to be accurate the simulation must look and feel as

realistic as possible. Once an accurate rule-based evaluation is created, and realistic simulations are created, the simulation will be able to measure a person's work performance.

One cornerstone of organizational practice is the measurement of one's work performance (Bennett, Lance, & Woehr, 2006). Bennett et al. (2006) postulated that nearly all personnel decisions are based on performance. With advancements in technology, several occupations have implemented simulators to train students and are currently looking at the ability to use simulations to evaluate in-service workers (Kunkler, 2006; Manca, 2013; Mantovani, Castelnuovo, Gaggioli, & Riva, 2003). Jones and Dagas (2003) suggested that an applicant's response to a virtual reality simulation can be used for personnel selection or certification purposes.

In the medical field, certifying professionals utilizing virtual reality is an important consideration (Kunkler, 2006). Many medical training programs are considering the use of virtual reality to measure a professional's ability for certification purposes (Kunkler, 2006). The Joint Commission on Allied Health Personnel in Ophthalmology (JCAHPO) evaluated certified ophthalmic technician (COT) skills by using computer-based simulations (Kunkler, 2006). The JCAHPO has replaced the hands-on skills evaluation with simulation-based evaluations. Boulet et al. (2003) suggested that the clinical performance of medical students and residents could be evaluated by using medical simulations. Because virtual reality simulations are being used to evaluate COT skills, could virtual reality simulations also evaluate the skill of current welders?

Previous research has shown that simulations can be used effectively to train an individual to perform work-related tasks. Virtual reality simulations have been used for several years in various occupational fields to evaluate individuals' abilities before they perform tasks in a real-life situation. Research has also suggested that virtual reality simulations can be employed to evaluate an individual prior to and after performing tasks in a real-life situation. Can the ability of virtual reality simulations to evaluate seasoned workers be transferred into a welding environment? If so, welding program managers can evaluate seasoned welders efficiently to maintain high-quality welding in a production setting.

Summary

This chapter has explained the theoretical framework, the theory of individual differences in task and contextual performance, guiding this study on a welding training program. With a need for more welders in the U.S. (U.S. Department of Labor Bureau of Labor Statistics, 2013), it is necessary to improve upon the selection and methods used in welding training programs.

The background of dexterity and how dexterity relates to technical jobs were also described. The ability and use of dexterity as a future performance indicator was explored to identify whether dexterity can be used to predict future performance of an individual in a welding training program. The effect of anxiety has been explored, showing both the advantages and disadvantages to those individuals exhibiting symptoms of anxiety in the workplace. One method, integrating virtual reality simulations, might lead to a reduction in anxiety symptoms exhibited by an individual.

Finally, the evaluation of seasoned personnel in the workplace was examined. The use of virtual reality simulations is popular in today's society for evaluating seasoned workers. The research leads to the question: Can virtual reality welding simulators be used to evaluate seasoned welders?

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CHAPTER III. IMPROVING DEXTERITY TO INCREASE TRAINABILITY OF PRE-SERVICE TEACHERS IN WELDING TRAINING

A paper prepared for the submission to the *Journal of Agricultural Education*

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Abstract

This study examined if dexterity is related to welding training. With a high demand for welders, it is imperative that welding training programs be efficient, which can be time consuming (Stone, Watts, & Zhong, 2011). With a need for skilled laborers, finding more efficient training methods has become a necessity while maintaining a high level of quality (Byrd & Anderson, 2012). The time required to train certified welders is a primary obstacle that training programs face. Many occupational fields have tried to predict students' future performance before admitting them into training programs by analyzing their dexterous abilities. This study used the Complete Minnesota Dexterity Test (CMDT) to examine participants' dexterity and visually inspected test welds. A point-biserial correlation was calculated using the recorded times and visual pass/fail rates. All three dexterity tests of the CMDT were found to have statistically significant relationships with the visual pass/fail rates for basic shielded metal arc welds (SMAW). It can be concluded that dexterity can predict future performance of beginning welders completing basic SMAW welds. This conclusion implies that industry personnel can use dexterity testing to select individuals to enter welding training programs that use basic SMAW welds.

Introduction

Because of a global boom in the industrial manufacturing sector, welders are in greater need now than ever before (Brat, 2006). According to the U.S. Department of Labor, Bureau of Labor Statistics (2012), the number of jobs for welders is expected to increase 15% between 2010 and 2020, which is more than the average for all other occupations reported. Welding is a technical skill that requires certification, which takes time, money, and talent (Stone, Watts, & Zhong, 2011). The time needed to train a person to become certified to weld is one area that many welding educators have tried to shorten. According to Giachino and Weeks (1985), for a skilled manual welder to master the craft requires years of on-the-job training. Since it takes years to master the craft of welding, what elements of a welding curriculum are needed in order to become successful?

According to Pate, Warnick, and Meyers (2012) one of the essential competencies include being able to perform welds with various type of arc welding. Furthermore, background knowledge of welding consumables, project planning, and shop maintenance were also included (Pate et al., 2005). Industry based welding training programs face a similar problem, trainees failing certification testing after extensive training periods (Hitchings & Moore, 1991). This means after extensive training an individual might not be able to proficiently perform a weld. So what improvements can be made to increase training program productivity?

Since their inception, welding training programs have been continually evolving to better prepare welders. Weld trainers have incorporated several computer-based

advancements into their programs, including virtual reality (VR) simulators (Byrd & Anderson, 2012). Simulations have been used in several occupational fields such as medical, dental, and welding to train students to become proficient at various skills (Boulet et al., 2003; Kunkler, 2006; Papadopoulos, Pentzou, Louloudiadis, & Tsiatosos, 2013; Stone et al., 2011). The use of VR simulators has helped increase the awareness of welding to the younger gamer generation (Postlethwaite, 2012). With the majority of learning and interaction occurring in a digital environment, VR simulators create an avenue to recruit new students (Lincoln Electric, 2013). Additionally, with an influx of newcomers into training programs, industry professionals question whether there is a way to predict who will have the best capability to become a certified welder.

Many occupations have tried to predict a student's ability of future performance prior admitting them into a training program. The typical tests used to predict future performance have analyzed cognitive ability, psychomotor skills, and perceptual tests (Gettman et al., 2003; Levine, Spector, Menon, & Narayanan, 1996; Hitchings & Moore, 1991; Brown & Ghiselli, 1951). Dental and surgical training programs have conducted studies examining the effectiveness of these aptitude tests at predicting future performance. Gettman et al. (2003) found that measures of innate ability were able to predict the future performance accurately in 65% of laparoscopic surgeons ($N = 20$).

Gansky et al. (2004) found that manual dexterity predicted future performance of dental students in subsequent preclinical restorative courses. According to Campbell (1999), dexterity is the skill of using one's hands and body, which addresses the quickness or the coordination of sight and other senses with muscles. Additionally,

researchers have validated dexterity in predicting performance in jobs that require routine assembly, coil winding, and packaging (Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969).

Existing literature states that welders need manual dexterity, good eyesight, and good hand-eye coordination (Giachino & Weeks, 1985; Jeffus, 2012; Jeffus & Bower, 2010a). Giachino and Weeks (1985) stated welders need to concentrate on detailed work, be free of disabilities that would prevent work in awkward positions, and be able to lift up to 100 pounds. To evaluate these criteria, welder training programs have employed tests on mechanical ability, ability to judge shapes and sizes, remember designs, and manual dexterity when selecting apprentices (Fleming, 1937); however, such research has not extensively evaluated the predictive ability of individual factors for future performance.

Mansell (1969) stated that technical teachers are mostly concerned with trainee knowledge and dexterity. Additionally, to teach dexterity of a skill, an analysis of that skill must first be completed because every skill has sub-skills that must also be known. Using dexterity and trainability testing technique requires that tests be designed around the particular job (Hitchings & Moore, 1991).

The welding parameters required during the welding process include arc length, weld position, travel angle, work angle, and travel speed (Jeffus, 2012; Jeffus & Bower, 2010a). These parameters are crucial for the welder to weld two pieces of material together correctly. In the process of shielded metal arc welding (SMAW), also known as arc or stick welding, these parameters are always in a state of flux (Jeffus, 2012) because

the welding electrode used is being consumed as the weld is being performed (Jeffus, 2012). Therefore, this type of weld requires the welder to maintain the correct position, angles, and travel speed all while slowly feeding the electrode downward to maintain the correct arc length. The use of weave patterns also increases the need for manual dexterity. By manipulating the electrode, weaving, can help control penetration, width, porosity, undercut, and slag inclusion (Jeffus, 2012; Jeffus & Bower, 2010b).

Understanding that welders need to be dexterous to weld correctly leads to the hypothesis that, if a person has a high level of dexterity, then he or she would be able to weld and vice versa. Therefore, if a dexterity test replicates the psychomotor skills necessary for welding were implemented in a training program, they might be able to accurately predict the future performance of the trainees.

Theoretical Framework

The theoretical framework that guided this study was Campbell, McCloy, Oppler, and Sager's (1993) determinants of job performance components. To understand determinants of job performance, one must determine a definition of performance. Campbell et al. (1993) stated that "performance consists of goal-relevant actions that are under the control of the individual, regardless of whether they are cognitive, motor, psychomotor, or interpersonal" (p. 40). To understand performance further, it is necessary to distinguish between effectiveness and productivity. Performance of any job will produce a result; effectiveness is the systematic evaluation of the results. Productivity refers to the ratio of effectiveness to the cost of rising to the next level of effectiveness (Campbell, 1999; Campbell et al., 1993).

Performance is comprised of components, determinants, and antecedents (Campbell et al., 1993). Performance components are categories of actions that individuals are expected to complete (Campbell, 1999; Campbell et al., 1993). Performance determinants include declarative, procedural knowledge, skill, and motivation (Campbell, 1999; Campbell et al., 1993). Differences between individuals who perform the same job are expressed through the performance determinants, which compose a performance component (Campbell, 1999; Campbell et al., 1993).

Declarative knowledge refers to knowledge about facts and things related to the job that an individual possesses (Campbell, 1999; Campbell et al., 1993). Procedural knowledge and skills are the combination of knowing what to do, declarative knowledge, with how to do it. Skills that fall under procedural knowledge include cognitive, psychomotor, physical, self-management, and interpersonal. The final determinant is motivation, which refers to the effort an individual puts toward a job and involves making the decision to expend effort and determining the level and time he or she will exert that effort when performing a job (Campbell, 1999; Campbell et al., 1993). See Figure 3.1.

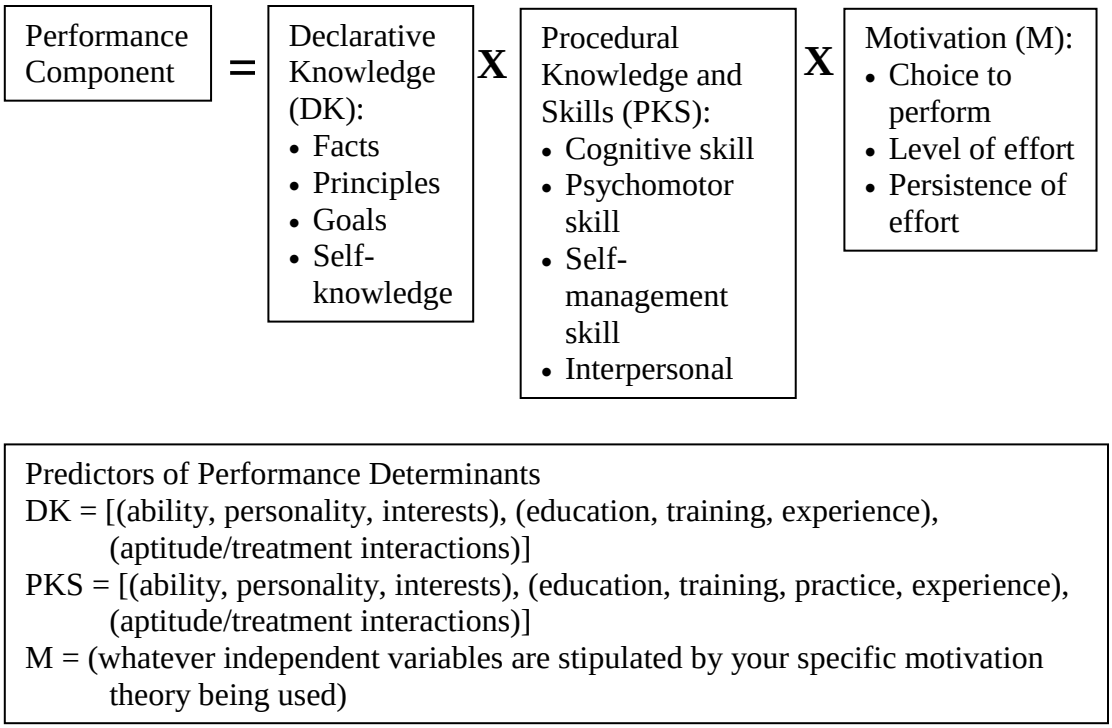

Figure 3.1. Determinants of Job Performance Components. Adapted from "A theory of performance," by J. Campbell, R. McCloy, S. Oppler, and C. Sager, in "Personnel selection in organizations" N. Schmitt, W. Borman, and associates (Eds.), 1993, San Francisco, California: Jossey-Bass Publishers. Reprinted with persmission.

