Establishing the Usability of a Virtual Training System for Assembly Operations within the Automotive Industry

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Abstract

Virtual training systems deliver training within a virtual environment (VE) using virtual reality (VR) or augmented reality (AR) technologies. However, to be fully accepted as a valid tool for training within the automotive industry, evidence is required on the ability of these systems to deliver effective and efficient training to the relevant users. This paper aims to investigate the effectiveness and efficiency of the first prototype of the virtual training system (VTS) developed within the VISTRA (Virtual Simulation and Training of Assembly and Service Processes in Digital Factories) project (FP7-ICT-285176), using real end users from the OPEL automotive plant in Rüsselsheim, Germany. Two separate and independent studies were employed that used objective and subjective methods of investigation to establish performance and usability measures. The objective results show that virtual training was effective in reducing error during task performance when compared to traditional training. The subjective results concluded that the opinions of the participants were mainly positive concerning the overall use of the VTS for assembly operation training; however, a number of issues were highlighted and reported to the developers for further advancement of the system.

Keywords: Virtual reality; Virtual environments; Virtual training; Usability; Effectiveness; Efficiency

1. INTRODUCTION

Customer-oriented production within the automotive industry has resulted in the manufacture of a number of different models and different model versions (Michalos, Makris, Papakostas, Mourtzis, & Chryssolouris, 2010) along with a customization process that allows for the addition of a variety of optional components (Hu et al., 2011). To accomplish this product variation, the assembly worker needs to either identify and memorize a large number of parts and operations for each product variation (which are often changed throughout the day) or spend time consulting instructions or seeking advice from supervisors or managers, with the quality of the final product relying on the ability of the worker to correctly perform the different assembly operations (Michalos et al., 2010). Therefore, training that is flexible and adaptive is essential for learning complex assembly procedures, including the acquisition of the correct mental model and the components and tools of the assembly procedure (Gavish et al., 2011).

Traditional methods for training usually involve a combination of paper-based and DVD or video-based instruction and/or a demonstration of the task by an experienced worker (Brough et al., 2007). However, advances in technology have led to a number of investigations into the potential of virtual training to improve

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and accelerate learning in a realistic and safe setting (Bergamasco, Bardy, & Gopher, 2012; ElMaraghy, ElMaraghy, Tomiyama, & Monostori, 2012; Huegel, Celik, Israr, & O'Malley, 2009; Mujber, Szecsi, & Hashmi, 2004; Patel, 2010; Salas, Wildman, & Piccolo, 2009; Salem & Kissner, 2007). Virtual training in this context is defined as training that is undertaken within a virtual environment (VE) using virtual reality (VR) and augmented reality (AR) technologies. It is often designed in a way that simulates the equivalent real-world scenarios, which allow a more intuitive learning environment than traditional classroom-based training (Mujber et al., 2004), enabling individuals to interact with the training system (Jia, Bhatti, & Nahavandi, 2009) and from which the user can experience success or failure (Mantovani & Castelnuovo, 2003). It can include the actions, sights, and sounds of the assembly area and can provide guidance and instruction of procedures and actions for assembly operations (Jou & Wang, 2012).

VISTRA (Virtual Simulation and Training of Assembly and Service Processes in Digital Factories) is a project funded by the European Commission's 7th Framework Program (FP7-ICT-285176). The overall aim of the project is to develop a comprehensive platform for simulation and training of manual assembly processes. One part of the project involves the development of the virtual training system (VTS) that provides training in assembly operations within a simulated environment. The aim of this paper is to provide evidence on the effectiveness and efficiency of the first VISTRA prototype of the VTS by performing two separate and independent performance and usability studies, using real end users. For the purpose of this paper, effectiveness is defined as the ability of the virtual training to communicate the appropriate learning principles so that the real-world task can be performed correctly. Efficiency is defined as the ability of the system to provide training in minimum time. These definitions are based on those provided by ISO9241-210 (International Organization for Standardization, 2010).

2. BACKGROUND

For virtual training to be fully accepted as a valid tool for training, evidence is required of the effectiveness of the virtual training program and the efficiency and acceptance in the use of a VTS. In other words, *Does the system provide effective training of the key skills required?* and *Can it do it efficiently within an easy-to-use system?* The section below gives an overview of evidence within the current literature on the effectiveness and efficiency of VTSs and is divided into studies that employed objective methods and studies that employed subjective methods of evaluation.

2.1. Objective Evaluation Studies into the Effectiveness of Virtual Training

Objective evaluation is a fundamental part of most investigations into training systems and involves the systematic collection of quantitative data to determine the effectiveness of the training requirements (Salas et al., 2009). Establishing the effectiveness of a VTS can involve a number of complex factors, such as evaluation of learning, performance, instructional materials and transfer of training (Eseryl, 2002), each of which can be quantified using an objective evaluation. There are a number of studies within the literature that have investigated the effectiveness of virtual training for assembly operations. These studies are shown in Table 1 with examples summarized in the text.

