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# Dexterity: An Indicator of Future Performance in Beginning Welders

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## Abstract

*This study examined the use of dexterity as an indicator of future performance of beginning welders. This could lead to the selection or recruitment of participants for welding training programs. With a high demand for welders, it is imperative that welding training programs be efficient at producing certified welders. The time required to train certified welders is one of the obstacles training programs face. Many occupational fields have tried to predict a student's future performance before admitting them into a training program by analyzing their dexterous ability. This study utilized the Complete Minnesota Dexterity Test to examine participants' dexterity during a welding training program. Upon completion of the training program, participants performed tests welds that were overseen by a certified welding instructor (CWI) who visually inspected each weld. All three dexterity tests were found to have statistically significant relationships with the visual pass/fail rates for basic shielded metal arc welds.*

*Keywords*: Dexterity, SMAW, welding, future performance, welding training

## Introduction

Due to a resurge in the industrial manufacturing sector, welders are in greater need now than in the recent past (Cohen, 2015). According to Cohen (2015), the American Welding Society estimated the number of jobs for welders to increase by at least 10% in the next decade. Welding is a technical skill that requires its practitioners to be certified, which takes time, money, and talent (Stone, Watts, & Zhong, 2011). The time that is needed to train a person to become certified to weld is one of the areas that many welding educators have tried to shorten. For a skilled manual welder to master the craft of welding, it requires years of experience and training (Allen, 2008; Giachino & Weeks, 1985). Many companies have expressed that after extensive training, individuals are not able to weld at acceptable standards, and this has led to the high interest in trainability testing (Hitchings & Moore, 1991). The use of trainability tests was a means to develop a measure for career guidance and selection at the initial stages of vocational training (Higuera & Riera, 2004).

Since its inception, both industry and post-secondary welding training programs have been continuously evolving to better prepare welders. The graduates from these training programs have primarily been trained to become full time welders. Others use their welding skills to teach others. One such population of trainers/teachers is agricultural education teachers. Within the average agricultural education teacher program, welding skills are commonly taught in agricultural mechanics courses (Burris, Robinson, & Terry, 2005). Upon graduating, the newly certified teachers instruct secondary students the same welding skills they were taught. As the welding training evolves, so does the ability of agricultural education teachers to train and expose a younger generation to welding. One of the newer welding training aids being used are computer-based advancements such as virtual reality simulators (Byrd & Anderson, 2012). Simulations have been used in several occupational fields such as medicine, dentistry, 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). Because today's youth are exposed to electronics and technology at an earlier age, the use of virtual reality simulators has helped increase the awareness of welding to the younger generation (Postlethwaite, 2012). With the majority of learning and interaction occurring in a digital environment, virtual reality simulators create an avenue to recruit new students (Lincoln Electric, 2013). With this potential influx of new trainees to training programs is there a way to predict which people will have the best capability to successfully become certified welders?

Many occupations have tested student's abilities to predict future performance prior to admitting them into a training program, such as laparoscopic surgeons (Gettman et al., 2003), craft jobs (Levine, Spector, Menon, & Narayanan, 1996), assembly workers (Hitchings & Moore, 1991) and clerical, mechanical repairmen, electricians, and machine operators (Brown & Ghiselli, 1951). Some of the common tests that have been utilized to predict future performance include the analysis of 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 how effective these aptitude tests are at predicting future performance. A study by Gettman et al. (2003) showed that the measures of innate ability were able to accurately predict the future performance of 65% of laparoscopic surgeons (N=20). Gansky et al. (2004) found that manual dexterity was able to predict future performance of dental students in subsequent preclinical restorative courses.

Dexterity is one physical trait that has been examined as a possible predictor of future performance. According to Campbell (1977), 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. Jobs that require routine assembly, coil winding, and packaging dexterity has been validated in predicting performance, but not with jobs that require higher order abilities (Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969). Welding is an occupation that requires higher order abilities to complete every weld that is performed (Byrd, 2014). Therefore, would dexterity be able to predict performance in a welder?