Antecedents of performance determinants are the predictors of performance (Campbell, 1999; Campbell et al., 1993). Performance indicators of declarative knowledge include ability, personality, interests, education, training, experience, and aptitude interactions (Campbell, 1999; Campbell et al., 1993). Procedural knowledge and skill performance predictors include ability, personality, interests, education, training, practice, and aptitude interactions (Campbell, 1999; Campbell et al., 1993). Finally, motivational antecedents include variables related to the theory of motivation used (Campbell, 1999; Campbell et al., 1993). For this study, the researchers focused on the performance antecedents of procedural knowledge and skill. The specific antecedent examined was psychomotor skills as they relate to welding performance.

Purpose and Objectives

The purpose of this study was to examine whether dexterity could predict future performance of a beginning welder in a welding training program. In addition, the study sought to describe the change in dexterity during a welding training program. This study also intended to describe the relationship between an individual's dexterity and pass/fail rate from a visual inspection of the test weld. This research aligns with the American Association for Agricultural Education's National Research Agenda Priority Area 3: Sufficient scientific and professional workforce to address the challenges of the 21st Century (Doerfert, 2011, p. 9). Specifically relating to improve agricultural productivity efficiency and effectiveness, is the need to increase sustainable growth in the private setting (Doerfert, 2011). The following objectives were addressed in this study.

1. Describe the average dexterity among participants in a welding training program.
2. Examine the pass/fail rates of visual inspection of test welds performed by participants.
3. Explore the relationship between participant dexterity and the pass/fail rates of visual inspection of test welds.

Methods

This study was part of a larger research study that examined the effectiveness of integrated virtual reality welding training programs using the VRTEX® 360 and VRTEX® Mobile units. This study was conducted at the Iowa State University 450 Farm where VR and real world welding training laboratories were constructed. To

gather participants for this study, email blasts were sent to Iowa State University students, Iowa agricultural and technology education teachers, and flyers were placed on the Iowa State University campus. Participation was voluntary and incentives for participation included having lunch provided every day and having the weld certification test fees waived.

A quasi-experimental design was used in this study since baseline data for the traditional welding training methods came from the previous study conducted by Stone, McClarin, Zhong, and Watts (2013). Depending on which week the individuals' participated dictated which training program they were in, which was unknown to the participant. During one of the two-week programs, participants were randomly assigned to one of the groups because of high participant numbers.

Three females and 20 males participated in this study. Participants' backgrounds varied and included college students, secondary educators, and industry workers. The welding training programs were offered in five variations. There were two one-week training programs, which utilized the VRTEX® Mobile unit. Also, there were three two-week training programs, which utilized the VRTEX® 360. The programs that were one-week long were broken into a 100% VR and 50/50 VR/traditional integrated training program. The two-week long programs were broken into a 50/50 VR/traditional, 75/25 VR /traditional, and 100% VR training groups. Refer to Table 3.1.

Table 3.1

Welding Training Program Type Characteristics

Program Type	Length	% Training	# of Dexterity Test Days*	Positions Tested
50/50 VRTEX® Mobile	1-week	50% - Virtual Reality 50% - Traditional	2	2F, 1G
100% VRTEX® Mobile	1-week	100% - Virtual Reality	2	2F, 1G
50/50 VRTEX® 360	2-weeks	50% - Virtual Reality 50% - Traditional	3	2F, 1G, 3F, 3G
75/25 VRTEX® 360	2-weeks	75% - Virtual Reality 25% - Traditional	3	2F, 1G, 3F, 3G
100% VRTEX® 360	2-weeks	100% - Virtual Reality	3	2F, 1G, 3F, 3G

Note: *Each test day participants completed the placing, turning, and displacement dexterity tests four times; one trial run and three timed trials.
2F – horizontal fillet weld, 1G – flat groove weld, 3F – vertical fillet weld, and 3G – vertical groove weld.

To obtain participants' dexterity data, the researchers used the Complete Minnesota Dexterity Test (CMDT). The CMDT is used to measure an individual's rapid eye-hand coordination and arm-hand dexterity, also known as gross motor skills (Lafayette Instrument, 2012). The CMDT includes five parts; however, only three were used because they closely replicated movements used during the welding process. The completed tests included (a) placing test, (b) turning test, and (c) displacement test. The CMDT uses two test boards, each containing 60 holes. Sixty corresponding disks were used during the tests that participants manipulated with their hands and arms. Participants were required to stand for all dexterity tests. Participants completed these tests on the first day of the welding training program and after the test welds were completed on test days. Depending on which training program participants were in

determined how many times they completed the dexterity tests. Participants in the 1-week session completed dexterity tests twice. Participants in the 2-week session completed the dexterity tests three times.

In the placing test, the two boards were laid on a tabletop, beside each other about 1" from the edge of the table. Disks were on the board farthest away. When the examiner said start, the participant used his or her dominant hand to maneuver the disks one-by-one from the top board to the bottom board. The participant's non-dominant hand could not be used to brace the participant in anyway during the test. Once all disks were placed, the time taken to complete the test was recorded.

The turning test required the use of only one board and all 60 disks. Starting at the top right corner, the participant used one hand to pick up a single disk, turn it with the other hand, and place it back on the board. The participant did this for each disk moving across the board, then proceeded to the next row below and worked back across the board. The participant followed this procedure until all disks were turned. The time taken to complete the test was recorded.

The displacement test also required the use of only one board and all 60 disks. With all the disks inserted into the board, the participant was instructed to remove the disk from the top left-hand corner of the board and place it to the side. This test requires the participant to move the disk directly below the empty space. The participant followed the same procedure until he or she has gone all the way across the board. The time was recorded once the participant completed the test.

For each test, participants were given a practice run to fully understand how the test was to be performed. Following the practice run, participants completed the test three times. The time for the practice run and all three test runs were recorded. The three test times were then averaged. The average was used along with the interpretation chart included with the test to determine the participants' percentile rank. The percentile scale was used to interpret each score in terms of percent of the normative population; the scale ranged from 0 to 100 (Lafayette Instrument, 2012).

After all participants completed the welding training programs, they were required to complete test welds visually inspected by a certified welding inspector (CWI). The length of the training program dictated how many test welds participants were required to complete. The four possible test welds a participant could perform were 2F (horizontal fillet weld), 1G (flat groove weld), 3F (vertical fillet weld), and 3G (vertical groove weld). Participants performed the welds using shielded metal arc welding (SMAW) and gas metal arc welding (GMAW) processes.

Participants in the 1-week session completed the 2F and 1G welds for both welding processes. Participants in the 2-week session completed all four weld types in both welding processes. The CWI examined the test weldment and measured for the following discontinuities: underfill, overfill, undercut, porosity, lack of fusion, and cracks according to AWS D1.1 structural welding code. The data from the visual inspection was recorded as pass or fail.

The data were analyzed using Microsoft Excel 2010 and Predictive Analytics Software (PASW) Statistics 18.0 software package. Descriptive statistics were

calculated to identify frequencies for pass/fail rates and dexterity percentile rankings. A point-biserial correlation was calculated to examine the relationship between recorded times and visual pass/fail rates. Because the data were numerical and dichotomous, it was necessary to conduct a point-biserial correlation calculation to evaluate the relationship between the variables. Researchers used the *r* squared (r^2) statistic to examine the effect size of the point-biserial correlation (Gravetter & Wallnau, 2009).

Results

The performance measures used in this study included the time it took to complete the dexterity tests and the visual inspection of participants' test welds. Objective one sought to describe the average dexterity of the participants of this study. The results can be seen in Table 3.2. Table 3.2 shows the average dexterity in quartiles of the population norm. For example, if you put the entire population on a scale of zero to 100, the quartiles would be 25 (low), 50 (medium), 75 (high), and 100 (very high). Dexterous ability was scored 0-100 with 100 being the highest possible score. This means that the participants in the first quartile are similar in dexterity as the least dexterous people in the entire population. The individuals in the third quartile are more dexterous than 50 percent of the population but less dexterous than the individuals in the fourth quartile.

Table 3.2

Average Overall Dexterity of Participants in Quartiles by Type of Dexterity Test

Type of Test	25% *f* (%)	50% *f* (%)	75% *f* (%)	100% *f* (%)
1st Day of Training[a]				
Placing	18(78.3)	3(13.0)	2(8.7)	0(0.0)
Turning	18(78.3)	3(13.0)	1(4.3)	1(4.3)
Displacement	9(39.1)	5(21.7)	1(4.3)	8(34.8)
Week 1 Test Day[a]				
Placing	11(47.8)	4(17.4)	3(13.0)	5(21.7)
Turning	13(56.5)	2(8.7)	0(0.0)	8(34.8)
Displacement	9(39.1)	1(4.3)	2(8.7)	11(47.8)
Week 2 Test Day[b]				
Placing	7(46.7)	0(0.0)	0(0.0)	8(53.3)
Turning	6(40.0)	0(0.0)	2(13.3)	7(46.7)
Displacement	3(20.0)	2(13.3)	0(0.0)	10(66.7)

Note. [a]$n = 23$, [b] $n = 15$.

Participant dexterity on the first day of training for the placing and turning tests indicated low dexterous ability (78.3%). Participants (34.8%) exuded a very high level of dexterity on the displacement test the first day of training. An increase in dexterous ability can be seen from the first day of training to the test day of Week 1. This increase was evident with the placing test where the first day of training showed that no participant had very high dexterity; however, on the test day of Week 1 21.7% ($n = 5$) of participants had very high dexterous abilities. This increase in dexterous ability was also evident in the turning and displacement tests. The increase of dexterous ability continued as seen in the results on the test day of Week 2. The number of participants exuding a very high level of dexterity increased from 21.7% to 53.3% with the placing test from week 1 to week 2.

To examine this increase in dexterous ability further, the data were grouped by type of training program (see Table 3.3). In the 50/50 VR/traditional training program, no change was found in dexterous ability between the first day of training and the test day of Week 1. However, in the 100% VR training program an increase in dexterous ability was found for all three types of tests. However, the displacement test showed that 25% of participants decreased in their dexterous abilities during the 1-week training program.

Table 3.3

Dexterity of 1-Week Training Program Participants Utilizing the VRTEX® Mobile (N = 4)

Type of Test	25% *f* (%)	50% *f* (%)	75% *f* (%)	100% *f* (%)
50/50 virtual/traditional				
1st Day of Training				
Placing	4(100.0)	0(0.0)	0(0.0)	0(0.0)
Turning	4(100.0)	0(0.0)	0(0.0)	0(0.0)
Displacement	3(75.0)	1(25.0)	0(0.0)	0(0.0)
Week 1 Test Day				
Placing	4(100.0)	0(0.0)	0(0.0)	0(0.0)
Turning	4(100.0)	0(0.0)	0(0.0)	0(0.0)
Displacement	3(75.0)	1(25.0)	0(0.0)	0(0.0)
100% virtual				
1st Day of Training				
Placing	2(50.0)	2(50.0)	0(0.0)	0(0.0)
Turning	2(50.0)	1(25.0)	1(25.0)	0(0.0)
Displacement	0(0.0)	2(50.0)	0(0.0)	2(50.0)
Week 1 Test Day				
Placing	1(25.0)	1(25.0)	1(25.0)	1(25.0)
Turning	1(25.0)	0(0.0)	0(0.0)	3(75.0)
Displacement	1(25.0)	0(0.0)	0(0.0)	3(75.0)

Participant dexterity for the 2-week training programs was grouped by training type. In the 50/50 VR/traditional training method, an overall increase in dexterous

ability was found across all three types of tests completed (see Table 3.4). The one exception was on Week 2 test day in which 13.7% of participants fell from the 50% group to the 25% group. This decrease indicated a loss of dexterous ability. The 75% VR to 25% traditional training group showed an increase in overall dexterous ability for all types of tests completed on the test days for both weeks. The most striking change was in the turning test, in which 80% of participants increased in dexterity. Within the 100% VR training group, participants also had an overall increase in dexterity. The placing and turning tests had the highest increase in ability in which 75% of participants had a positive shift in ability.