All of these studies undertook some sort of evaluation that aimed to compare virtual training with traditional training, either by assessing an individual's performance during the training session or by assessing the posttraining transfer of skill during performance of the real task. Each study reported on an evaluation that consisted of using task completion time as a performance measure. However, there is evidence that highlights the benefits of recording error as a measure, because it is a key indicator of skill level (Gallagher, Lederman, McGlade, Satava, & Smith, 2005).

Analysis of error has been used within five of the nine studies in Table 1, as a measure to investigate virtual assembly training. Baines and Lawson (2012) compared the effect of preparing trainees with virtual assembly procedures with trainees who used printed diagrams and written instructions, during a real task performance and produced positive evidence from both time and error measures on the effectiveness and efficiency of this system. Webel et al. (2012) developed an AR-based training system for maintenance and assembly skills and found no significant difference in task completion time but did see a reduction in error from AR-trained participants when compared with traditional training. Vo, Vance, and Marasinghe (2009) investigated the benefits of haptic feedback for performing virtual assembly tasks and found that addition of haptic feedback had no significant effect on user

TABLE 1. Reference List of Objective Investigations Undertaken in Virtual Training of Assembly Operations

Author	Test System (AR/VR/Both)	*n*	Measure Used	Results
Baines (2012)	VR	40	Task completion time, error, number of attempts to complete the task, and the number of references made per attempt	VR preparation resulted in fewer errors, a reduction in the number of attempts, and a quicker training and task completion time when compared to the group that used traditional training
Boud, Baber, and Steiner (2000)	VR/AR	25	Task completion time	VR or AR training resulted in a reduction in task completion time of the final assembly, when compared to conventional training methods
Brough et al. (2007)	VR	30	Task completion time and error	The system was shown to be able to support a wide variety of training preferences during the training of assembly operations
Edwards et al. (2004)	VR	24	Task completion time and the number of collisions that occurred during a virtual assembly task	The results showed that the addition of force feedback increased the number of collisions and the task completion time when compared to visual cues alone
Garbaya and Zaldivar-Colado (2007)	VR	11	Task completion time	The results showed statistically significant reduction in task completion time due to contact force sensation during part-to-part assembly
Gavish et al. (2011)	VR/AR	40	Task completion time and solved and unsolved errors	AR training produced a significant decrease in errors during real task performance, while VR training produced a similar performance to traditional training
Jia et al. (2009)	VR	76	Task completion time, error, and a memory test on recognition and recall	Overall, a high level of object assembly skills was shown after virtual training
Vo et al. (2009)	VR	27	Task completion time and error	The addition of haptic feedback into the VR system improved user placement accuracy when compared to using visual sensory information alone
Webel et al. (2012)	AR	20	Task completion time and error	The AR-trained group produced fewer unsolved errors when compared to traditional training

Note: AR: augmented reality; VR: virtual reality.

completion times; however, the haptic rendering of contact forces improved user placement accuracy when compared to using visual sensory information alone (Vo et al., 2009).

The above studies provide encouraging results for virtual training; however, not all studies have such positive conclusions. Gavish et al. (2011) recorded solved errors (when the trainee made an error but corrected it) and unsolved errors (when the trainee made an error and did not correct it) to establish the effectiveness and efficiency of both AR and VR training. The study found that there were no significant differences between VR and traditional training (Gavish et al., 2011), but the authors acknowledged that the study used a small sample size of technicians who were inexperienced in the use of the technologies. A study by Edwards, Barfield, and Nussbaum (2004) investigated a virtual assembly task, involving five interconnecting virtual parts and evaluated performance using task completion time and the number of collisions that occurred between these parts. However, for both these measures, negative results were found, with the authors suggesting that this could be due to the limitations in realism of the collision and haptic technology (Edwards et al., 2004). Although both of the above studies used error as a measure to highlight the limitations of the virtual systems, it is still a valid measure for identifying issues and focussing development.

The reasons for the skepticism in virtual training by industry may be numerous and include the return on the initial investment, relating to the cost of the instillation of the systems hardware and software (Gallagher et al., 2005). However, the discrepancy in scientific evidence to support the use of VR in training could also be a contributing factor. Ongoing research needs to establish the effectiveness of virtual training through multiple measures of performance and accuracy, so that industry gains enough confidence in virtual training to invest fully in expensive systems.