Previous welding researchers have stated that welders need manual dexterity, good eyesight, and good hand-eye coordination (Giachino & Weeks, 1985; Jeffus, 2012; Jeffus & Bower, 2010a). Giachino and Weeks (1985) also stated that welders need the ability to concentrate on detailed work and be free of disabilities that would prevent work in awkward positions. To evaluate these criteria, welder training programs have employed tests that evaluate mechanical ability, ability to judge shapes and sizes, remember designs, and manual dexterity when selecting apprentices (Fleming, 1937), but have 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. Mansell (1969) also stated that to teach dexterity of a specific skill, an analysis of the skill must first be completed because every skill has sub-skills that must also be known. Using dexterity and trainability testing techniques require the tests be designed around the skills of the particular job being studied (Hitchings & Moore, 1991).

A few of the welding parameters that a welder is required to maintain during the welding process are arc length, weld position, travel angle, work angle, and travel speed (Jeffus, 2012; Jeffus & Bower, 2010a). These parameters are crucial in order for the welder to correctly weld two pieces of material together. In the process of shielded metal arc welding (SMAW), these parameters are always in a state of flux (Jeffus, 2012). The state of flux is created by the welding electrode being consumed during the welding process (Jeffus, 2012). This 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 other aspect of welding that enhances the need of manual dexterity is the use of weave patterns. The manipulation of 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 effectively could lead a researcher to hypothesize that if a person has a high level of dexterity then they could be able to weld. Therefore, if a dexterity test that replicates the psychomotor skills necessary for welding were implemented in a training program, would the results of the dexterity test accurately predict the future performance of the individuals tested?

## Conceptual 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 define 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). Evaluating performance, effectiveness, and productivity within an industry setting can be difficult and may lead to confusion. Therefore, an individual must understand the differences between the terms in order to fully comprehend what performance truly represents. Performance of a job will produce a result, whereas effectiveness is the systematic evaluation of the results of a performance and productivity refers to the financial side, which studies how much money and effectiveness of workers is needed to achieve the next level of effectiveness (Campbell, 1999).

A performance component is comprised of determinants and antecedents as seen in Figure 1. Performance components are categories of actions people are expected to complete as part of a job (Campbell, 1999). Differences between people that perform the same job are expressed through performance determinants. Performance determinants include declarative knowledge, procedural knowledge and skill, and motivation. The three performance determinants compose a performance component. Declarative knowledge refers to the knowledge about facts and principals related to the job that an individual possesses. Procedural knowledge and skill refers to the physical and cognitive skills needed in order to complete a performance component. Skills that fall under procedural knowledge include cognitive, psychomotor, physical, self-management, and interpersonal. The final determinant is motivation, which refers to the effort a person puts towards a job. This involves an individual making the decision to expend effort, determine what level of effort to exert, and how long to exert effort when performing a job.

| Performance Component | = | Declarative Knowledge (DK): | X | Procedural Knowledge and Skills (PKS): | X | Motivation (M): |
|---|---|---|---|---|---|---|
| | | • Facts<br>• Principles<br>• Goals<br>• Self-knowledge | | • Cognitive skill<br>• Psychomotor skill<br>• Self-management skill<br>• Interpersonal skill | | • Choice to perform<br>• Level of effort<br>• Persistence of effort |

Predictors of Performance Determinants

DK = [(ability, personality, interests), (education, training, experience), (aptitude/treatment interactions)]

PKS = [(ability, personality, interests), (education, training, practice, experience), (aptitude/treatment interactions)]

M = (whatever independent variables are stipulated by your specific motivation theory being utilized)

...ance," 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.

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. Procedural knowledge and skill performance predictors consist of ability, personality, interests, education, training, practice, and aptitude interactions. Motivational antecedents are comprised of variables related to the theory of motivation being utilized. For this study, the researchers will focus on the performance antecedents of procedural knowledge and skill. The specific antecedent that will be examined is psychomotor skill as it relates to welding performance. The psychomotor skills will be evaluated in the terms of dexterous ability.

## Purpose and Objectives

The purpose of this study was to examine if dexterity could predict the future performance of a beginning welder. In addition, the study sought to describe the change in dexterity during the welding training study. This study also sought to determine if a relationship exists between an individual's dexterity and pass/fail rating from the visual inspection of the test weld based on the AWS D1.1 standards. This research aligns with the National Career and Technical Education research agenda objective 3.2.1 Innovative Instructional Technologies by providing technology to assess dexterity levels in the participants (Lambeth, Elliot, and Joerger, 2008). This study also aligns with research objective 4.1.5 Technical Skill Assessment because we are looking at if participants could produce a passing test weldment (Lambeth, Elliot, and Joerger, 2008). This research aligns with the American Association for Agricultural Education's National Research Agenda Priority Area 5: Efficient and Effective Agricultural Education Programs by specifically relating to how school-based agricultural education programs contribute to career and technical education and broader educational initiatives (Roberts, Harder, & Brashears, 2016). The following objectives were identified to address the purposes of this study.

