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Automated Kinesthetic Trainer enhances Kinesthetic Memory development

Peihan Zhong
Iowa State University

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Automated Kinesthetic Trainer enhances kinesthetic memory development

by

Peihan Zhong

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE

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Richard T. Stone, Major Professor

Gary Mirka

Stephen Vardeman

Iowa State University

Ames, Iowa

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TABLE OF CONTENTS

LIST OF TABLES	iv
LIST OF FIGURES	v
ABSTRACT	vi
CHAPTER 1. Introduction	1
1.1 Kinesthetic Memory and Training	1
1.2 Welding Training	3
1.3 Hypothesis	3
CHAPTER 2. Background	5
2.1 Welding Parameters	5
2.2 Kinesthetic Weld Trainer Design	6
CHAPTER 3. Method	9
3.1 Participants	9
3.2 Experimental Design	9
3.3 Experimental Setting	11
3.4 Procedure	11
CHAPTER 4. Result	14
4.1 Overall Performance	14
4.2 Welding Speed	15
4.3 Elbow angle	15
4.4 Muscle Activity Pattern	16

CHAPTER 5. SUMMARY AND DISCUSSION	18
5.1 Overall Performance	18
5.2 Kinesthetic Memory Development	19
5.2.1 Moving Speed	19
5.2.2 Posture	20
CHAPTER 6. Conclusion	22
6.1 Conclusion	22
6.1.1 Performance	22
6.1.2 Kinesthetic Memory	22
6.2 Limitaions	23
6.3 Future Work	23

LIST OF TABLES

Table 4.1	Bend Test Result	14
Table 4.2	Moving Speed Summary	15
Table 4.3	Data Summary of Elbow Angle grouped by training method	15

LIST OF FIGURES

Figure 2.1	Relationship between travel speed and R (reinforcement), P (penetration), W (width of bead), and D (dilution)	5
Figure 2.2	Work and Travel Angle	6
Figure 2.3	Photo of KWT	7
Figure 2.4	Demonstration of using the weld gun stablizer	8
Figure 3.1	Welding Workstation	11
Figure 3.2	Collaboration	13
Figure 4.1	Bend Test Result	14
Figure 4.2	Muscle Activity Pattern	16
Figure 4.3	Muscle Activity Pattern with Angle	17

ABSTRACT

This research studied the usefulness and effectiveness of providing movement guidance and haptic feedback in enhancing kinesthetic memory development. Participants were trained to perform horizontal welding in two different settings: free-hand (traditional group) or under such guidance (machine group). Their welding performance, as well as kinesthetic memory were evaluated. As for kinesthetic memory, since it is related to movement and posture, three parameters were measured: moving speed, muscle activity, and elbow angle. Machine group significantly outperformed traditional group in performance, and also showed significant better control of moving speed than the traditional group. However, muscle activity pattern and elbow angle didn't differ significantly between two groups.

CHAPTER 1. Introduction

1.1 Kinesthetic Memory and Training

Kinesthetic memory refers to the extent to which the human body can recall its movements and postures for specific tasks. Through the use of sensory-motor learning and the development of kinesthetic memory, a person can accomplish specific physical movements without thinking about how his/her body's parts should move (Ebert, 2009). The development of kinesthetic memory is important in regards to learning to perform a task that require certain movement or posture.

Providing movement guidance and haptic feedback for a specific task is useful in aiding the development of kinesthetic memory. Guidance can help restrict errors, while encouraging the trainee to perform a task in the correct manner. According to Schmidt and Lee (2005), it may be most effective in early practice when the task is unfamiliar to the trainees. In fact, the idea of providing movement guidance in training has been used for a long time, especially in training and rehabilitation after experiencing a stroke. Exoskeleton and robot-assisted movement training have been applied to various fields, and in some studies have been shown to be an effective way of helping people to learn a certain posture or movement better and faster (Peter, 2002, Burgar, 1999). Alternatively, other studies, especially those evaluating the usefulness of movement guidance and haptic feedback, found the training is not superior to only providing visual guidance, as in Feygin (2002) and Liu (2006). Armstrong (1970b) found that the guidance only provided temporary boosts to performance. Comparing the performance among three groups (guidance, concurrent visual feedback on movement, and terminal feedback on movement), guided group performed best under practice but not as good as the other two groups in the transfer test. This finding suggested providing guidance might not be as useful

as expected, and was in accord with findings of other studies, such as those by Schmidt and Wulf (1997), Singer and Pease (1976), and so on.