Table 3.4

Dexterity of 2-Week Training Program Participants Utilizing the VRTEX® 360

Type of Test	25% *f* (%)	50% *f* (%)	75% *f* (%)	100% *f* (%)
50/50 virtual/traditional[a]				
1st Day of Training				
Placing	5(83.3)	0(0.0)	0(0.0)	0(0.0)
Turning	6(100.0)	0(0.0)	0(0.0)	0(0.0)
Displacement	3(50.0)	0(0.0)	0(0.0)	3(50.0)
Week 1 Test Day				
Placing	3(50.0)	3(50.0)	0(0.0)	0(0.0)
Turning	4(66.7)	2(33.3)	0(0.0)	0(0.0)
Displacement	3(50.0)	0(0.0)	1(16.7)	2(33.3)
Week 2 Test Day				
Placing	4(66.7)	0(0.0)	0(0.0)	2(33.3)
Turning	4(66.7)	0(0.0)	1(16.7)	1(16.7)
Displacement	3(50.0)	1(16.7)	0(0.0)	2(33.3)
75/25 virtual/traditional[b]				
1st Day of Training				
Placing	4(80.0)	1(20.0)	0(0.0)	0(0.0)
Turning	4(80.0)	1(20.0)	0(0.0)	0(0.0)
Displacement	1(20.0)	1(20.0)	1(20.0)	2(40.0)
Week 1 Test Day				

Table 3.4 (Continued)

Placing	2(40.0)	0(0.0)	1(20.0)	2(40.0)
Turning	3(60.0)	0(0.0)	0(0.0)	2(40.0)
Displacement	1(20.0)	0(0.0)	1(20.0)	3(60.0)
Week 2 Test Day				
Placing	2(40.0)	0(0.0)	0(0.0)	3(60.0)
Turning	1(20.0)	0(0.0)	1(20.0)	3(60.0)
Displacement	0(0.0)	0(0.0)	0(0.0)	5(100.0)
100% virtual[c]				
1st Day of Training				
Placing	3(75.0)	1(25.0)	0(0.0)	0(0.0)
Turning	4(100.0)	0(0.0)	0(0.0)	0(0.0)
Displacement	2(50.0)	1(25.0)	0(0.0)	1(25.0)
Week 1 Test Day				
Placing	1(25.0)	0(0.0)	1(25.0)	2(50.0)
Turning	1(25.0)	0(0.0)	0(0.0)	3(75.0)
Displacement	1(25.0)	0(0.0)	0(0.0)	3(75.0)
Week 2 Test Day				
Placing	1(25.0)	0(0.0)	0(0.0)	3(75.0)
Turning	1(25.0)	0(0.0)	0(0.0)	3(75.0)
Displacement	0(0.0)	1(25.0)	0(0.0)	3(75.0)

Note. [a]$n = 6$, [b]$n = 5$, [c]$n = 4$.

Objective two examined the visual inspection of participants' test welds; pass or fail as determined by a CWI (see Table 3.5). The data revealed that the participants fared better with the groove welds than with the fillet welds in both weld processes. This result is shown in the overall pass/fail rates as the groove welds were the only weld type that a majority of participants passed visual inspection in both weld processes. The weld type that had the highest number passed visual inspections were the 1G in each weld processes. The most difficult weld for the participants of this study was the 3F in both weld processes.

The examination of the pass/fail rate by training program type revealed several patterns. In the 50/50 VR to traditional 1-week program, the majority of the participants

failed visual inspection in all weld types except the 1G in the GMAW welding process. In the 100% VR 1-week training program, a majority of participants passed visual inspection, except in the GMAW 2F weld. When examining the 2-week training programs, the 50/50 VR to traditional group failed 60% (N = 29) of test weld visual inspections. However, the 75/25 VR to traditional group, 62.5% (N = 25) passed the visual inspections. The 100% VR group failed 59% (N = 19) of the test weld visual inspections.

Table 3.5

Frequencies of Visual Inspection of Test Welds

Program Type	SMAW				GMAW			
	2F *f* (%)	1G *f* (%)	3F *f* (%)	3G *f* (%)	2F *f* (%)	1G *f* (%)	3F *f* (%)	3G *f* (%)
Overall								
Pass	10 (43.47)	16 (69.56)	4 (26.67)	8 (53.33)	8 (37.78)	14 (60.86)	4 (26.67)	8 (53.33)
Fail	13 (56.53)	7 (30.44)	11 (73.33)	7 (46.67)	15 (65.22)	9 (39.14)	11 (73.33)	7 (46.67)
50/50 VR/T[a]								
Pass	0 (0.0)	1 (25.0)	-	-	1 (25.0)	3 (75.0)	-	-
Fail	4 (100.0)	3 (75.0)	-	-	3 (75.0)	1 (25.0)	-	-
100 Virtual[a]								
Pass	2 (50.0)	4 (100.0)	-	-	1 (25.0)	2 (50.0)	-	-
Fail	2 (50.0)	0 (0.0)	-	-	3 (75.0)	2 (50.0)	-	-
50/50 VR/T[b]								
Pass	2 (66.7)	4 (66.7)	1 (16.7)	3 (50.0)	2 (66.7)	3 (50.0)	1 (16.7)	3 (50.0)
Fail	4 (33.3)	2 (33.3)	5 (83.3)	3 (50.0)	4 (33.3)	3 (50.0)	5 (83.3)	3 (50.0)
75/25 VR/T[b]								
Pass	3 (60.0)	3 (60.0)	2 (40.0)	3 (60.0)	3 (60.0)	4 (80.0)	3 (60.0)	4 (80.0)

Table 3.5 (Continued)

Fail	2 (40.0)	2 (40.0)	3 (60.0)	2 (40.0)	2 (40.0)	1 (20.0)	2 (40.0)	1 (20.0)
100 Virtual[b]								
Pass	3 (75.0)	4 (100.0)	1 (25.0)	2 (50.0)	0 (0.0)	2 (50.0)	0 (0.0)	1 (25.0)
Fail	1 (25.0)	0 (0.0)	3 (75.0)	2 (50.0)	4 (100.0)	2 (50.0)	4 (100.0)	3 (75.0)

Note. VR = virtual reality, T = Traditional.
[a]1-week training program using the VRTEX® Mobile unit.
[b]2-week training program using the VRTEX® 360 unit.

The third objective of this study sought to examine the relationship between participant dexterity and visual inspection pass/fail rates of test welds. To examine these relationships, the researchers calculated a bivariate Pearson's correlation (see Table 3.6). All three dexterity tests were statistically significant in terms of the visual pass/fail rates of the participants for the 2F and 1G weld types in the SMAW welding process. The correlation between the placing test was statistically significant with the 2F weld type on the first day of training. All three dexterity tests had a statistically significant relationship with the 2F weld type on the test day of Week 1. The relationship between the turning test was statistically significant with the 2F weld type on the test day of Week 2. The 1G weld type was statistically significant on both test days with the turning test only.

Table 3.6

Point-biserial correlations between Participant Dexterity and Visual Inspection Pass/Fail Rate

	SMAW				GMAW			
Type of Test	2F *r(p)*	1G *r(p)*	3F *r(p)*	3G *r(p)*	2F *r(p)*	1G *r(p)*	3F *r(p)*	3G *r(p)*
1st Day of Training								
Placing	.417*	.257	.504	.358	.203	-.077	.110	-.087
	(.048)	(.237)	(.055)	(.190)	(.353)	(.726)	(.695)	(.758)
Turning	.117	.351	.344	.355	.084	-.202	.359	.355
	(.596)	(.100)	(.209)	(.209)	(.705)	(.355)	(.188)	(.194)
Displacement	.206	.244	.354	.111	.383	-.151	.069	.095
	(.345)	(.262)	(.196)	(.695)	(.072)	(.491)	(.807)	(.736)
Week 1 Test Day								
Placing	.590**	.351	.424	.229	-.118	.140	.052	.115
	(.003)	(.101)	(.115)	(.411)	(.593)	(.523)	(.509)	(.684)
Turning	.614*	.546**	.181	.113	-.132	.019	-.185	.184
	(.002)	(.007)	(.518)	(.688)	(.548)	(.933)	(.509)	(.512)
Displacement	.619*	.406	.272	.298	.200	.067	.152	.231
	(.002)	(.055)	(.326)	(.280)	(.359)	(.760)	(.588)	(.407)
Week 2 Test Day								
Placing	.428	.066	.328	.204	-.018	.338	-.019	-.018
	(.111)	(.815)	(.232)	(.467)	(.950)	(.218)	(.946)	(.950)
Turning	.642**	.560*	-.085	.312	-.179	.454	-.092	.183
	(.010)	(.030)	(.764)	(.257)	(.524)	(.089)	(.745)	(.513)
Displacement	.450	.140	.109	.430	-.228	.486	.100	.107
	(.092)	(.620)	(.699)	(.110)	(.413)	(.066)	(.724)	(.703)

Note. $*p < 0.05$, $**p < 0.01$.

To interpret the magnitude of the relationship between the two variables, Gravetter and Wallnau (2009) indicated that r^2 should be used (see Table 3.7). Gravetter and Wallnau (2009) suggested the following scale when interpreting the r^2 statistic: 0.01 = small effect; 0.09 = medium effect; 0.25 = large effect. Following these criteria, all dexterity tests exhibited very large effects on the pass/fail rates of the participants' test

welds. The turning test on the test day of Week 2 exhibited the largest effect in the study. The placing test on the first day of training exhibited a large effect on the pass/fail rate.

Table 3.7

Effect Size of Dexterity Tests and Visual Pass/Fail Rates

Dexterity Test	*N*	*r*	*p*	r^2
2F-SMAW				
Placing Test (0)	23	.417	.048*	.173
Placing Test (1)	23	.590	.003**	.348
Turning Test (1)	23	.614	.002**	.377
Displacement Test (1)	23	.619	.002**	.383
Turning Test (2)	15	.642	.010**	.412
1G-SMAW				
Turning Test (1)	23	.546	.007**	.298
Turning Test (2)	15	.560	.030*	.313

Note. *$p < 0.05$, **$p < 0.01$.

Conclusions and Discussion

Several conclusions can be drawn from the results of this study. First, one trend identified was that dexterity increased for a majority of participants during the training program. However, several participants either exhibited no change in dexterous ability or reduced dexterity during the training program. The change in ability supports the notion that it takes time to master the craft of welding (Giachino & Weeks, 1985). The increase in dexterous ability over the first week of training raises the question of whether it might be better to test for dexterity after the first week of training. Additionally, do participants need a sufficient amount of time to become acclimated to the new skills they are learning before being tested or should their innate abilities before learning new skills be the basis of selection?

It can also be concluded that more time in a VR environment will yield larger increases in dexterous ability. This result is evident in all but the 50/50 VR to traditional training methods. In relation to the determinants of job performance, this relates to the increase in procedural knowledge and skills (Campbell et al., 1993). This finding suggests that VR gives participants the capability to hone task-related abilities, which supports previous research that has used simulations in the medical, dental, and welding fields for training purposes (Boulet et al., 2003; Kunkler, 2006; Papadopoulos et al., 2013; Stone et al., 2011). This increased ability within the procedural knowledge and skills area may lead to an improvement to the number of performances an individual could complete. With the VRTEX® systems, users can receive instant feedback through numerical grades and graphical representations of the welding parameters. The use of cheater lenses that help guide the user to the correct angles, speed, position, and arc length can also be used. Traditional training method is a trial-and-error type of learning environment in which no instant feedback is available; therefore, feedback must come after showing one's work to an instructor. From the results, it can be concluded that dexterity can increase with the use of instant and accurate feedback.

When examining the pass/fail rates from the visual inspections, it can be concluded that participants were better at performing simpler welds. It can also be concluded that participants in the 100% VR training programs performed the 1G weld better than did those in the other training programs. Additionally, the 75% VR to 25% traditional training methods outperformed the other training method types. This finding suggests that this training method may better prepare beginning welders. Allowing

participants to practice longer in VR environments also allows them to become proficient in the psychomotor skills needed before entering the real-world welding environment.

Objective three sought to explore the relationship between participant dexterity and the pass/fail rates of the visual inspection to examine the predictability of dexterity on future performance. This objective reinforced Campbell et al.'s (1993) determinants of job performance component of procedural knowledge and skill because dexterity can affect overall task performance. It can be concluded that dexterity can predict future performance of beginning welders completing basic SMAW welds, which supports findings from other occupational fields (Gansky et al., 2004; Gettman et al., 2003; Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969). All tests showed significant relationships with beginning welders' abilities to visually pass/fail inspection by a CWI. This finding implies that industry personnel can use dexterity to select people to enter welding training programs that use basic SMAW welds.

Understanding that dexterity is linked to the performance of simpler welds, industry can utilize this information to be able to select participants for training programs. This ability will help allow industry to improve productivity, efficiency, and effectiveness of welding training programs. This is the objective of the Priority Area 3 of the American Association of Agricultural Education's National Research Agenda (Doerfert, 2011). If agricultural educators are able to teach the basic psychomotor skills in secondary schools, it may lead to further efficiency by providing a more prepared individual to go into a welding training program.

Recommendations

Conclusions from this study lead to several recommendations. First, it is recommended that welding training programs use VR simulations to aid in the training process, which also allows novices to become more efficient. With the increase need for certified welders, it is a necessity to create efficient training programs.

With the ability to use dexterity to predict future performance with simple welds, it is recommended that training programs that teach simple welds use dexterity testing to select individuals for their programs. Additionally, the prerequisite of good dexterity, may lead to better candidates applying for welding training programs. The ability to select individuals to train will also help welding training programs be objective when there is an influx of individuals drawn to welding by VR simulators.