1. Describe the dexterity of the participants in a welding training program at the beginning and after the completion of test welds.
2. Report the pass/fail rating of the AWS D1.1standard visual inspection of test welds performed by participants.
3. Determine if a relationship exists between participant dexterity and the pass/fail rating 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 utilizing the VRTEX® virtual reality welding simulators. This study was conducted at the [UNIVERSITY] where a virtual reality and welding training laboratory were utilized. The individuals who participated in this study did so voluntarily. There were incentives for participation that included having lunch provided each day and having the weld certification test fees paid for. There were three female and twenty male participants within this study. The background of the participants varied between college students, secondary educators, and individuals interested in entering the welding industry. The welding training programs were offered in five variations. The first variation was a one-week training program with a 50/50 virtual reality to traditional training. The second variation was a one-week training program with 100 percent virtual reality training. The third variation was a two-week training program with a 50/50 virtual reality to traditional training. The fourth variation was a two-week training program with a 75/25 virtual reality to traditional training. The fifth variation was a two-week training program with a 100 percent virtual reality training. The variation of training programs was based on the programs used in the study conducted by Stone, McLaurin, Zhong, and Watts (2013), plus the 75/25 virtual reality to traditional training group. The 75/25 virtual reality to traditional training group was added to determine if this treatment could be more successful at training participants to weld than the other two treatments from the previous study. Refer to Table 1 for the training program demographics.

To obtain dexterity data about the participants, the researchers utilized the Complete Minnesota Dexterity Test (CMDT). The CMDT is used to measure a person's rapid eye-hand coordination and arm-hand dexterity, also known as gross motor skills (Lafayette Instrument, 2012). This test consists of five individual tests, but only three tests were utilized because they closely replicated the movements used during the welding process. The tests that were completed by the participants included: a) placing test; b) turning test; and c) displacement test. The CMDT utilizes two test boards, each containing 60 holes. Sixty corresponding disks are utilized during the tests that participants manipulated with their hands and arms. The participants were required to stand for the dexterity tests and were not allowed to lean against the table because that would affect their dexterity. The dexterity tests were completed by participants on the first day of the welding training program and after the test welds were completed on test days. Depending on the length of the training program the participants were in determined how many times the dexterity tests were completed. Participants in the one-week session completed dexterity tests twice. During the two-week long session, participants completed the dexterity tests three times: once at the beginning of the training program and at the end of each week.

Table 1

*Welding Training Program Type Characteristics*

| Program Type | Length | % Training | *n* |
|---|---|---|---|
| 50/50 VR/Trad.[a] | 1 week | 50% - Virtual Reality | 8 |

| | | | |
|---|---|---|---|
| | | 50% - Traditional | |
| 100 VR[a] | 1 week | 100% - Virtual Reality | 8 |
| 50/50 VR/Trad.[b] | 2 weeks | 50% - Virtual Reality<br>50% - Traditional | 24 |
| 75/25 VR/Trad.[b] | 2 weeks | 75% - Virtual Reality<br>25% - Traditional | 20 |
| 100 VR[b] | 2 weeks | 100% - Virtual Reality | 16 |

*Note*: Each test day participants were tested to evaluate dexterous ability.

In the placing test, the two boards were laid on a tabletop side-by-side about 1" from the edge of the table. The board farthest away will have the disks in it. When the examiner says "start", the participant, using their dominant hand, will move the disks one by one from the top board to the bottom board. The participant's non-dominant hand was not allowed to brace the participant in any way during the test. Once all of the disks have been placed the time taken to complete the test was then recorded.

The turning test used only one board and all 60 disks. Starting in the top right corner, the participant used one hand to pick up a single disk, turn it with the other hand, and then place it back in the original spot on the board. The participant replicated this process for all discs on the top row of the board, then proceed to the next row below and work back across the board. They continued to follow this procedure until all of the disks have been turned, and the amount of time needed to complete the test was then recorded.