In rehabilitation after a stroke, robot-assisted therapy has been widely studied. However, many studies failed to show overall significance in favor of such a method, according to a systematic review by Kwakkel, et al. (2008). Kahn, et al(2006) investigated the effect of a robot-assisted reaching exercise and compared it with a free reaching voluntary exercise in improving arm movement ability after experiencing a stroke, but still found no significant difference between the two groups. The author believes that this is due the nature of such therapy; it simply utilizes robots as vehicles to deliver highly repetitive movement therapy, and if all variables are the same in robotic therapy and human-delivered movement therapy, the result should not be different. This explanation was supported by another study done by Kahn, et al. (2001), indicating that with robot-assisted therapy that was able to impose a smoother trajectory during practice of the reaching movements, subjects learned how to produce smoother movements. Additionally, even if there is no significant difference between the two therapy, the movement is still guided by a human in traditional therapy. Providing guidance is the most important factor in rehabilitation after stroke.

In sports and other physical training, devices that restrict peoples' movement while training are widely used based on the belief that such devices can help a person learn a certain movement or posture faster and more accurately. There are several training devices for golf training, such as those developed by Mayley, et al (2000), Doerrfeld (1989), Ritson, et al (2003). However, the underlying belief was not studied scientifically. In the contrary, several studies that evaluated the role of haptics in training, especially in learning motor tasks with complex kinematics, suggested that there is no significant advantage using haptic guidance. In the study by Feygin, et al.(2002), a comparison is made between the training methods of only visual, only haptic, and visual plus haptic, discovering that haptic training alone was less effective than visual training with respect to position and shape measures, but more effective with respect to timing. The same result was found by Liu, et al.(2006). Lotze, et al (2003) and Laelin-Lang, et al (2005) also found subjects learned the task better when they practiced by themselves as compared to being passively guided. Although these studies are not in favor of haptic guidance, these studies

all used a simple task like drawing a 3D line, which may not be representative of training of real world tasks. Under the experimental setting, participants were passively guided. According to Schmidt, et al.(1999), when passively guided, the training effect is not as good as when actively guided practice occurs. Some studies also supported this by showing some guidance to be beneficial when interspersed with active practice trials (Hagman, 1983; Winstein, Pohl, and Lewthwaite, 1994). Moreover, these studies did not study the aspect of physical development, which relates to kinesthetic memory. Therefore, an argument cannot be made regarding the long term effect. As a result, a more thorough and task tailored study that focuses on physical development needs be done.

1.2 Welding Training

In the welding industry, the traditional training simply allows trainees to practice repeatedly for a long period, which not only takes a lot of time but also requires copious amounts of raw material and other consumable materials for practice before a welder can develop sufficient skills to perform commercial or industrial welding. Efforts are continuously being made to improve the training method. Although virtual reality training or augmented reality training has been shown to enhance training, such methods traditionally only provide visual feedback/guidance, differing from traditional training in which the trainees can be provided with direct guidance pertaining to their posture and movement by the trainers.

A study by Wang, et al. in 2006 points out this limitation and presented a new welder training method by providing some haptic guidance. However, as of today, no scientific human-centered study has proven the effectiveness of providing movement guidance and feedback in training.

1.3 Hypothesis

For this purpose, the author developed a simple human-centered device that restricts the movement of the arm to maintain an ideal moving speed and studied the effect of using this tool by examining the welding performance and the physiological development after training.

It is hypothesized that providing appropriate movement guidance and feedback in training can help a person develop appropriate kinesthetic memory faster and more accurately in terms of movement and posture than can be achieved through traditional training.

CHAPTER 2. Background

2.1 Welding Parameters

In welding, travel speed and work/travel angle are two important parameters. Many studies have shown that travel speed can affect the welding quality. Gery, et al. (2005) found that the travel speed affects the transient temperature distributions in the welded plate, and improper temperature distributions can result in inevitable distortions and residual stresses in the joint and the parent metals (Goud, 1995; Puchaicela, 1998). Another study by Murugan and Parmar (1994) showed the relationship of travel speed and penetration, reinforcement and width of the bead, as shown in figure 2.1 below:

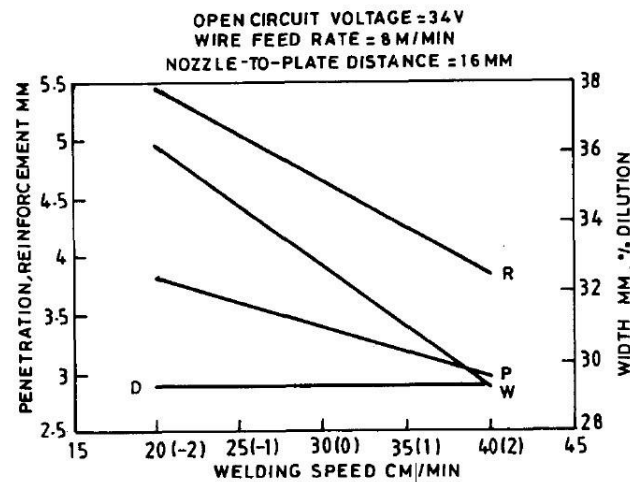


Figure 2.1 Relationship between travel speed and R (reinforcement), P (penetration), W (width of bead), and D (dilution)

It is clear that as the travel speed increases, P (penetration), R (reinforcement), and W (width of the bead) decrease. Karadeniz et al. (2007) further studied the relationship between speed and penetration, finding out that the penetration value increases at the very beginning

as travel speed increases, but after a certain point, it decreases. This finding suggests that there is an optimal travel speed for welding. The optimal travel speed for different welding type differs. According to the Welding Procedure Specification (WPS), the travel speed in this study should be set to 12 inches per minute.

Work and travel angle refers to the relative position of the weld gun and welding plate. Mathers(2002) pointed out that the work and travel angle can affect the air entrainment in the shielding gas and also the degree of penetration. Work and travel angles are demonstrated in figure 4.3. Travel angle is the angle of the torch's traveling plane, while work angle is the side plane of the plate. For MIG welding at the 2F position, the optimal work angle is 45° , while optimal travel angle is 15° .

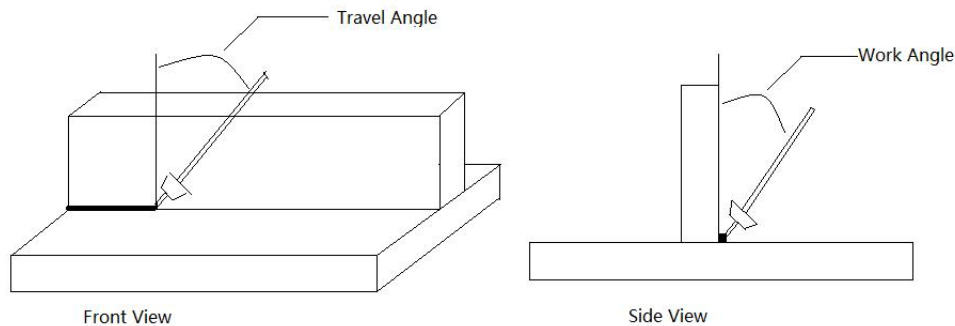


Figure 2.2 Work and Travel Angle

2.2 Kinesthetic Weld Trainer Design

The kinesthetic weld trainer (KWT) consists of seven parts: 1)pedal, 2)step motor and electronics control system, 3)conveyor, 4)shield, 5)armature, 6)weld gun stabilizer, and 7)welding bench, as shown in figure 2.3. The weld gun stabilizer is connected to the shield through the armature, and this is attached to the conveyor, so it can move together with the conveyor. The pedal is used to control the moving status and direction of conveyor. When it is pushed forward, the conveyor will move to the right, and move to the left when pushed backwards. The moving speed can be set by adjusting one button on the step motor.

As mentioned in the introduction, one potential drawback of using such guidance is that



Figure 2.3 Photo of KWT

participants may become passive when guided. Therefore the design of the weld gun stabilizer was aimed at overcoming this phenomenon by forcing the participant to hold the weld gun instead of resting on the stabilizer and also to put effort towards following the moving piece. This ensures that the participant pushed tightly against the two pillars on the torch holder. Figure 2.4 demonstrates how the torch holder works.