The researchers also recommend that future studies be conducted to examine the use of dexterity to predict future performance using different dexterity tests. Future study is needed to examine the dexterity required to predict future performance for complex welds. It is suggested that dexterity tests also evaluate fine, finger and hand, and gross, hand and arm, dexterity. Finally, it is recommended that future studies examine the possibility of creating a dexterity test that more closely resembles the movements of a welder to improve the ability of dexterity to predict future performance.

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CHAPTER IV. THE EFFECT OF VIRTUAL REALITY SIMULATION ON ANXIETY IN WELDING TRAINING

A paper prepared for the submission to the *Journal of Agricultural Education*

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Abstract

This study examined the use of virtual reality to reduce anxiety of individuals in a welding training program. Byrd and Anderson (2012) posited that a more efficient way to train welders has become a necessity. With the multiple safety concerns related to the welding profession, numerous triggers of anxiety are present. This study used the VRTEX® Mobile and 360 virtual reality welding simulator to examine whether virtual reality could reduce anxiety in welders. Researchers recorded anxiety related measures with the BioHarness® data logger system. Live readings were made via the BioHarness® and a laptop. Data collected related to anxiety included heart rate, respiration rate, body temperature, and pulse. Participants were also video recorded during the completion of the test welds to aid in identifying triggers of anxiety during the welding process. It can be concluded that all participants experienced anxiety during the completion of test welds, which affected their abilities to produce a passing weldment. This finding implies that, if the industry and agricultural education teacher preparation programs can reduce the amount of anxiety that trainees experience, it may lead to improved performance.

Introduction

One area that agricultural education pre-service teachers experience anxiety is in teaching agricultural mechanics (Foster, 1986; Hubert & Leising, 2000). Furthermore, numerous studies have indicated that teacher competence within agricultural mechanics was needed before and after accepting a teaching position (Hubert & Leising, 2000; Schlautman & Siletto, 1992). Knoblock and Whittington (2002) posited that education, experience, and support can help novice teachers become more efficacious and effective teachers. Therefore, understanding what makes pre-service teachers anxious about learning and teaching agricultural mechanics is needed so that methods of reducing anxiety can be created. In order to create methods that reduce anxiety, researchers must first understand what anxiety is and how it can affect an individual.

Anxiety is a tense and unsettling anticipation of a threatening event that has a negative effect on an individual, yet the cause is unknown (Rachman, 2004). Anxiety and fear are closely related because both feelings have negative effects, which has led to the two words to be used interchangeably (Barlow, 1988; Goodwin, 1986; Rachman, 2004). However, distinctions between the two can be made to understand how each feeling affects different individuals. Rachman (2004) stated that distinctions could be made between the causes, duration, and maintenance of fear and anxiety.

Fear is described as a reaction to a specific, perceived danger and identifiable threat. Reactions to fear are usually intense and recede after the danger is removed (Rachman, 2004). On the other hand, anxiety is described as a heightened vigilance to

an emergency reaction, which causes an uneasy tension of which the cause is not readily identifiable (Rachman, 2004). Anxiety can be experienced at any given time or place.

While researchers have identified several types of anxiety, this study only examined social anxiety and social phobia because of the social nature of a learning environment. The terms social phobia and social anxiety are used interchangeably and are associated with social anxiety disorder (Barlow, 1988; Rachman, 2004). The critical feature of social anxiety is an intense and persistent fear of social or performance situations (Barlow, 1988; Goodwin, 1986; Rachman, 2004). Manifestation of anxiety symptoms can take many forms because this anxiety is experienced in social situations (Barlow, 1988; Goodwin, 1986; Rachman, 2004). Specifically, the innate fear of possible scrutiny because one might behave in a manner that is embarrassing, unacceptable, or inept occurs among individuals who suffer from social anxiety (Rachman, 2004).

Individuals who suffer from social phobia have a predisposition to feeling anxious in social situations (Rachman, 2004). Cognitive theorists hold three beliefs about those who suffer from social anxiety: (1) perfectionist standards for social performance, (2) false beliefs about social evaluation, and (3) negative views about the self. Another difference is a more direct focus on internal feelings and their significance, including whether the emotional state one is in is visible to others (Rachman, 2004).

Rachman (2004) noted that individuals who suffer from social anxiety might misinterpret the emotional reactions of others as an indication of criticism, which makes

these individuals think they are the center of attention. When interpreting others' emotions, these individuals may feel threatened because they think others can see that they are inept or inadequate within the social situation. If the person interprets the emotional reaction as benign, a friendly or accepting feeling will occur and anxiety will subside. If the reaction were interpreted as harmful, the person would get the feeling that they may be shunned or rejected. If an individual experiencing social anxiety interprets a reaction as negative it may lead them to escape, avoid, cope, or block that social interaction from happening again (Rachman, 2004).

Although symptoms of anxiety are mostly negative, in the workplace, anxiety can yield positive results (Stein & Hollander, 2003). Specifically, Stein and Hollander (2003) noted that anxiety, to some degree, is always present in the workplace and can be beneficial sources of motivation. The concept of anxiety and stress in the workplace and learning how to manage these feelings are widely accepted; however, some believe that they are the victims of anxiety and stress.

Having employees who suffer from anxiety and stress can have detrimental effects to the rest of the organization (Pflanz & Heidel, 2003). Specifically, workers who suffer from stress and anxiety may experience poor job performance, job dissatisfaction, absenteeism, and interpersonal conflict. In fact, psychiatric illnesses have been shown to affect at least 48% of Americans during their lifetimes, and approximately 30% of the U.S. population deals with anxiety related illnesses annually (Pflanz & Heidel, 2003). Pflanz and Heidel (2003) found that anxiety related disorders cost industries approximately $4 billion per year, and 88% were attributed to decreased

productivity. One such occupation that could be affected by anxiety disorders is welding.

In a welding environment, many factors might trigger anxiety. A majority of the triggers that may lead to anxiety stem from safety issues related to welding such as electrical shock, compressed gases, air contamination, fire, explosion, and arc radiation (Cary & Helzer, 2005; Jeffus, 2012). Electrical shock is a concern because of the voltage used to weld, which ranges from 115 to 460 volts for most alternating current (AC) sources; however, fatalities can occur with equipment using less than 80 volts (Jeffus, 2012). Additionally, the welding arc emits ultra-violet (UV) rays, also known as arc radiation, which is harmful. The UV rays emitted can cause flash burn to unprotected eyes and severe sunburns to exposed skin while welding (Cary & Helzer, 2005; Jeffus, 2012).

Another safety concern is air contamination, which is the smoke or fumes that rise from the welding process. The smoke or fumes are created by the metal being welded, the chemical composition of the flux, and the length of time a welder is exposed to the fumes (Cary & Helzer, 2005). Welding also produces sparks that can travel up to 40 feet and contact flammable substances; therefore, working in an area that is not suitable for welding, can cause fire and explosions (Cary & Helzer, 2005; Jeffus, 2012). A safety concern with compressed gases is specifically the gas cylinders used to provide the shielding gas for various welding operations (Cary & Helzer, 2005; Jeffus, 2012). Inadvertently breaking off the tank valve would allow a cylinder to act like a rocket.

With the different safety issues related to the welding occupation, it is clear that beginning welders may exhibit more anxiety related symptoms. Ursano, Fullerton, Wiesaeth, and Raphael (2007) postulated that inexperienced disaster volunteers might be at higher risks for acute effects of psychological discomfort than experienced personnel might. Understanding that inexperienced individuals may exhibit more symptoms of anxiety is imperative when examining methods to reduce anxiety within training programs. Further, reducing anxiety levels may lead to increased levels of performance (Pflanz & Heidel, 2003).

One suggested method to reduced anxiety in beginning welders is the integration of virtual reality (VR) simulations (Byrd & Anderson, 2012), but research into this topic has not been conducted. Kunkler (2006) stated that the use of simulations provides a safe realistic computer-based environment for individuals to practice. Virtual reality environments can be used to train workers to acquire the basic skills necessary to perform the tasks required for a job in a technical field (Manca, 2013). Additionally, the use of VR simulations allows trainees to learn basic skills in a safer environment (Lucas, Thabet, & Worlikar, 2007). One study found that full and partial VR integration into a welding training program was appropriate, but depended on the level of task difficulty (Stone, McLaurin, Zhong, & Watts, 2013). Therefore, this study examined whether the introduction of VR into a welding training program would reduce anxiety exhibited by inexperienced individuals.

Conceptual Framework

The guiding framework of this study was a model of anxiety by Rachman (2004). Rachman (2004) described anxiety as a process, not a categorical event that does or does not occur. Specifically, anxiety is a feeling created through several cognitive realizations as shown in Figure 4.1.

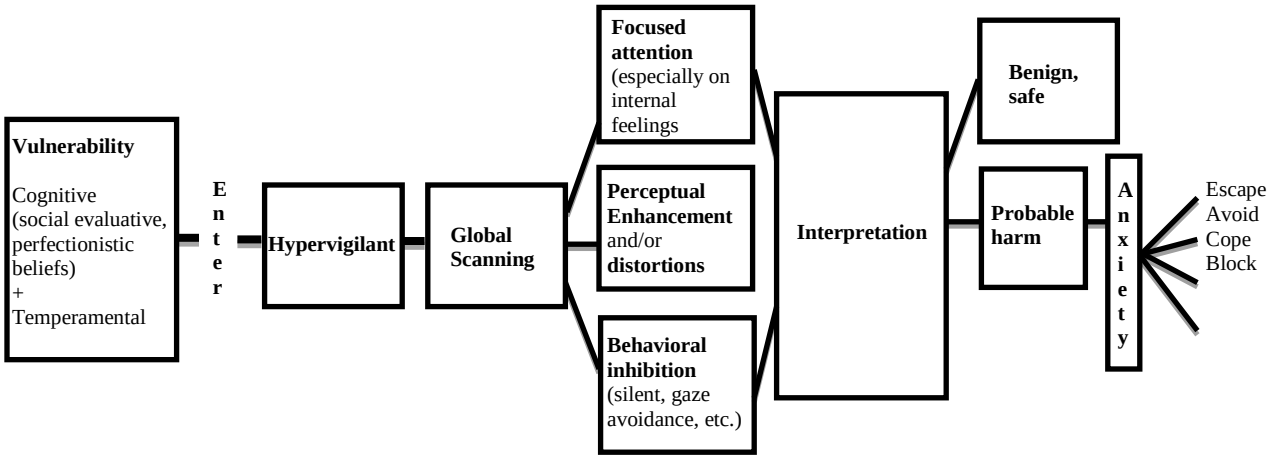

Figure 4.1. A model of anxiety. From *Anxiety* (p. 5), by S. Rachman, 2004, New York, NY: Taylor & Francis, Inc. Copyright 2004 by Psychology Press, Ltd. Reprinted with permission.

Rachman (2004) terms an individual's susceptibility to anxiety as *vulnerability*, and the degree of vulnerability varies from person to person. Temperamental vulnerabilities are not controlled by one's mind and are experiential and biological in nature (Rachman, 2004). Cognitive vulnerabilities are shaped from personal experiences and present beliefs that are controlled by one's mind. Susceptibility to anxiety is tested when individuals enter new or unfamiliar environments.

Rachman (2004) also proposed that an individual predisposed to anxiety becomes hypervigilant upon entering an environment. Hypervigilance can be observed

when an individual begins global scanning using rapid eye movements throughout the visual field (Rachman, 2004). When global scanning, individuals first broaden their attention to detect any threats; if a threat is found, their attention will narrow as they process the threat. Hypervigilance usually does not continue after individuals overcome their anxiety (Rachman, 2004).

Focused attention occurs when threats are identified and individuals focus all of their attention solely on the threat; they also appear inattentive to everything else around them (Rachman, 2004). Rachman (2004) noted that in extreme cases of anxiety, perceptual enhancements or distortions occur. For example, once an individual leaves a familiar place they are fixated by globally scanning for threats. Behavioral inhibition may occur as the individual detects a threat and decides to find a place of safety to avoid that threat (Rachman, 2004). The information gathered from global scanning and focusing one's attention on a threat is used to determine whether the threat is benign or harmful. Rachman posited that misinterpretations have two dimensions in which the probability or the seriousness of an event occurring is exaggerated.

Rachman (2004) stated that, if a threat were found to be benign, the individual would not experience anxiety. Conversely, if the threat is found to be harmful, the individual would attempt to reduce the anxiety. Four common ways exist in which an individual can reduce the effects of anxiety: escape, avoid, cope, and block (Rachman, 2004). Once an individual experiences anxiety, he or she will try to reduce the effects by escaping the situation as quickly as possible (Rachman, 2004). If this occurs several times at the same place, the individual will begin to avoid that place (Rachman, 2004).

To cope with not being able to go into an environment that causes anxiety, an individual might ask someone else to go or to accompany him or her (Rachman, 2004).