The displacement test used one board and all 60 disks. With all of the disks inserted on 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 would leave an empty space in the top left-hand corner of the board. The participant would then pick up the disk located directly below the empty space and then place it into the empty space. The participant would then continue moving the disks in the same manner until they reached the last disk in the bottom right hand corner. Time was recorded once the participant has completed the test.

For each test, the participants were given a practice run to fully understand how to perform the tests. Following the practice run, the participants completed each test three times. The time taken to complete 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 developed by the American Guidance Service (1969), to identify the participants' percentile rank. The percentile scale is used to interpret a subject's score in terms of percent of the normative population, the scale ranged from zero to 100 (Lafayette Instrument, 2012).

After the participants completed the welding training programs, they were given the opportunity to complete test welds that were visually inspected by a certified welding inspector (CWI). The visual inspection of the test welds represents the actual welding performance for this study. The length of the training program dictated how many test welds were completed by the participants. 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). The participants performed the welds utilizing SMAW and gas metal arc welding (GMAW) processes. The participants in the one-week session completed the 2F and 1G welds for both welding processes. Whereas the two-week session participants 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 American Welding Society (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 software package. Descriptive statistics were calculated to identify frequencies for pass/fail rates and dexterity percentile rankings. A bivariate correlation was calculated to examine the relationship between recorded times and visual pass/fail rates. With a numerical variable and a dichotomous variable utilizing the bivariate correlation calculation was needed to evaluate the relationship between the variables (Gravetter & Wallnau, 2009). Researchers utilized the *r* squared ($r^2$) statistic to examine the effect size of the bivariate correlation. To evaluate the effect size of a bivariate correlation Gravetter and Wallnau (2009) indicated that $r^2$ should be used.

## 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 in this study. Table 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 ranged from zero (low) and to 100 (high). This means that the participants in the 25 percent quartile represent those with the least dexterous ability. The individuals in the 100 percent quartile represent those with the most dexterous ability within the population.

When examining participant dexterity on the first day of training, it was identified that with the placing and turning tests 78.3 percent of the participants had low dexterous ability. However, 34.8 percent of participants demonstrated a very high level of dexterity on the displacement test on the first day of training. An increase in dexterous ability can be seen from the first day of training to the test day at the end of week one. This is evident on the placing test where the first day of training shown where none of the participants were identified as having very high dexterity; however, after the end of week one test day, 21.7 percent ($n = 5$) of the participants had a very high dexterous ability. This increase in dexterous ability was also evident in the turning and displacement tests. The improvement of dexterous ability continued to grow through the week two test day. The number of participants exuding a very high level of dexterity increased by 11.9% – 31.6%.

Table 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] $n = 15$.

To further examine this increase in dexterous ability, the data were separated by the type of training program. The participants in the 50/50 virtual/traditional training program had no change in dexterous ability from the first day of training to the week one test day. However, in the 100 percent virtual training program a growth in dexterous ability can be seen in all three dexterity tests. Although, it is interesting to note that 25 percent of participants' dexterous ability dropped in the one-week training program.

In the two-week 50/50 virtual and traditional training method, an overall increase in dexterous ability can be seen across all three types of tests completed. The one exception was during the week-two test day where 13.7 percent of participants fell from the 50 percent group to the 25 percent group. The drop indicates a loss of dexterous ability. The 75/25 virtual/traditional training group shown an increase in overall dexterous ability for all types of tests completed on test days for both weeks. The most striking change is in the turning test, where 80 percent of the participants had an increase in dexterity. Within the 100 percent virtual training group, participants also had an overall increase in dexterity. The placing and turning tests had the largest increase in ability where 75 percent of participants had a positive shift in ability.

Objective two examined the visual inspection, based on AWS D1.1 standards, of participants' test welds. The rating of the visual inspection was either a pass or fail, determined by a CWI. It can be determined that the participants fared better with the groove welds than the fillet welds in both weld processes. This is shown in the overall pass/fail rates as the groove welds were the only weld type that majority of participants passed the visual inspection for both weld processes. The weld type that had the highest number visual inspections that passed was the 1G in each weld processes. The most difficult weld for the participants of this study in terms of successfully passing was the 3F in both weld processes.

When examining the pass/fail rate by training program type, several patterns can be identified. In the 50/50 virtual/traditional one-week program, most of the participants failed visual inspection in all weld types except the 1G in the GMAW welding process. Within the 100 percent virtual one-week training program many of the participants passed visual inspection, expect for the GMAW 2F weld. When examining the two-week training programs, the 50/50 virtual to traditional group failed 60 percent (*n* = 29) of the visual inspections. However, the 75/25 virtual/traditional group passed 62.5 percent (*n* = 25) of visual inspections. The 100 percent virtual group failed 59 percent (*n* = 19) of the test weld visual inspections.