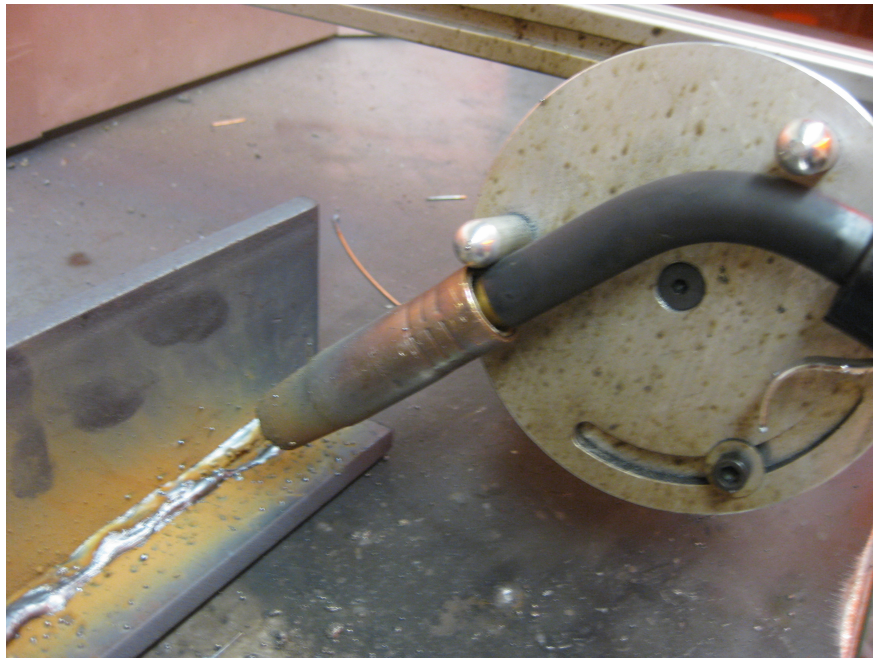


Figure 2.4 Demonstration of using the weld gun stabilizer

CHAPTER 3. Method

3.1 Participants

16 university students participated in this experiment, with ages ranging from 19 to 24, with a standard deviation of 2.342.

3.2 Experimental Design

The independent variable in this study is the training method, with 2 levels: training under guidance of KWT (machine group), and training without guidance (traditional group).

There are two dependent variables in this study: 1) overall performance and 2) kinesthetic memory development.

The overall performance is determined by the quality of participants' test welds. Their test welds are sent to a certified welding inspector (CWI) for both visual inspection and a bend test. The visual inspection scoring is a subjective measurement performed by a CWI. If a weld does not pass this inspection, then it is impossible for it to pass the bend test. The bend test is an objective and quantitative measurement for the quality of a weld. The welded plate is bent by a machine and a score is given regarding the welding joint's strength.

As for the kinesthetic memory development, so far no standard measurement has been proposed. Most studies that addressed this issue have taken the performance as a measurement. Intuitively, performance can be a valid indicator, since well-developed kinesthetic memory will definitely lead to a good performance. However, many other factors also affect performance, which might contaminate the validity of this measurement. Considering the definition of kinesthetic memory, the author believes that studying the physical development would be a reasonable and better way, due to its relation to the physical movement used to complete a

task, including posture (static) and movement (dynamic).

As related to this research, physical development can be described as welding posture and welding speed. Welding speed is calculated from the time each participant used to perform the test weld. The welding posture can be described by two factors: 1) elbow angle when performing the test weld and 2) muscle activity pattern. To measure the elbow angle, a goniometer was attached to participant's arm, and the reading was videotaped so that the experimenter can read it afterwards without interrupting the participant's test weld. The muscle activity pattern is measured by electromyography (EMG) feedback for the deltoid, trapezius, extensor digitorum, and the flexor carpi ulnaris muscles, which are identified to be the major muscles used to perform welding, according to Beauchamp et al. (1997), Herberts and Kadefors(1976) and feedback/observations gathered from welding experts. The activation and interactions of these muscles serve to define expert welder control, ability, and stability during the commission of a weld. For this measurement, electrodes were placed on participants' skin in parallel with the fibers of these muscles according to recommendations of Zipp (1982) and Perotto (1996). EMG readouts allowed the experimenter to specifically examine the interactions between these muscles during the performance of welding tasks.

A maximum voluntary contraction (MVC) measurement was taken in order to get a baseline for the maximum that participants were willing to exert their muscles. In order to get the MVC for the trapezius and deltoid, the participants abducted their arms at the shoulder joint in the coronal plane at 90° against a stationary force. In order to gather the MVC for the extensor digitorum, the participants were asked to perform an extension of the wrist against a stationary object while the participant's extended arm (abducted about the shoulder in the sagittal plane) was held horizontally in front of them. Finally, in order to gather the MVC of the flexor carpi ulnaris, the participants were asked to squeeze a handle in order to achieve a power grip. This was achieved while the participant's extended arm (abducted about the shoulder in the sagittal plane) was held horizontally in front of them.