Purpose and Objectives

The purpose of this quasi-experimental study was to examine the effects of VR on the anxiety level of participants in a welding training program. In addition, the study sought to describe the effects of participants' anxiety susceptibility on the visual inspection pass/fail rates on test welds. This study also intended to describe the relationship between the time participants experienced anxiety when completing the test welds and the visual inspection pass/fail ratings. Insight gained relating to how anxiety affects beginning welders can benefit welding training programs and other educational setting that teaches welding-based skills (e.g., agricultural education programs). This research aligns with the American Association for Agricultural Education's National Research Agenda Priority Area 3: Sufficient scientific and professional workforce to address the challenges of the 21st Century (Doerfert, 2011, p. 9). Specifically relating to improve agricultural productivity efficiency and effectiveness, is the need to increase sustainable growth in the private setting (Doerfert, 2011). The study aimed to address the following objectives:

1. Describe the average welding program trainee in terms of susceptibility to anxiety.
2. Examine the pass/fail rates of visual inspection of test welds performed by participants.

3. Determine whether a relationship exists between participants' susceptibility to anxiety and visual inspection pass/fail rates.
4. Examine the number of instances participants exhibited anxiety in terms of ECG heart rate spikes.
5. Determine whether a relationship exists between participants' anxiety and the visual inspection pass/fail rates.
6. Identify triggers of anxiety experienced by participants during the completion of test welds.

Methods

This study was a small portion of a larger study that used VR integrated welding school and real-world welding school environments. The welding schools were constructed at the agricultural mechanics laboratory located on the Iowa State University 450 Farm. During this study, a certified welding instructor (CWI) oversaw the real-world welding school. The materials stocked for the real-world welding school included welding jackets, gloves, slag hammers, wire brushes, auto-darkening welding helmets, Miniflex® Portable weld fume control units, and Power Wave® C300 multi-purpose welders. The consumable material used included 3/8 inch thick coupons (groove weldments), 1/2 inch thick coupons (Tee weldments), and Excalibur® 7018 electrodes conditioned in an electrode oven.

The researchers were trained extensively on the VRTEX® 360 Virtual Reality Arc Welding Trainer and oversaw the VR welding school portion. The VR welding school was equipped with three VRTEX® 360 Virtual Reality Arc Welding Trainers

with shielded metal arc welding (SMAW) stingers, helmet, and plastic coupons. This trainer was chosen because it was the highest fidelity VR simulator available at the time of this study. Additionally, this VR simulator allowed users to be fully immersed in a 3D VR welding environment. For the virtual training, users wore a welding helmet with integrated stereoscopic VR screens and used dynamic visual feedback in the form of visual overlays for known welding variables.

Participants

Before any training took place, participants were given an informed consent form, which the participants signed and returned. Twenty male and three female participants were randomly assigned to either an integrated training or the full VR training. The number of participants was initially limited to have a student to CWI ratio that was representative to a real-world welding training program, which generally does not exceed 12 students at a time. Participants fell into two groups of experience. The first group had little to no practical experience in SMAW prior to beginning the study. The second group had practical experience in SMAW, but did not hold any welding certifications. To create a true random sampling, the amount of experience was not known until after participants were grouped. Participants chose to complete either a 1- or 2-week welding training program according to their availability during the summer. When participants volunteered, the details of the training programs were not given and the participants were placed into one of the virtual reality integrated training programs by the researchers. The 1-week program taught participants how to SMAW the 2F (horizontal fillet weld) and 1G (flat groove weld) welds. The 2-week program also

taught the 3F (vertical fillet weld) and 3G (vertical groove weld) welds. Refer to Table 4.1.

Table 4.1

Welding Training Program Type Characteristics

Program Type	Length	% Training	# of Dexterity Test Days*	Positions Tested
50/50 VRTEX® Mobile	1-week	50% - Virtual Reality 50% - Traditional	2	2F, 1G
100% VRTEX® Mobile	1-week	100% - Virtual Reality	2	2F, 1G
50/50 VRTEX® 360	2-weeks	50% - Virtual Reality 50% - Traditional	3	2F, 1G, 3F, 3G
75/25 VRTEX® 360	2-weeks	75% - Virtual Reality 25% - Traditional	3	2F, 1G, 3F, 3G
100% VRTEX® 360	2-weeks	100% - Virtual Reality	3	2F, 1G, 3F, 3G

Note: *Each test day participants completed the placing, turning, and displacement dexterity tests four times, one trial run and three timed trials.

The experimental groups included 100% VR training, 75% VR and 25% real-world training, and 50% VR and 50% real-world training. Participants received safety training before entering the welding environment. Within the VR training room, participants received instruction from the researchers on using the VRTEX® 360 Virtual Reality Arc Welding Trainers. In the VR training, participants worked in groups of three or four per VRTEX® 360 simulator. In the real-world training, participants had individual welding booths, but could work together if they wanted. In the real-world welding training portion, participants received instruction from the CWI on using the Power Wave® C300 multi-purpose welders. The weld training program included practice time from Monday through Thursday and a test on Friday. The only exception

to this schedule was the 100% VR group, which received real-world training on Thursday afternoon to acclimate to real-world welding so participants could perform the test welds on Friday.

To assess anxiety levels, participants filled out the Zung (1971) self-rated anxiety scale (SAS), and the researcher took electrocardiogram (EKG or ECG) readings. The Zung SAS was used to measure the participants' susceptibility to anxiety. The Zung SAS is a survey instrument of 20 statements on how an individual might feel when anxious. Participants rated each statement on a summated rated scale of none or a little of the time, some of the time, good part of the time, or most of the time (Zung, 1971). Responses were converted into a point system between one and four. The points were then added together for an overall raw score, which was then converted into an anxiety index that ranged from 25 to 100. Zung recommended the following scale to interpret the anxiety index: 25-45 = normal range; 45-59 = minimal to moderate anxiety; 60-74 = marked to severe anxiety; and 75-100 = extreme anxiety. This interpretation was used to describe participants' susceptibility to anxiety.

The ECG measurements included blood pressure, respiration rate, temperature, and pulse rate. Heart rate was used because prior research has linked heart rate to anxiety (Shinba et al., 2008). To obtain these measures, participants wore BioHarness® data logger systems. The BioHarness® is a chest strap with two sensors and a removable transmitter/logger built in. Data were streamed live to a laptop computer and logged onto the built in transmitter/logger.

To identify periods of anxiety accurately, a basal reading was taken for all participants while standing at rest. The basal reading was taken in a standing position because real-world welding stations require the participants to stand while welding. The basal reading was compared to the ECG measurements to identify moments of anxiety; specifically, based on individuals' heart rates. Participants were also recorded via a closed-circuit camera system as they welded their certification test plates. When periods of anxiety were identified, researchers used the time stamp to review the recordings of participants' test welds to help identify the cause(s) of the anxiety.

Data were analyzed using Microsoft Excel 2010 and Predictive Analytics Software (PASW) Statistics 18.0 software package. Descriptive statistics were calculated to identify frequencies of pass/fail rates and dexterity percentile rankings. A point-biserial correlation was calculated to examine the relationship between participants' susceptibility to anxiety and visual pass/fail rates. Because anxiety data were numerical and the visual inspection pass/fail rates were dichotomous, the point-biserial correlation calculation was necessary to evaluate the relationship between the variables (Gravetter & Wallnau, 2009). The researchers used the *r* squared (r^2) statistic to examine the effect size of the point-biserial correlation (Gravetter & Wallnau, 2009).

Results

This study sought to describe the effect of VR on anxiety in individuals in a welding training program. The intent of objective one was to describe participants' susceptibility to anxiety as measured using the Zung (1971) SAS instrument. The results are shown in Table 4.2. Of the 23 participants, only two exhibited susceptibility to

anxiety in the range of minimal to moderate. The other 21 participants fell into the normal range of anxiety susceptibility. The two participants who had the higher susceptibility to anxiety were in the 75% VR and 25% traditional and the 100% VR groups.

Table 4.2

Anxiety Susceptibility of Participants by Welding Training Program

Program Type	*N*	%
Overall		
Normal	21	91.3
Minimal - Moderate	2	8.7
50/50 VR/Trad.[a]		
Normal	4	100.0
Minimal - Moderate	0	0.0
100 VR[a]		
Normal	4	100.0
Minimal - Moderate	0	0.0
50/50 VR/Trad.[b]		
Normal	6	100.0
Minimal - Moderate	0	0.0
75/25 VR/Trad.[b]		
Normal	4	80.0
Minimal - Moderate	1	20.0
100 VR[b]		
Normal	3	75.0
Minimal - Moderate	1	25.0

Note. VR = virtual reality, Trad. = Traditional
[a]1-week training program using VRTEX® Mobile.
[b]2-week training program using VRTEX® 360.

The second objective sought to describe participants' visual inspection pass/fail rates of the completed test welds (see Table 4.3). Overall, participants in all groups had similar pass/fail rates (N = 38, 50.0%) of the 76 test welds completed. Only two welding training programs visually failed a majority of the test welds: 1-week 50% VR and 50% traditional and 2-week 50% VR and 50% traditional groups. The program that

exhibited the highest percentage of failed test welds (*N* = 7, 87.5%) was the 1-week 50% VR and 50% traditional training program. When examining the pass/fail rates by weld type, participants visually passed more of the simple welds (2F and 1G, 56.5%) than the complex welds (3F and 3G, 43.5%).

Table 4.3

Visual Inspection Pass/Fail Rates of Participants' Test Welds by Program Type

Program Type	*N*	Pass *f* (%)	Fail *f* (%)
Overall	76	38 (50.0)	38 (50.0)
50/50 VR/Trad.[a]	8	1 (12.5)	7 (87.5)
100 VR[a]	8	6 (75.0)	2 (25.0)
50/50 VR/Trad.[b]	24	10 (41.7)	14 (58.33)
75/25 VR/Trad.[b]	20	11 (55.0)	9 (45.0)
100 VR[b]	16	10 (62.5)	6 (37.5)

Note. VR = virtual reality, Trad. = traditional
[a]1-week training program using VRTEX® Mobile.
[b]2-week training program using VRTEX® 360.

Objective three examined the relationship between the visual pass/fail rates and participants' susceptibility to anxiety calculated from the Zung's SAS instrument. The researcher calculated a point-biserial correlation to determine whether any relationship existed between the two variables (see Table 4.4). The results showed no statistical significance between the average participant susceptibility of anxiety and visual inspection pass/fail rate for any test weld type.

Table 4.4

Point-biserial correlation of Average Participants' Susceptibility of Anxiety and Visual Inspection Pass/Fail Rates by Weld Type

SMAW Weld Type	*N*	*r*	*p*
2F	23	-.271	.212
1G	23	-.131	.551
3F	15	.207	.459
3G	15	-.026	.926

The researchers further examined the correlation by the visual pass/fail rates and participants' susceptibility to anxiety by looking at the type of welding training program to determine whether anxiety susceptibility was affected by the training program type. The statistical results of the point-biserial correlation between the participants' susceptibility of anxiety and visual inspection pass/fail rates by welding training program type are shown in Table 4.5. The only statistically significant relationship for participants' susceptibility to anxiety was found with the 2F weld in the 100% VR training program that used the VRTEX® 360 (p = .000). To interpret the magnitude of the relationship, the researchers calculated r squared (r^2) following the suggestions of Gravetter and Wallnau (2009) who suggested using the following scale: 0.01 = small effect; 0.09 = medium effect; 0.25 = large effect. In this instance, participant susceptibility of anxiety had a very large effect (r^2 = 1.00) on the visual inspection pass/fail rate.

Table 4.5

Point-biserial correlation of Average Participants' Susceptibility of Anxiety and Visual Inspection Pass/Fail Rates

SMAW Weld Type	*n*	*r*	*p*	r^2
100 VR[a]				
2F	4	-1.00	.000	1.00

Note. VR = virtual reality, Trad. = traditional
[a]2-week training program using VRTEX® 360.

The fourth objective aimed to examine the number of times participants exhibited anxiety while completing the test welds. To determine the number of instances that participants exhibited anxiety, the researchers used the ECG readings and counted the number of spikes in heart rate above the initial basal readings. When examining the 1-week training session, the 100% VR group, on average, experienced anxiety more than the 50/50 VR/Traditional group. The same trend was seen within the 2-week program. Also in the 2-week training programs, average anxiety decreased between week one and two. The decrease in participants' average anxiety between week one and two was observed in all three variations of the programs in varying degrees. Table 4.6 displays the average number of instances of anxiety by training group and welding position.

Table 4.6

Average Number of Instances of Anxiety by Training Group and Welding Position

Training Program	Flat Position *N*(*M*)	Vertical Position *N*(*M*)	Overall *N*(*M*)
50/50 VR/Trad.[a]	34 (8.5)	-	34 (8.5)
100 VR[a]	33 (11)	-	33 (11)
50/50 VR/Trad.[b]	39 (6.5)	32 (6.4)	71 (11.8)
75/25 VR/Trad.[b]	39 (7.8)	28 (5.6)	67 (13.4)
100 VR[b]	33 (8.25)	26 (6.5)	59 (14.75)

Note: VR = virtual reality, Trad. = traditional

[a]1-week training program using VRTEX® Mobile.
[b]2-week training program using VRTEX® 360.