The third objective of this study sought to examine the relationship between participant dexterity and the participants corresponding visual inspection pass/fail rates. To examine the relationship a bivariate Pearson's correlation was calculated. The results can be seen in Table 3. All three dexterity tests given were found to be significant with the visual pass/fail rates of the participants for the 2F and 1G weld types in the SMAW welding process. The placing test was found to be significant with the 2F weld type on the first day of training. However, all three dexterity tests were found significant with the 2F weld type on test day of week one. The turning test was significant with the 2F weld type on test day of week two. The 1G weld type found significance on both test days with the turning test only.

Table 3

*Bivariate Correlations between Participant Dexterity and SMAW Visual Inspection Pass/Fail Rate*

| | SMAW | | | |
|---|---|---|---|---|
| Type of Test | 2F *r(p)* | 1G *r(p)* | 3F *r(p)* | 3G *r(p)* |
| 1st Day of Training | | | | |
| Placing | .417*(.048) | .417*(.048) | .417*(.048) | .417*(.048) |
| Turning | .117 (.596) | .117 (.596) | .117 (.596) | .117 (.596) |

| | | | | |
|---|---|---|---|---|
| Displacement | .206 (.345) | .206 (.345) | .206 (.345) | .206 (.345) |
| Week 1 Test Day | | | | |
| Placing | .590** (.003) | .590** (.003) | .590** (.003) | .590** (.003) |
| Turning | .614* (.002) | .614* (.002) | .614* (.002) | .614* (.002) |
| Displacement | .619* (.002) | .619* (.002) | .619* (.002) | .619* (.002) |
| Week 2 Test Day | | | | |
| Placing | .428 (.111) | .428 (.111) | .428 (.111) | .428 (.111) |
| Turning | .642** (.010) | .642** (.010) | .642** (.010) | .642** (.010) |
| Displacement | .450 (.092) | .450 (.092) | .450 (.092) | .450 (.092) |

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

In Table 4, the results of the bivariate correlations are displayed. None of the dexterity tests utilized in this study were found to have any significant relationship with the visual inspection pass/fail rates.

Table 4

*Bivariate Correlations between Participant Dexterity and GMAW Visual Inspection Pass/Fail Rate*

| | GMAW | | | |
|---|---|---|---|---|
| Type of Test | 2F *r(p)* | 1G *r(p)* | 3F *r(p)* | 3G *r(p)* |
| 1st Day of Training | | | | |
| Placing | .203 (.353) | -.077 (.726) | .110 (.695) | -.087 (.758) |
| Turning | .084 (.705) | -.202 (.355) | .359 (.188) | .355 (.194) |
| Displacement | .383 (.072) | -.151 (.491) | .069 (.807) | .095 (.736) |
| Week 1 Test Day | | | | |
| Placing | -.118 (.593) | .140 (.523) | .052 (.509) | .115 (.684) |
| Turning | -.132 (.548) | .019 (.933) | -.185 (.509) | .184 (.512) |
| Displacement | .200 (.359) | .067 (.760) | .152 (.588) | .231 (.407) |
| Week 2 Test Day | | | | |
| Placing | -.018 (.950) | .338 (.218) | -.019 (.946) | -.018 (.950) |
| Turning | -.179 (.524) | .454 (.089) | -.092 (.745) | .183 (.513) |
| Displacement | -.228 (.413) | .486 (.066) | .100 (.724) | .107 (.703) |

To interpret the magnitude of the relationship between two variables, Gravetter and Wallnau (2009) indicated that $r^2$ should be used. The results of the $r^2$ calculations can be seen in Table 5. 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 the suggestions of Gravetter and Wallnau (2009), all dexterity tests exhibited a very large effect on the pass/fail rates of the participants' test welds. The turning test exhibited the largest effect in the study on test day of week two. The placing test on the first day of training exhibited a large effect on the pass/fail rate yet was the lowest out of the tests that revealed a significant relationship.