2.2. Subjective Evaluation Studies on the Efficiency and Acceptability of Virtual Training Systems

Subjective studies are a useful method to gather in-depth information on the opinions, attitude, behavior, satisfaction, and preferences on the system under investigation and can contribute to knowledge on human-computer interaction (DeLone & McLean, 2002). Table 2 shows the studies that have adopted subjective measures to explore aspects of virtual training systems with examples summarized in the text.

The most frequently used subjective method of evaluation from Table 2 is questionnaires, with five out of the eight studies using this method. Out of these five studies, three studies rated there questions on a scale, so that the results could be quantitatively analyzed. However, there are a handful of studies that used different methods of evaluation. Xia, Lopes, Restivo, and Yao (2012) applied a heuristic evaluation method, which focused on immersion, interaction, haptic feedback, motion simulator sickness, and fatigue. Jia et al. (2009) evaluated their system using a novel evaluation framework through large-scale user testing, including observations and interviews to establish critical usability problems and the efficacy of the virtual training. A study performed by Fernandes, Raja, and Eyre (2003) involved the Cybersphere, a fully immersive VE composed of a spherical projection system that the user can enter and create walking movements, which cause the large sphere to rotate. The evaluation involved a think-aloud method, followed by interviews that encouraged the participants to discuss usability issues and to make suggestions that could be used in further development of the system (Fernandes et al., 2003).

These studies show that the perception of those that have participated in virtual training was generally positive. However, the identification of usability issues indicates a need for further development of these systems. This paper reports on a formative evaluation of the first prototype of the VTS developed within the VISTRA project, with the intention of performing future evaluations as the system progresses. Further details of the overall design of VISTRA system can be found in Hermawati and Lawson (2013) and Stork, Gorecky, Stahl, and Loskyll (2012). The purpose of the evaluation is to investigate the efficiency and effectiveness of the VTS for training assembly operations within the automotive industry, using real end users.

3. METHOD

Two separate and independent studies were performed to obtain evaluative information from trainee and experts associated with assembly operations. Study 1 was an objective study that aimed to investigate the effectiveness of the VTS system using real trainees who had no knowledge of the assembly operation taught. Study 2 was the subjective study performed to establish the efficiency and acceptance of the VISTRA system from a group of real end users, including trainers and managers, who could compare the system with the previous training methods. The two independent studies were undertaken in the OPEL plant in Russelsheim, Germany, and performed within the same week. Figure 1 shows the overall methodology of both studies and presents each of the investigations and the respective evaluation measures, and the subsections are divided into Study 1 and Study 2.

3.1. Study 1—Training Effectiveness Based on Objective Measures

The aim of the first study was to compare VTS training with traditional training methods undertaken at the OPEL plant, which included paper, video, and expert demonstrations. Objective measures were taken during the execution of three trials involving a real-world assembly task.

3.1.1. Participant Selection

Thirty real technical apprentices were recruited from the OPEL plant in Russelsheim, Germany (1 woman 29 men; average age 20.31 years [$SD = 2.28$]; age range 17–28 years). The apprentices were screened to ensure that a range of different technical job profiles were represented in the study and undertook a Computer Self-Efficacy Scale measure (Compeau & Higgins, 1995) to establish their perception of their own

TABLE 2. Reference List of Subjective Investigations Undertaken in Virtual Training of Assembly Operations

Author	Test system (AR/VR/Both)	n	Measure used	Results
Baines (2012)	VR	40	A usability questionnaire with each question rated on a Likert scale (1: strongly agree, 5: strongly disagree)	The overall results of the virtual training were positive with the experience reported as being more fun, interesting and stimulating
Edwards et al (2004)	VR	24	A usability questionnaire composed of six 10-point rating scales (1: strongly agree, 10: strongly disagree)	Gender, force feedback and sound had significant effects on the user's perception and the perceived utility of the system
Fernandes et al (2003)	VR (Cybersphere)	5	A think-aloud method, that obtained opinions and comments on the system, and interviews that discussed usability issues	The results showed that the users thought that the Cybersphere would be a valuable tool for training and enhanced the learning motivation and experience
Garbaya & Zaldivar-Colado (2007)	VR	11	Questionnaire to obtain the opinions on the interaction mode	The results showed that contact force sensation was useful
Gavish et al (2011)	VR/AR	40	Questionnaires to obtain feedback on the usability and effectiveness of both platforms	The results found that most of participants gave positive comments on both platforms, VR and AR, as a training tool
Jia et al (2009)	VR	76	Usability evaluation of a haptic based system	The results identified critical usability problem, but the overall attitude was positive towards the utility of the system
Toma, Gîrbacia, and Antonya (2012)	VR	8	A usability questionnaire with each question rated on a Likert scale (5: completly agree, 1: completely disagree)	Results show that the opinion of the users towards the multimodal system was positive
Xia et al (2012)	VE	10	Heuristic evaluation method was used to investigate a haptic-based VE system	The results showed that the system provided valuable training and that gravity, friction, and collision detection could be realistically simulated

computer skills and abilities. The measure involves a questionnaire with a 10-point scale (where 1 = *not at all confident*, 5 = *moderately confident*, and 10 = *totally confident*) and established the participant's opinion of their capability regarding computer-related knowledge and skills. The participants were divided into three classifications, that is, low, medium, and high self-efficacy based on the score from the questions. Understanding participants' self-efficacy is important to the successful implementation of software systems in organizations as it influences the individual's experience (Compeau & Higgins, 1995). Ten participants, representing each classification, were selected and then allocated into either the traditionally trained group or the VTS trained group.