For objective five, the researchers analyzed data to determine whether a relationship existed between participant anxiety (heart rate and breathing rate) and the visual inspection pass/fail rate using a point-biserial correlation (see Table 4.7). Not all weld types yielded a statistically significant relationship with the overall anxiety measures of heart and breathing rate. The 3F-SMAW weld type indicated statistical significance with the minimum ($r = .736$, $p < .01$) and average heart rate ($r = .750$, $p < .01$) on the test day of Week 1, and with the maximum heart rate ($r = .770$, $p < .01$) on the test day of Week 2. Statistical point-biserial correlations were also found between heart or breathing rate and 2F and 3G in SMAW and 1G, 3F, and 3G in GMAW. Only the 2F-SMAW weld type and maximum breathing rate on the test day of Week 1 yielded a medium effect size; the other significant relationships yielded large to very large effect sizes.

Table 4.7

Point-biserial correlation (r) and Effect Size (r^2) of relationships between Participant Anxiety Measures and Visual Inspection Pass/Fail Rates

Weld Type/ Anxiety measure	2F-SMAW	3F-SMAW	3G-SMAW	1G-GMAW	3F-GMAW	3G-GMAW
Week 1						
HR – Min		.736** (0.541)				
HR – Max	-.497* (0.247)					
HR – Avg		.750** (0.562)			.632* (.399)	
BR – Min				.497* (0.247)		

Table 4.7 (Continued)

BR – Max	-.446* (.198)				
Week 2					
HR – Max		.770** (.592)			
BR – Min					-.713** (.508)
BR – Max	-.562* (.315)		-.626* (.391)		

Note: $r(r^2)$, $^{**}p < .01$, $^{*}p < .05$. HR = heart rate, BR = breathing rate.

To examine whether training program type had an effect on the relationship between anxiety measures and the visual inspection pass/fail rates, the data were grouped by training program type (see Table 4.8). The 3F-SMAW weld type yielded statistical relationships with the five anxiety related measures. The four complex welds all yielded statistically significant relationships with the anxiety related measures. The 2-week 50/50 VR and traditional training method using the VRTEX® 360 revealed the largest number of statistical relationships. Following Gravetter and Wallnau (2009) all the relationships were large.

Table 4.8

Point-biserial correlation between Participant Anxiety Measures and Visual Inspection Pass/Fail Rates by Training Program

Weld Type/ Anxiety measure	3F-SMAW	3G-SMAW	1G-GMAW	3F-GMAW	3G-GMAW
50/50 VR/Trad[a]					
BRw1 – Min			.986* (.972)		
50/50 VR/Trad[b]					
HRw1 – Min	.863* (.744)			.863* (.744)	

Table 4.8 (Continued)

HRw2 – Max	.963** (.927)		.963** (.927)	
BRw2 – Max		-.954* (.910)		
75/25 VR/Trad[b]				
HRw1 – Min	.919* (.844)			
BRw1 – Min	.920** (.846)			
HRw2 – Min				-.995** (.990)
100 VR[b]				
HRw2 – Min	-.998* (.996)			
BRw2 – Min				-1.00** (1.00)

Note: $r(r^2)$, $^{**}p < .01$, $^{*}p < .05$. HR = heart rate, BR = breathing rate.
[a]1-week training program using VRTEX® Mobile.
[b]2-week training program using VRTEX® 360.

To examine the relationship between participant anxiety and visual inspection pass/fail rates further, a point-biserial correlation was calculated between the average number of instances that participants experienced anxiety and the visual inspection pass/fail rates. Only two instances were statistically significant: the 2F (r = .448, p = .036) and 3F (r = .530, p = .042). When examining the magnitude of the relationships, anxiety exhibited a medium effect on the 2F (r^2 = 0.20) and a large effect on the 3F (r^2 = 0.28) weld types.

Objective six sought to identify triggers of anxiety during the completion of test welds. Anxiety triggers were identified using the logged ECG readings and video recordings of participants' test welds. Moments of anxiety were identified using individuals' basal ECG readings compared to their ECG readings during the individual

test welds. Time stamps were used to pinpoint the moment during the video recordings to identify what may have caused an individual's anxiety.

In the flat position test welds moments of anxiety were present at various times during the welding process such as before the weld, starting the weld, during the weld, completing the weld, and after the weld was completed. Several participants revealed anxiety while setting up their weldments in preparation to begin the welding process. Anxiety at this stage as identified by participants practicing the psychomotor skills needed prior to striking an arc and shuffling the weldment around trying to get into a better position to perform the weld. Multiple participants revealed anxiety at the start of the weld. Identified anxiety triggers of participants at the beginning of a weld included the electrode sticking when trying to establish an arc and an arc not being established while striking the electrode.

Several participants experienced anxiety during the welding process. The identification of the triggers in several cases was impossible because participants blocked the view of the camera. The anxiety triggers identified here included moments when participants realized they were at the wrong travel/work angles or off position with the bead. These indicators were identified by participants shifting their hands and body positions. Another anxiety trigger was stopping and trying to restart a weld.

Participants also exhibited anxiety when completing a weld properly. Several participants' anxieties were triggered when they realized that they did not completely finish a weld or realized the weld was poor. Not properly finishing a weld refers to participants running out of an electrode before reaching the end of a weldment. The

most common time that participants' anxieties were triggered was after a weld was completed. Specifically, after a weld was complete, all participants had to chip away the protective slag covering left by the flux and clean the weld with a wire brush. Anxiety was identified in most participants during the chipping and cleaning phase after a weld.

Conclusions and Discussion

Several conclusions can be drawn from the results of this study. First, one trend identified was that participants' susceptibility to anxiety was normal; however, participants experienced anxiety during the completion of test welds. Pflanz and Heidel (2003) postulated that anxiety could have negative effects on job performance. The pass/fail rate of the test welds reinforced this notion. It can also be concluded that participants' susceptibility to anxiety did not affect their chances of passing or failing a test weld. Participants' anxiety during the completion of weld tests did not relate to their being susceptible to anxiety. This conclusion leads to the question of whether the Zung (1971) SAS is appropriate to access anxiety susceptibility for a welding training program.

Another conclusion that can be drawn is that heart rate during the completion of test welds is related to participants' abilities to produce passing weldments 50 percent of the time. An increase in heart rate could be an indication of harmful anxiety triggers. Rachman's (2004) model of anxiety portrays harm as being directed at an individual mentally or physically. The manner that an anxiety trigger could be harmful in this study might not represent harm as Rachman (2004) described; however, could be harmful to the weldment causing it to fail visual inspection. Furthermore, the

subsequent passing or failing of the weldment could create harm. Participants in this study reacted to the anxiety triggers in the same manner by coping with it and completing the test welds.

Furthermore, the number of instances that participants experienced anxiety affected the completion of test welds. One trend identified was as the percent of VR training increased, so did the number of instances that anxiety was experienced. In addition, the number of instances of anxiety decreased from week one to week two. This finding could be because participants became more familiar with the welding environment and were able to cope with the anxiety (Rachman, 2004).

Finally, anxiety affected an individual's ability to complete a weldment that could pass visual inspection. The effect of anxiety may be linked to the action of focused attention as described in Rachman's (2004) model of anxiety. When an individual notices that a mistake has occurred, he or she might focus attention on how the mistake might affect the ability to pass visual inspection by the CWI, instead of on the weld being performed.

Recommendations

Conclusions from this study lead to several recommendations. First, it is recommended that welding programs prepare trainees for anxiety triggers, as highlighted in this study, to reduce the effects during the completion of certification test welds. With the high need for welders, it is imperative to create environments that are conducive to learning, and to avoid triggering anxiety in trainees. Using an instrument that assesses an individual's susceptibility could allow a welding training program to create separate

training groups. Employing groups could also allow instructor to use different teaching methods that are better suited to individuals susceptible to anxiety.

It is also recommended that training programs use teaching methods and strategies that are proven to reduce anxiety in both formal and informal instructional settings (e.g., evaluating various transitioning schedules from VR to a real welding booth). This process might include having students who exhibit a susceptibility to anxiety observe a certified welder to help acclimate to a real welding situation. The ability to acclimate an individual to a situation by placing them into it allows them to observe and might lead to reduced levels of anxiety when he or she tries to complete the same task. The inclusion of anxiety reducing strategies will help achieve the goal of the American Association of Agricultural Education Research Agenda Priority Area 3 of addressing the challenges faced by industry in the 21st century. By reducing the time needed to certify welders would increase the efficiency, productivity, and effectiveness of the training programs to provide sustainable growth in the private setting.

Future studies are recommended to assess the ability of an individual's level of susceptibility to anxiety to predict future performance by purposively selecting participants. The researchers also recommend using various instruments that assess susceptibility to anxiety to determine whether a better instrument is suited for a welding training program. Purposively selecting participants will allow for a higher ratio of individuals who susceptible to anxiety than did the present study.

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CHAPTER V. THE USE OF VIRTUAL WELDING SIMULATORS TO EVALUATE EXPERIENCED WELDERS

A paper prepared for the submission to *The Welding Journal*

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Abstract

Virtual reality welding simulations have been and continue to be a current trend in welding training programs. The goal of this study was to examine the use of virtual reality simulations as an assessment tool for existing welders. This study used a virtual reality welding simulator, specifically the VRTEX® 360, to assess the existing skills of experienced and trained novice welders. This study used the Shielded Metal Arc Welding (SMAW) process to perform simple (2F and 1G) and complex welds (3F and 3G). Performance was computed with the virtual reality welding simulator in the form of a quality score. The quality score was based on five welding parameters: arc length, position, work angle, travel angle, and travel speed. The virtual reality welding simulator distinguished performance between experienced and trained novice welders. On average, experienced welders scored 10 quality points higher than did trained novice welders. Welding experience also had a large to very large effect on the quality score for each weld type. One identified trend for both experienced and trained novice welders was as weld difficulty increased, the quality score decreased. The results demonstrated the ability of a virtual reality welding simulator to distinguish between experienced and trained novice welders for the weld types used in this study. It is recommended that industries use virtual reality simulators to evaluate experienced welders to ensure high quality welding in production practices.

Introduction

An emerging method of assessment within several industries is the immersion of individuals into a virtual reality (VR) simulation (Ref. 1). This theme is the result of industry use of VR simulations to allow trainees to learn basic skills in a safer environment (Ref. 2). One study found that full and partial VR integration into a welding training program was appropriate, but depended on the level of task difficulty (Ref. 3). However, the ability of VR simulations to evaluate existing skill has received only limited attention.

Virtual reality environments can be used to train workers to acquire the basic skills to perform the tasks required for a job in a technical field. However, performance in a VR environment could be used as an indicator to hire an individual. Training within a VR environment can prepare a trainee on how to anticipate and recognize when situations go awry, as well as to test an individual's decision-making skills under normal and stressful conditions. Such evaluation is possible through dynamic and continuously changing VR environments. Training in such environments can lead to increased memory retention, reduced human error, and a deeper understanding of the complexities of a work environment. Evaluating the critical thinking skills is also possible by evaluating how an individual adapts to changing conditions within a VR environment (Ref. 4).

A study conducted at Yale University trained surgical residents in postgraduate years 1-4 utilizing virtual reality surgical simulation to train skills and reduce surgical error in the operating room. It was concluded that residents trained on the VR surgical

simulator were 20% more efficient at performing gallbladder surgery. The residents who were not trained on the simulator were five times more likely to injure the gallbladder and non-target tissue. The study found that using a VR surgical simulator helped the residents to hone their surgical skills in a safe environment, thus, reducing surgical error in the operating room. The results from the study demonstrate the ability of VR simulators to train individuals without prior experience and to adequately prepare them for the workforce. Thus, it is possible to determine whether an employer should hire an individual based on their performance in a virtual environment (Ref. 5).

Obtaining the resources to train workers using a VR simulator is necessary; however, being able to measure how competent the trainee is after using the simulation is imperative. A potential advantage of VR simulation is the ability to measure technical competence using software programming. A key aspect to evaluate an individual's competency successfully using reality simulation is creating a rule-based analysis of the performance (Ref. 6). To enable the programming to measure an individual's competence accurately, the simulation needs to look and feel as realistic as possible (Ref. 7)

Virtual reality offers the potential to act as an evaluation tool because every simulation within the virtual reality environment can be recorded and produce quantitative feedback that could facilitate assessment tasks (Ref. 8). Research has found that simulations can be used with the young and old. Furthermore, the focus of incorporating virtual simulation is changing from educating novices and interns to the importance of continued training of experienced personnel. One example of experienced

personnel using VR is found in aviation. Aviation simulations are applied regularly individually and to groups regardless of participant seniority (Ref. 9). Another example is in the utilization of medical simulators. One study that used virtual reality medical simulations found that on average medical residents' (M = 64.9) performed better than medical students (M = 57.1) (Ref. 10). The study suggested that VR simulations could play a future role in continuing medical education and recertification (Ref. 11).