3.3 Experimental Setting

The welder used in this experiment is the WIRE-MATIC 255 by Lincoln Electric. The training was conducted at a welding lab in Iowa State University. The welding bench used for training was the KWT described in chapter 2, specially made to enable the use of movement guidance and haptic feedback. The welding bench's dimensions are 1 foot deep by 2 foot wide, and fixed at the normal height of conventional welding bench at 36". Details are provided in figure 3.1 below:

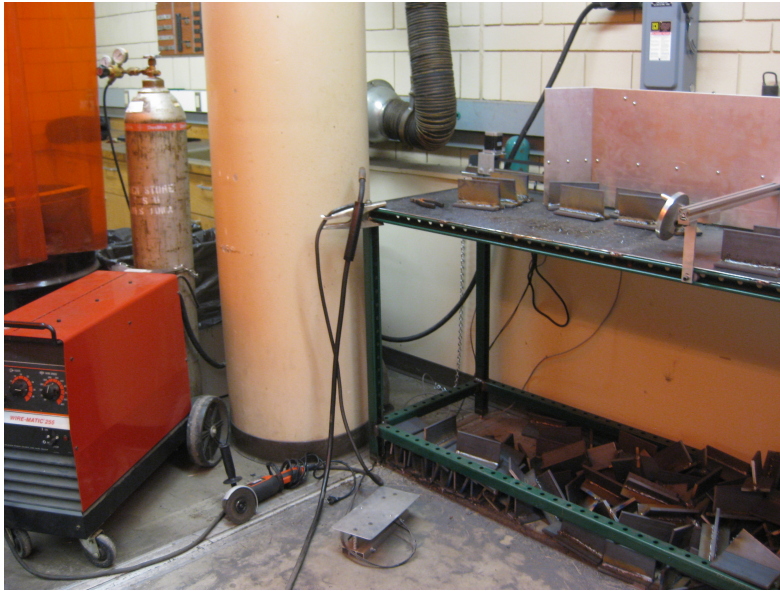


Figure 3.1 Welding Workstation

3.4 Procedure

Prior to the experiment, demographic information for each participant was gathered. Participants were evenly assigned to each group based on their experience with welding and gender. Before training, every participant was required to perform a maximum voluntary contraction (MVC) for later physiological development analysis.

During the training period, 2 participants were trained at the same time to weld at the 2F position for 2.5 hours. In the first 15 minutes of this training period, they were instructed by one instructor that has AWS welding certification for 2F. The instruction included: 1)

basic knowledge and safety information of a MIG weld; 2) two demonstration welds by the instructor; 3) two trials by the participant under guidance of instructor. The latter two were different between two groups such that for the traditional group all welds were done free-hand, while for the machine group all demonstration were done under guidance of KWT. The optimal moving speed - 12 inches per minutes(ipm) and optimal angles - work angle being 45° and travel angle being 15° were emphasized continuously.

When instruction completed, participants were required to practice either under guidance of KWT or free-hand. In the machine group, the arm's moving speed was set to the optimal value of 12 ipm, and the angles would be optimal if participants did hold the gun as instructed. Their collaboration on learning during training, as shown in figure 3.2, was encouraged. Participants in the machine group were forced to practice under guidance for the first one hour and then move to a mixed practice section that had both free-hand and guided practice. From observation during the training, the experimenter found out that in this mixed practice section, all participants in the machine group followed this common pattern: firstly they would choose free-hand practice, however, they would immediately find their performance was far from satisfactory, so they would try to explore the difference between the two by either going back to guided practice or making more free-hand trials. Participants would change between guided and free-hand practice back and forth until they were satisfied with their free-hand performance. After that, they would stick with free-hand practice.

To make sure all other factors were the same across two groups, the welding parameters of the welder were pre-set by the experimenters to the optimal value. Participants were not allowed to change any of them.

When the training period was over, participants were required to perform one test weld, during which time for this weld was recorded by a stop watch, posture was video recorded and muscle activity was measured by EMG. Before sending the test welds to a CWI for visual inspection and a bend test, participants' numbers were marked on their test welds respectively.