## Conclusions and Discussion

From the results of this study several conclusions can be drawn. First, one trend that was identified was dexterous ability for many of the participants increased during the training program. Conversely, there were several participants that either exhibited no change in dexterous ability or they lost 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). Because of the increase in dexterous ability over the first week of training, would testing for dexterity after the first week of training so that participants could become acclimated to the welding process be better? Do participants need a sufficient amount of time to become acclimated to the new skills they are learning before being tested or should a person's innate ability before learning new skills be the basis of selection? Would offering a weeklong introduction to the welding program where individuals could be recruited based on growth and potential help draw a better set of trainees?

Table 5

*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.

It can also be concluded that with more time in a virtual reality environment the more dexterous ability increased. This is evident in all but the 50/50 virtual/traditional training methods. This suggests that virtual reality gives participants the capability to hone their task related abilities, which supports the conclusions of previous research using 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). With the VRTEX® systems users can get 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. With traditional training methods, it is a trial and error type of learning environment where there is no instant and accurate feedback provided when welding. The feedback in a traditional training program comes from the instructors talking during the welding process if they can physically watch you and after the completion of a weld by visual inspection by the instructor. From the results, it can be concluded that dexterity can increase with the use of both instant and accurate feedback.

When examining the pass/fail rates from the visual inspections, it can be concluded that participants were better at performing the less complex welds. It can also be concluded that the participants in the 100 percent virtual training programs performed the 1G weld better than the other training program participants. The 75/25 virtual/traditional training methods outperformed the other training method types. This suggests that the 75/25 virtual/traditional training method may be best suited at preparing beginning welders. As virtual reality trainers give the ability to replicate welds faster than traditional training methods leads to the notion that practicing in a virtual environment may lead to quicker development of participants' psychomotor skills.

Objective three sought to explore the relationship between participant dexterity and the pass/fail rating of the visual inspection to examine the predictability of dexterity on future performance. It can be concluded that dexterity can predict future performance of beginning welders completing basic SMAW welds. The dexterous ability of the participants did affect their ability to weld, which aligns with the determinants of job performance that states procedural knowledge (how to weld properly) and skill (dexterity) did affect the overall task performance (test weld) (Campbell et al., 1993). The ability of dexterity to predict future performance supports the finding in other occupational fields (Gansky et al., 2004; Gettman et al., 2003; Hitchings & Moore, 1991; Levine et al., 1996; Mansell, 1969). All the tests utilized shown a significant relationship with a beginning welder's ability to visually pass or fail inspection. This implies industry personnel can use dexterity to select people to enter welding training programs that use basic SMAW welds.

## Recommendations

Conclusions from this study lead to several recommendations. First, it is recommended that welding training programs utilize virtual reality simulations to aid in the training process. With the use of virtual reality, welding training programs can become more efficient, in terms of passing visual inspections, which is imperative to meet today's demand for certified welders. With the increased 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 to enter the training program. With the requirement of demonstrating a high dexterity ability prior to training may lead to better candidate selection and success of certifying welders in welding training programs. With the large industry demand for certified welders, welding training programs will be able to objectively select the best individuals for training.

In secondary agricultural education programs, it is recommended that teachers work with local welding training programs, industries, and post-secondary schools to expose students to advanced welding training methods, such as virtual reality simulators. The primary objective of career and technical education programs is to provide basic skill development and spark an interest in pursuing a career related to agriculture such as welding. It is recommended that teachers continue to work with local industry, post-secondary institutions, and weld training programs to increase their own welding abilities, as well as enhance their knowledge of welding to provide more advanced training methods. It is recommended that agricultural educators seek out opportunities to borrow VR equipment from programs when they are not in use, as well as partnering with industry to provide industry type training for students. In an effort to prepare students to become successful at welding, agricultural education teachers need to examine the hands-on skill they teach to examine if a sequence of skills can be created to help improve students' gross dexterity.

The researchers also recommend that future studies be conducted to further examine the use of dexterity to predict future performance by utilizing different dexterity tests. Further investigation is needed to examine if dexterity can predict future performance for more complex welds. It is suggested to use dexterity tests that evaluate fine, gross, finger and hand, hand and arm dexterity. It is also recommended that future studies investigate the possibility of creating a dexterity test that more resembles the movements of a welder to improve the ability of dexterity to predict future performance. One question that needs to be examined is if there is a difference in dexterity between certified welders versus non-certified welders within industry settings? Further investigation is needed to determine if dexterity can predict future performance of GMAW type welds.

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