A VR simulation in certifying medical personnel is an important consideration for medical programs. Several associations and training programs are considering the use of simulators for health care professionals' skills certification. For example, the Joint Commission on Allied Health Personnel in Ophthalmology (JCAHPO) uses simulations to evaluate Certified Ophthalmic Technician (COT) skills. Simulator-based evaluations have replaced hands-on skills used in JCAHPO evaluations in 250 test centers nationwide. Research has found that simulations that look and feel like actual procedures help clinicians develop skills and maintain those skills throughout their professional practice (Ref. 7).

Theoretical Framework

The theory of individual differences in task and contextual performance guided this study. Individual performance is described as behavioral, episodic, evaluative, and multidimensional. Furthermore, performance is defined as an aggregate of behavioral episodes that add value to an organization. The theory of individual differences uses the distinction between task and contextual performance to identify and define behavioral episodes to describe an individual's performance. Refer to Fig 5.1.

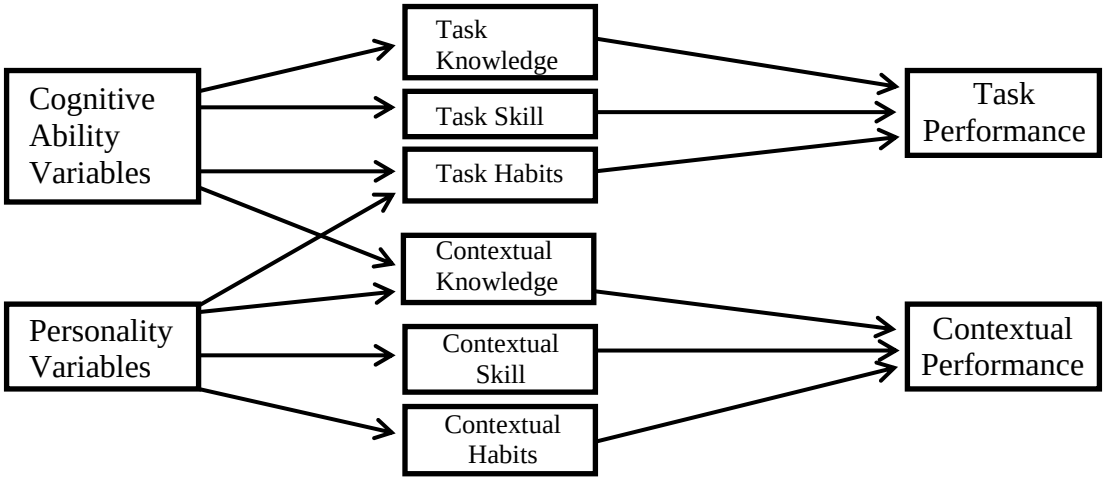

Figure 5.1. A theory of individual differences in task and contextual performance. Adapted from "A theory of Individual Differences in Task and Contextual Performance," by S. Motowidlo, W. Borman, and M. Schmit, 1997, *Human Performance, 10*(2), p. 79. Copyright 1997 by Lawrence Erlbaum Associates, Inc. Reprinted with permission.

Contextual performance refers to behaviors that influence the psychological, social, and organizational environments of an organization. Task performance refers to an individual's affect to the technical core of an organization, which assembles the products of that organization. Task performance is divided into two types of tasks. The first type of tasks includes the transformation of raw material into a finished product or service. The second includes service and maintenance of the technical core by helping restock raw materials, move finished products, planning, and supervising or coordinating the first type of task performance (Ref. 12).

For this study, the researchers focused on the first type of task performance that deals with the construction of finished products. Task skill is affected directly by an individual's cognitive abilities, such as prior experiences. Additionally, cognitive ability can have positive or negative effects on performance depending on the nature of prior experiences. Specifically, cognitive ability can affect three intervening variables of task

performance: task knowledge, task skill, and task habit. Task knowledge, which is largely affected by an individual's cognitive ability, allows for a higher rate of retention and mastery of procedures, principles, and facts. Task skill refers to an individual's ability to use technical information, make judgments, and perform technical skills related to an organization's core functions. Task habits refer to patterns of learned behavior that contribute or impede to the execution of organizational tasks (Ref. 12). Within a task performance, the researchers focused specifically on the effect of an individual's cognitive ability for task knowledge and task skill when completing welding related tasks.

Research Goal

The goal of the study was to examine the ability of VR as an effective assessment tool for existing skill among welders. The researchers addressed this goal by comparing experienced welders to trained novice welders in terms of participants' VR performance. Performance was defined in terms of a quality score based on five welding parameters. For this study, the VRTEX® 360 welding simulator was selected because it is capable of providing realistic simulations that were appropriate for this study. The researchers hypothesized that a VR simulator would be able to indicate the difference between experienced welders and trained novice welders.

Methods

Experimental Materials

This portion of the study used one VRTEX® 360 Virtual Reality Arc Welding Trainer with SMAW stinger, helmet, and plastic coupons. This trainer was chosen

because it was the highest fidelity VR simulator on the market at the time of this study. This VR simulator allowed users to be fully absorbed in a VR welding environment. Participants wore a welding helmet with integrated stereoscopic VR screens.

Location

This study took place at several locations to obtain a sufficient number of participants during the fall of 2013. The research sites varied between nine locations ranging from classrooms to union halls. The researchers moved the VRTEX® 360 Virtual Reality Arc Welding Trainer from one facility to the next when invited. The day, time, and number of participants at each location with the VRTEX® 360 Virtual Reality Arc Welding training simulator varied because of the specific times requested by each location.

Participants

The population of this study consisted of 49 male participants of varying ages. All the participants of this study have been through a formal welding training program and currently employed as a welder. The participants were categorized as either experienced welders or trained novice welders. Experienced welders were categorized based as either having at least 10 years of welding experience or being a certified welder (CW). Trained novice welders were individuals that had no more than one year of experience. This study included 18 experienced and 31 trained novice welders.

Independent and Dependent Variables

The dependent variable was the quality score for the SMAW test welds (2F, 1G, 3F, 3G). The two independent variables were experience level of participants and weld

type (in order of increasing difficulty: 2F (horizontal fillet weld), 1G (flat groove weld), 3F (vertical fillet weld), and 3G (vertical groove weld).

Participant performance was evaluated using a quality score generated by the VR simulator. The quality score was determined by averaging the individual scores of five welding parameters: weld position, arc length, work angle, travel angle, and travel speed. Weld position refers to where the weld bead is formed in relation to the center of the weld joint. The appropriate distance from the tip of the electrode should be at the weld coupon, which is termed arc length. Work and travel angles are the appropriate horizontal and vertical angles the welder should keep between the electrode and weld coupon. Travel speed is the appropriate horizontal speed that a welder should move the electrode across a weld joint. After the completion of each test weld, the VRTEX® 360 welding simulator calculated a score that ranged from 0 to 100. The VRTEX® 360 welding simulator also averaged the five parameter scores into an overall quality score, which was recorded for each participant.

The researchers specifically wanted to know how the VR simulator would be used if brought in as an assessment tool in a real-world setting. As a result, the study was designed in a manner consistent with an independent evaluator used to assess a worker's welding skills. Therefore, participants were not trained to use all of the features available on the VRTEX® 360 welding simulator. Allowing participants to learn how to use the VRTEX® 360 fully would not have aided in answering the research questions of this study.

Experimental Procedure

At each research site prior to experimentation, participants were given informed consent forms followed by a questionnaire. The researchers then trained all participants to use the VRTEX® 360. To minimize usability of the VR system as a factor, all participants were allowed enough time to become acclimated with the system until they were comfortable with using the VR simulator. This included participants being able to correctly adjust the stereoscopic VR screens and produce a proficient bead on a practice plate. The participants then were instructed to perform test welds as they would in a real-world welding environment. The sequence of the tests performed were 2F (horizontal fillet weld), 1G (flat groove weld), 3F (vertical fillet weld), and 3G (vertical groove weld). The tests were done in sequence with no breaks in between. It should be noted that participants had only one chance to complete the test welds, and the settings for each weld were identical for each participant. The score for each test weld was recorded from the Live Action Student Evaluation Report (LASER) Screen (Ref. 13). This protocol was followed with every participant for this portion of the study at all locations.

Results

The performance measures for this study were welder's experience and test weld quality scores; the relationship between these variables was also examined.

Test Weld Quality Score

Once participants completed each test weld, a quality score was recorded (see Table 5.1). Differences were identified between experienced and trained novice welders

in several instances. A major difference was found in the range in quality scores, in which trained novices had a wider range of scores than did experienced welders. Another difference was identified when examining the minimum quality scores recorded. Experienced welders maintained an average minimum score in the low 70s for all weld types; the 3G weld yielded the lowest quality score at a 49. Trained novice welders' minimum scores fluctuated between 20 (3G) and 61 (2F). Examining the standard deviation, experienced welders were more consistent in ability than were trained novice welders for each weld type. Consistency amongst experienced welders is very evident with the 3F weld type in which the standard deviation was 4.43.

Table 5.1 – Quality Scores by Experience and Weld Type

Experience and Weld Type	N	Range	Minimum	Maximum	Mean	SD
Experienced 2F	18	30	70	100	86.33	7.88
Experienced 1G	18	30	70	100	84.89	8.24
Experienced 3F	18	17	72	89	82.50	4.43
Experienced 3G	18	41	49	90	77.39	10.57
Trained Novice 2F	31	38	61	99	78.94	9.05
Trained Novice 1G	31	57	32	89	74.68	11.41
Trained Novice 3F	31	38	52	90	71.97	9.10
Trained Novice 3G	31	65	20	85	62.35	16.23

When comparing the minimum score of the experienced welders and the maximum score of the trained novice welders, it is evident that there is overlap. This data illustrates that the VR simulator can evaluate current skill, but cannot accurately identify an individual as an experienced welder or a novice welder.

The test weld quality scores were averaged for each weld type by welder experience. An overall average was also calculated by averaging all scores for each experience level (see Fig. 5.2). Based on the data, the experienced welders outperformed the trained novice welders by an average 10 quality points. As a descriptive trend, the experienced welders outperformed the trained novice welders on all weld types. The separation in quality scores grew progressively as weld difficulty increased. The separations in average quality scores were 2F (7.39), 1G (10.21), 3F (10.53), and 3G (15.04). Another identified trend was that the 2F weld was the easiest weld performed by welders of both experiences levels. The scores then decreased progressively as the weld difficulty increased. Overall performance was highest among the experienced welder group with an average of 83, which was higher than the trained novice welder group by 12 quality points.

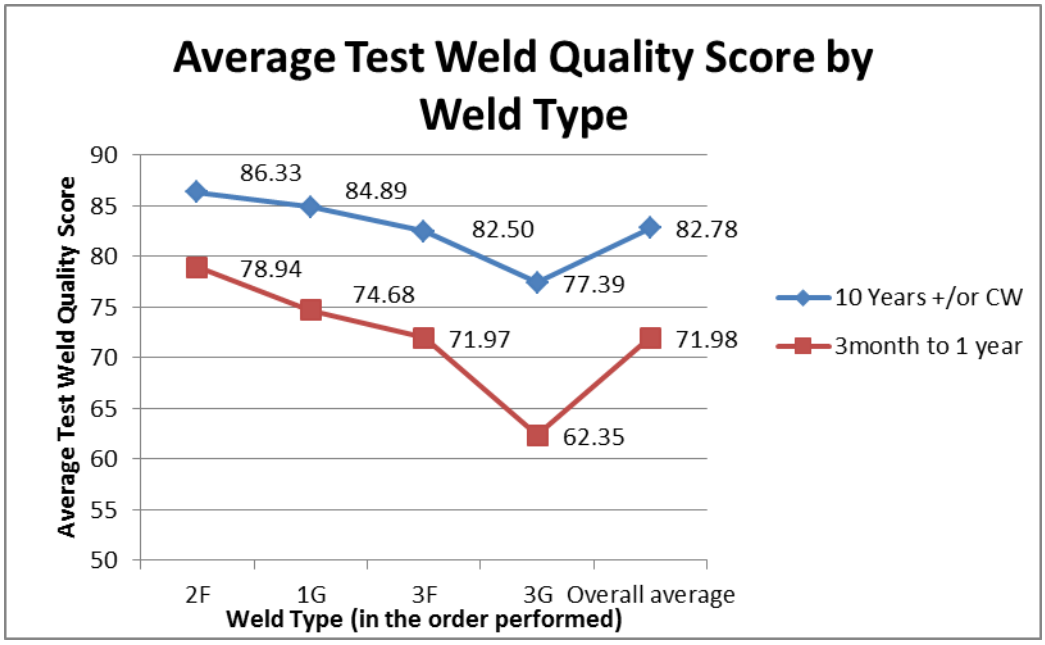

Fig. 5.2 – Average SMAW test weld quality score by weld type

To determine whether the groups were significantly different, it was necessary to determine whether the data were normal and had homogeneity of variance. Homogeneity of variance was examined by conducting Levene's Test (Ref. 14) (see Table 5.2). Each test was conducted using $\alpha = 0.05$ to indicate significance. Significance of the Levene's Test indicates that equal variances are not assumed. All weld types, except for 3F had equal variances; 3F has a *p*-value of 0.015, indicating which line to use to interpret the following *T*-test.