Figure 3.2 Collaboration

CHAPTER 4. Result

4.1 Overall Performance

Overall Performance was demonstrated by participants' test weld quality, which was determined by professional bend test. The bend test result is shown in table 4.1 and figure 4.1. In the machine group, all 8 participants managed to perform a qualified weld, while in the traditional group, only 1 participant achieved that level. The χ^2 test was used to test the difference between groups, and a significant difference was found, with $\chi^2_{(1,0.05)} = 12.444$, $p = 0.0004$, suggesting the machine group significantly outperformed traditional group.

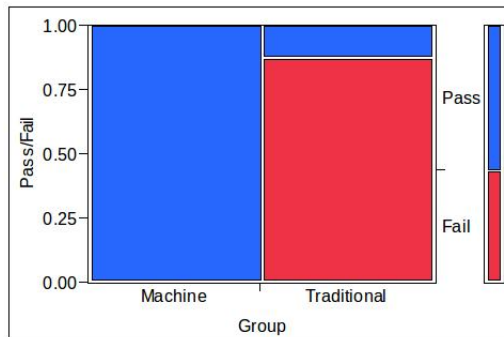


Figure 4.1 Bend Test Result

Table 4.1 Bend Test Result

Group	Pass	Fail
Traditional	1	7
Machine	8	0

4.2 Welding Speed

Welding speed is measured by the time each participant used for one pass from beginning a weld to the finish of that weld. A summary of the data is shown in table 4.2. The data used for analysis was the original time data instead of speed so that calculation error can be avoided. The two sample T-test showed a significant difference between groups, with $p = 0.0226$.

Table 4.2 Moving Speed Summary

Group	Mean	Std.Dev.	Prob > t
Traditional	19.630"	7.697	2*0.0026*
Machine	27.659"	4.401	

From the optimal speed (12ipm) and the length of the plate (5 inches), the optimal time for a pass should be 25 seconds. From table 4.2, it can be seen that participants in the machine group had times closer to 25 seconds. To prove this, a one-sample t test was used. For the machine group the p-value was 0.1313, while for the traditional group the p-value was 0.0891. This indicates a significant difference between the traditional group mean and the optimal value of 25.

The statistic tests above provided strong evidence that participants in the machine group had a significantly better control of welding speed than those in the traditional group.

4.3 Elbow angle

Welding posture was demonstrated by the participants' elbow angle and muscle activity pattern. For the elbow angle, a two sample t-test was performed to analyze the difference between the two groups. The result is summarized in table 4.3. Data analysis suggested that the training method has no significant impact on the elbow angle, with a p-value of 0.8194.

Table 4.3 Data Summary of Elbow Angle grouped by training method

Group	Mean	Std.Dev.	Prob > t
Traditional	95.938	17.699	2*0.8194
Machine	94.000	15.536	

4.4 Muscle Activity Pattern

Muscle activity pattern was expressed by the percentage of maximum voluntary contraction (MVC) for the interaction of the four muscles of interest (extensor digitorum, flexor carpi ulnaris, deltoid, and trapezius).

A multivariate analysis of variance (MANOVA) was used to account for the interaction among multiple dependent variables (4 different muscles) that describe the muscle activity pattern developed in this study. Prior to analysis, data was log transformed to meet the normality assumption of MANOVA. The result revealed no significant difference between the groups (p-value = 0.7304).

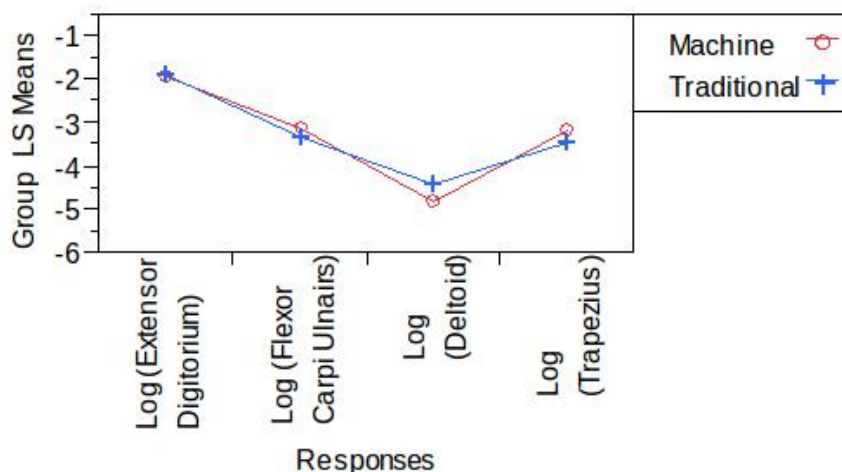


Figure 4.2 Muscle Activity Pattern

Since elbow angle and muscle activity together defines the posture in this study, and considering that interaction between elbow angle and muscle activity pattern exists (because different elbow angles utilize different muscles, and even for the same muscle it requires different levels of exertion), a MANOVA on 4 muscles together with the angle was also performed. However, no significant difference was found (p value = 0.8562).

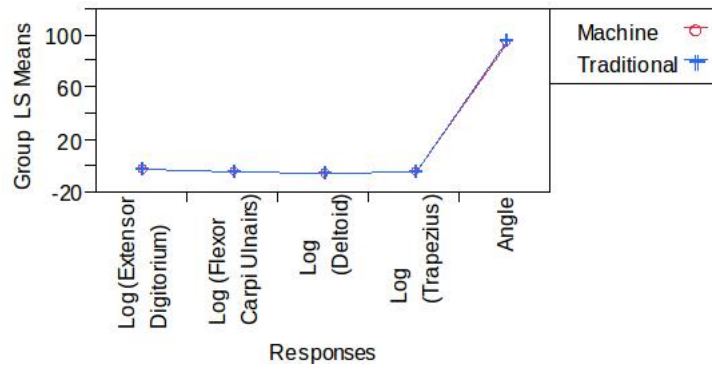


Figure 4.3 Muscle Activity Pattern with Angle

CHAPTER 5. SUMMARY AND DISCUSSION

The purpose of this study was to evaluate the effect of providing movement guidance and haptic feedback in training. It was assessed by several aspects: welding performance, welding speed, and welding posture. The first two aspects showed significant difference, while the third aspect did not. These results will be discussed in detail in this chapter.

5.1 Overall Performance

The overall performance was significantly improved with external guidance. Being trained for the same amount of time, the machine group had 100% pass rate while the traditional group only had 12.5%, indicating that the external guidance is able to help people achieve a certain level using less time and achieving a better level using the same amount of time, which supported the use of providing such guidance. Comparing this result to other studies that failed to find a significant difference, several points are worthy to be pointed out:

1. The machine designed for this study requires participants to actively make effort to follow and push toward it when moving along with it, so that participants are not passively guided as in the study by Lotze, et al. (2003) or Kaelin-Lang, et al.(2005). According to Schmidt, et al. (1999), learning a skill through passively guided practice cannot help a person achieve the same level of skill as actively practicing can. In this study, participants were encouraged and forced to practice actively, which turned out to be an efficient way of assisting learning.
2. Participants in the machine group were also required to have some free-hand practice after the first hour. As mentioned by Schmidt, et al.(1999), being assisted by external guidance, participants might be dependent on the guidance and feedback, resulting in a

dissatisfied performance during the actual task. To counteract this possible drawback, there was a mandatory free-hand section in the training procedure. The result strongly supported such a training setting, in accordance with the finds by Winstein, Pohl, and Lewthwaite (1994).

3. Appropriate haptic feedback and movement guidance were provided for this specific kind of task. While most of the previous research used simulation tasks with only general guidance provided, such as those by Liu, et al.(2006) and Feygin, et al. (2002), this study selected a task in the realm of skills training - welding. External guidance was carefully studied and tailored in order to provide the most appropriate help, which was proved to be successful. It can be then inferred that performance can be improved significantly with external guidance provided specifically to that certain task.

5.2 Kinesthetic Memory Development

As proposed in this paper, kinesthetic memory for a 2F weld was divided into two parts, dynamic aspect (controlling of time, measured by welding speed), and static aspect (posture, measured by elbow angle and muscle activity pattern).

5.2.1 Moving Speed

This study found a significant difference between groups in welding speed. The significant difference did not only lie in the time participants in each group used to finish one weld, but also existed in the comparison with the optimal value 25 seconds. Participants in the machine group showed a better control of moving speed than those in the traditional group. Since the primary guidance provided by the machine is the control of moving speed, the effectiveness and usefulness of providing external help was strongly supported by this result. This finding is consistent with previous research by Blandin, et al. (1999), and Black and Wright (2000) that pointed out physical practice had more positive impact on controlling time than observational practice. Moreover, in a study on haptic training by Feygin, et al.(2002) it was also found that timing accuracy was dominated by haptic training while position and shape accuracy were

dominated by visual training. Additionally, the linkage between welding quality and welding speed also explained the inner relationship between these two results. It is well recognized by expert welders and welding instructors, and also proved in a previous study by Stone (2010) that, the key factor for a successful 2F weld is the welding speed, therefore maintaining the welding speed at an optimal value is the most important skill for a novice. Taking this fact into account, it is easy to understand why participants in the machine group outperformed those in the traditional group.