Table 5.2 – Levene's Test for Equality of Variance

Weld Type	F Ratio	P Value
2F	0.657	0.422
1G	1.402	0.242
3F	6.315	0.015
3G	2.458	0.124

After homogeneity of variance was calculated, a *t*-test was calculated for the levels of experience on all four weld types. The *t*-test was conducted for each weld using $\alpha = 0.05$ and 47 degrees of freedom (see Table 5.3). The results identified statistical significance for all weld types with *p* values ranging from 0.000 to 0.007. These findings indicated that a significant difference existed between the experienced welders' and trained novice welders' average quality score for each weld. To examine the effect that experience had on the average quality score, Cohen's d was calculated, which describes the effect size on the dependent variables, and is interpreted as small (0.2), medium (0.5), and large (0.8) (Ref. 14). According to the results of the Cohen's d,

experience had large effect on the 2F (0.830) and 1G (0.977). The 3F (1.582) and 3G (1.024) weld types exhibited a very large effect as Cohen's d was above 1.00.

Table 5.3 – T-Test Results for Welder's Experience

Weld Type	T	P Value	Cohen's d
2F	2.846	0.007	0.830
1G	3.352	0.002	0.977
3F	5.426	0.000	1.582
3G	3.512	0.001	1.024

Discussion

For the effectiveness of VR as an assessment tool to assess existing ability in welders, it was hypothesized that VR simulations would indicate a difference between experienced and trained novice welders. A discussion in light of this hypothesis follows for each of the weld types.

2F Weld Type

In this study, the 2F weld type was the simplest to complete. This was seen in both groups as the 2F weld had the highest average quality scores of all weld types tested. This finding indicates that the welders, both experienced and trained novices, are, on average, most competent to complete the 2F weld type. However, the VR simulator was able to distinguish between an experienced and trained novice welder. From the results obtained, it was determined that experience level had a large effect on an individual's weld quality score.

1G Weld Type

The 1G weld type was the second easiest weld for both levels of welders, experienced and trained novices. The difficulty was identified in the results as the average quality scores were second highest when performing the 1G weld. The 1G average quality score decreased from the average quality scores of the 2F weld type. The relationship between experience and quality score was also apparent with this weld type based on the results of the *t*-test. Specifically, the findings revealed a large effect of experience on the 1G weld type quality score. The results of the VR simulator continued to show a difference between experienced and trained novice welders with the 1G weld type.

3F Weld Type

The vertical fillet weld, 3F, was the second most difficult weld performed in this study by both experienced and trained novice welders. The average quality scores continued to decrease as the 3F weld type was identified as more complicated to perform than were the 2F and 1G weld types. A distinct difference was identified between the quality scores of experience and trained novice welders for the 3F vertical fillet weld. The results also revealed that the experience level had a very large effect on the quality score for the 3F weld type. Experience yielded the largest effect on performance with the 3F more than did any other weld type in this study. Experienced welders also demonstrated more consistent ability when examining the standard deviation of the quality scores on the 3F weld type compared to the trained novice welders. The VR

simulations were able to distinguish between both experienced and trained novice welders for the 3F weld type.

3G Weld Type

The most difficult weld performed by the experienced and trained novice welders in this study was the 3G weld type. Experienced and trained novice welders both scored the lowest quality scores on this weld type. A distinct difference was also apparent using the VR simulation between experienced and trained novice welders for the 3G weld type. Experience was also identified as having a very large effect on quality scores.

Conclusions

The results of this study suggest that VR simulations can be used as assessment tools to assess existing skill levels in welders. The differences between the experienced and trained novice welders were distinct for all weld types examined in this study. These findings support the theory of individual differences because individuals with more experiences were able to perform tasks at a higher level of success due to increased task knowledge and skill.

It can also be concluded that experienced welders were able to perform significantly better than were trained novice welders. Both groups showed a trend of decreasing quality scores as weld difficulty increased. The 2F and 1G welds tended to be easier for both the experienced and trained novice welders. Where the 3F and 3G welds were more complex in nature, and yielded a lower quality score from both experienced and trained novice welders. This conclusion supports the studies based on

the theoretcial framework as experience allows welders to perform better because of prior task knowledge and task skill of each weld type. However, the quality scores were able to identify which weld types the welders were most competent and least competent to complete.

Because VR has demonstrated the ability to assess existing welding skills, this method could be used to track a welder's skills over a period of time. This use of longitudinal data could be used in quarterly worker assessments for promotional purposes, as well as identifying when novice welders are ready to test for certification. In a setting where VR simulation would be used to assess existing skills, a system could be put into place for rountine assessment to ensure high quality welds in a production setting. The results of this study demonstrated the ability of VR simulation, specifically the VRTEX® 360, in assessing existing skills in welders in terms of a quality score based on five welding parameters (position, arc length, work angle, travel angle, and travel speed).

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CHAPTER VI. GENERAL CONCLUSIONS

This dissertation research resulted in three papers that examined different aspects of a welding training program. The first article analyzed the ability of a welding training participant's dexterity to predict future performance. The second article reported the effects of VR simulations on a welding training participant's anxiety levels during the completion of test welds. The third article reported the ability of VR simulations to evaluate seasoned welders. This chapter presents a summary, general conclusions, recommendations, and implications of the three research studies.

Several conclusions can be drawn from the results of this study. The first trend identified from this study was that participants' dexterous ability increased through one week of training. The change in dexterous ability supports Giachino and Weeks' (1985) notion that mastering the craft of welding takes time. Thus, one can conclude that the use of VR welding simulations helps improve the dexterous ability of users. In addition, one can conclude that the more time training with VR, the larger the increase in dexterous ability, which supports the findings of Stone, McLaurin, Zhong, and Watts (2013). In relation to the theory of individual differences in task and contextual performance, an increase in dexterous ability changes an individual's cognitive ability variables. Motowidlo et al. (1997) posited that cognitive ability variables shape an individual's task skills and habits. Using VR simulations in a training situation, further increasing the individual's dexterous abilities, may have a positive impact on the completion of task performance.

Although dexterous ability increased through the training program, the Complete Minnesota Dexterity Test was only able to predict future performance in the completion of simple welds. This supports the welding literature's notion that dexterity is an attribute needed to be a welder (Cary & Helzer, 2005; Giachino & Weeks, 1985; Jeffus, 2012; Jeffus & Bower, 2010).

Among the various training programs, the 75/25 VR/traditional training method may be the best suited to prepare beginning welders because the participants are given ample time to learn the correct psychomotor skills by replicating welds faster than in a traditional training method. This contradicts the findings of Stone et al. (2013) study that found the 50/50 VR/traditional training method to be the preferred method of training. Another aspect of the 75/25 VR/traditional training method that supports this notion is that the participants also have time to acclimate to the traditional welding environment. In comparison to the other two training programs, the 50/50 VR/traditional training method allows for ample time to acclimate to the traditional welding environment, but not as much time to learn the correct psychomotor skills. The 100 percent VR training method does not allow time for participants the time needed to become acclimated to the traditional welding environment.

Another identified trend was that anxiety was experienced by all participants during the completion of test welds. The average heart rate of the participants did not have a significant relationship with their ability to pass the CWI's visual inspection. However, the frequency of anxiety the participants experienced did affect their performance on the test weld. This supports the notion that is the anxiety experienced is

more related to workplace anxiety because it had an impact on the result of the completion of test welds (Stein & Hollander, 2003). Because the anxiety experienced by participants was during the welding process.

In relation to the theory of individual differences in task and contextual performance, anxiety plays a role in an individual's personality variables. A change in personality variables can affect task habits, which in turn affect task performance. If there is, an increase in the instances of anxiety during the welding process may lead to negative affects to an individual's task habits. A negative affect could lead to poor task performances. Another trend was that Zung's (1971) self-rating anxiety scale (SAS) proved inconclusive when using an individual's personality variable and anxiety susceptibility to predict whether participants who are more susceptible to anxiety exhibit more instances of anxiety.

When examining how task performance can be affected in an industry setting, anxiety can have a large effect. This effect was evidenced by participants' test welds failing the CWI's visual inspection. The anxiety participants experienced indicates a change in their task skill and habits in the completion of a task. According to Motowidlo, Borman, and Schmit (1997), task skill is the ability of an individual to perform technical skills; in this study, the skill was producing a weldment that would pass the CWI's visual inspection. Task habits are patterns of behavior learned over time that can contribute to or impede the completion of task performance (Motowidlo et al., 1997). Individuals who experience anxiety in a welding situation may learn work habits that are detrimental to completion of a weld that passes visual inspection. The learned

behavior will in turn decrease the individual's task skill by decreasing his or her ability to perform technical skills in an industry setting.

The last trend identified in this study was that virtual reality welding simulations can distinguish between novice and seasoned welders. The ability to distinguish between novice and seasoned welders supports the notion by Boulet et al. (2006) that virtual reality could be used evaluate trainees and seasoned workers. This supports the theory of individual differences in task and contextual performance because the differences in prior experiences affect task skill and habits (Motowidlo et al., 1997). As novice welders have basic task knowledge, skill, and habits, they did not perform as well as seasoned welders who had superior knowledge, skill, and habits. Although a distinction was made between the two groups, it was evident that both groups had areas that needed improvement. This was identified when examining the score for the four weld types that were tested. As the weld type increased in difficulty, the average scores decreased.

Industry use of virtual reality welding simulations to evaluate welders may lead to reduced costs in maintaining high-quality welders. Data gathered via the VR welding simulator can be used as longitudinal data to demonstrate growth in skill and performance, which in turn can be used in quarterly reports and promotions. The ability to evaluate a seasoned worker's task performance in a VR environment can lead to improved task skill and habits. Instituting an evaluation system that may lead to positive impacts on an individual's task skill and task habits may also lead to improved task performance.

It is recommended that the welding industry utilize dexterity testing to identify individuals more apt to successfully finish welding training and become certified welders. Secondly, industry should incorporate VR training methods into existing welding training programs. Furthermore, VR should also be integrated into quality control to provide an avenue to continually monitor existing welder's skills. By implementing these steps welding training and quality control can become more efficient.

The conclusions and implications of this study raise questions that warrant further research with regard to using dexterity as an indicator of future performance, employing virtual reality to reduce anxiety in beginning welders, and evaluating seasoned welders with virtual reality simulations.

Questions that warrant further research include:

1. What are the current teaching methods and strategies used to train beginning welders?
2. What are the most appropriate teaching methods and strategies to prepare beginning welders to face the different triggers of anxiety?
3. What would be the impact on a welding training program if dexterous ability were a selection criterion when choosing future trainees?
4. Would another dexterity test that focuses on fine motor skills be more accurate in measuring the dexterous movement of welders?
5. How would you identify when a novice welder is ready to test for certification in a virtual reality integrated welding training program?

6. What would be the financial impact on the welding industry if virtual reality simulations were used to evaluate seasoned welders?
7. How would a welding training program be setup if participants were selected based on dexterous ability and integrated virtual reality simulations?

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APPENDIX A

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Figure 4.1 Determinants of job performance components

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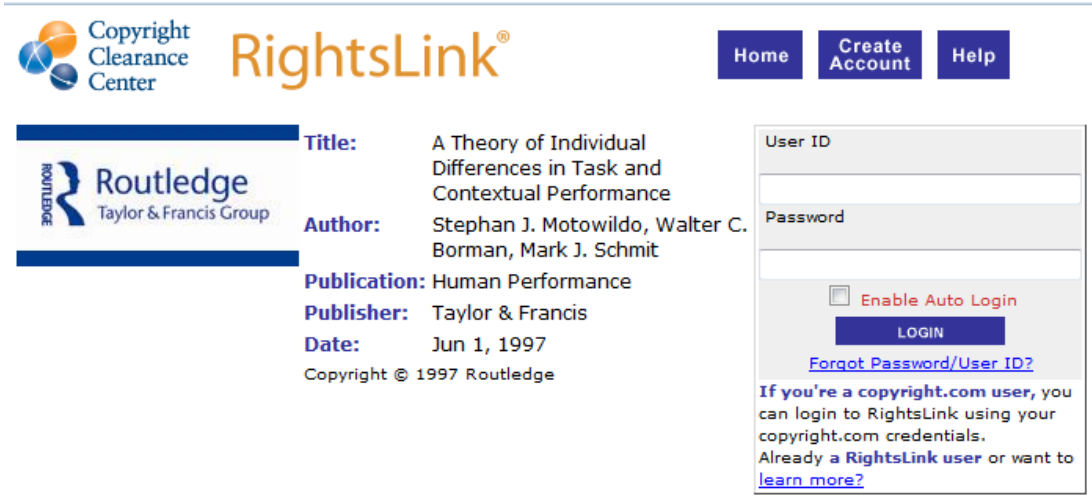

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