5.2.2 Posture

Results of this study showed participants in both groups developed similar posture in terms of elbow angle and muscle activity pattern, both of which had a p value > 0.8 . In spite of the fact that no significant difference was found for posture, several facts should be considered before drawing any conclusion.

The first is the nature of this task. As stated in the previous section, welding speed is the most important factor. Even though the posture adapted by participants in each group was similar, overall performance did differ significantly between the two groups, thus making it reasonable to assume that posture doesn't play an important role in performing a successful 2F weld. As soon as participants noticed this, they would find the most comfortable posture and be concentrated on controlling their speed. Moreover, being the simplest weld, the posture for 2F weld is very close to drawing a straight horizontal line, which left little room for posture adjustment. Therefore it is very possible that participants were not learning a new posture but simply applying how they would perform when drawing a straight line instead, weakening the effect that the machine was supposed to have.

Apart from that, restriction and guidance provided by the machine can also explain for the result. Since only the posture of the right arm is restricted, participants had full freedom to move their left arm. In fact, from observation, participants did have different strategies to use their left arm, which made their posture completely different. For example, some used their left hands to hold the weld gun while some placed their left arms on the welding bench, etc. Even for the right arm, it was the position of weld gun that was directly restricted other than

their arms, leaving the participants with much freedom to adapt arm posture based on their own judgment.

However, although the study didn't find a significant effect of providing the external help on posture and muscle activity patterns, one thing worth noting is the usage of providing such help should not be denied merely based on this study. Considering both overall performance and the similarity of posture developed by participants in both groups, the author is inclined to believe the nature of this task (2F weld) was the main reason for no significant result. A task relying mostly on appropriate posture will leave little room for alternative postures, thus the impact of training with or without external restriction might make a greater difference. In future studies, a more difficult task should be selected to determine the effectiveness of providing such guidance.

CHAPTER 6. Conclusion

6.1 Conclusion

This study was focused on evaluating the effect of providing haptic feedback and movement guidance in training, specifically in the aspects of overall performance and kinesthetic memory. The author developed a measurement of kinesthetic memory specifically for the selected task in this study, which are moving speed, elbow angle and muscle activity pattern. The latter two together describe posture. This study supported the idea of providing such external guidance in training.

6.1.1 Performance

When the method of external guidance is carefully selected for the specific task and participants are forced to actively practice, performance can be significantly improved with external guidance. An integrated training that consists of practice both under guidance and without guidance would also be helpful to learning.

6.1.2 Kinesthetic Memory

Kinesthetic memory does play an important role in skills learning. However, since it is a broad concept that can refer to any factor that is related to remembering limb position, velocity, etc., it is necessary to specify the factors for each specific task. In this study, related factors were moving speed, elbow angle and upper limb muscle activity pattern. Concurring with previous study on haptic feedback, it was found that under external guidance participants had better control of their moving speed, while no significant effect was found on elbow angle and upper limb muscle activity pattern, due to several confounded reasons.

6.2 Limitations

The major limitation of this study is the tasks level of difficulty. A more difficult task should also be included so the effect could be better evaluated. As discussed in the previous chapter, the 2F weld has little requirement on posture, providing participants with lot of freedom to develop their own posture. However, more difficult welds are more affected by posture, thus leaving participants will little room for posture adjustment. A previous study by Stone, Watts, Zhong, and Wei (2010) showed the posture development didnt differ between Virtual Reality training and traditional training for the 2F weld type, but started to serve as an important factor for the 1G weld type, which is more difficult than 2F weld type. Therefore, it can be expected that for 1G weld type or even harder weld, the posture development between machine group and traditional group would be significantly different, and more significantly affected by training method.

6.3 Future Work

Further study could be performed on the evaluation of how the effect would change when the same guidance is applied to tasks with different levels of difficulty, looking for general guidelines for guidance selection and designing standard measurement of kinesthetic memory. Moreover, since virtual reality training has been increasingly used, assisting it with haptic feedback and movement guidance should be able to enhance the effectiveness. Research on whether this is the case and how to integrate the two is also of great value.

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