3.1.2. VTS Apparatus

The hardware setup of the first VISTRA prototype included a laptop; Microsoft Kinect for Windows to perform the motion tracking of the trainees and support movement, voice, and gesture recognition; Wii Mote as an interactive device used as an wireless input device, for example, to interact with the training system; and a projector to visualize the assembly task scenario. Figure 2 shows the setup of the hardware architecture. The software used in the first VISTRA prototype of the VTS includes VTS executable software, a data folder with plugins and resources, a configfile for the VTS to point to other repositories, and a configfile for VTS to point to the 3D CAD model files.

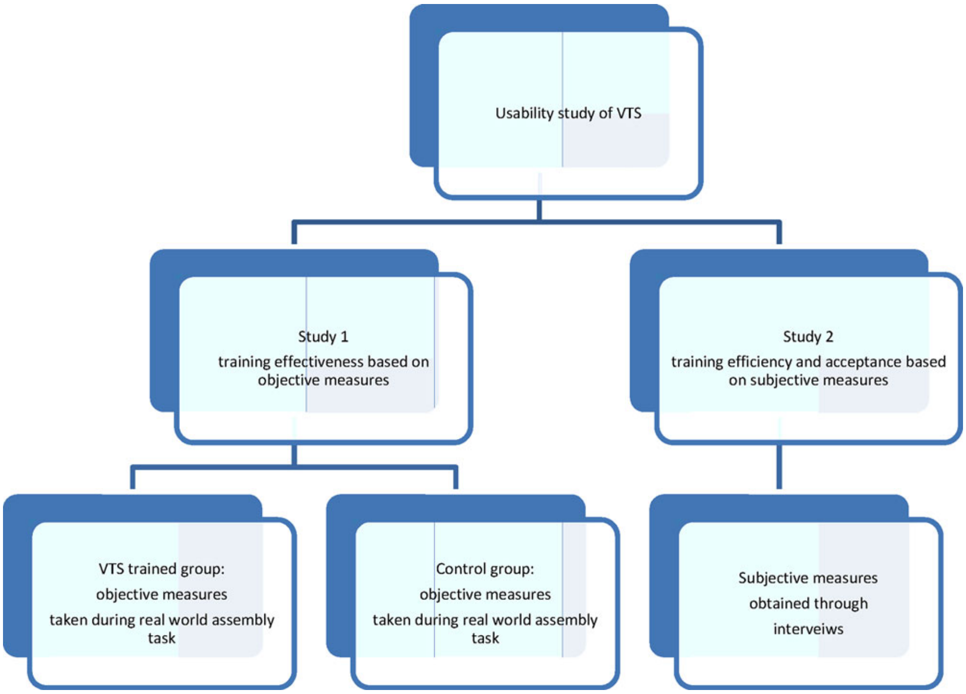

Figure 1 Methodology of each of the investigations.

Figure 2 VTS training equipment.

The training starts with a calibration session that involves the system collecting information regarding the anthropometric size of the user (height and arm span). This is followed by a display of the menu navigation screen in which the user can initiate the assembly sequence training. The virtual assembly training involved a procedural exercise in the assembly of a car door with a virtual environment that included a scene of a production line, the car door assembly parts, and the tools for this assembly. The target location of the part to be assembled is indicated by the VTS system by a blue circle, while the tool or the part that is required for the assembly, is highlighted by a yellow circle. During training, the user can change orientation to get a different view by either using the Wii Mote or by physically moving around. The objective for the user is to align the two circles together, simulating the tool or a part connecting with the target location. This results in a snapping noise.

3.1.3. Study Procedure

The evaluation of the training effectiveness was conducted at the OPEL plant on the first VISTRA prototype of the VTS. The experimental method is summarized in Figure 3 and compared the performance of a group of technical apprentices who had been trained using the VTS with a control group of technical apprentices who used conventional paper-based training.

Both groups undertook either virtual or traditional training for 1 hr and performed the real-world assembly task 1one week later, which corresponds with the way training normally takes place within OPEL, before the employees undertake a new assembly. The real-world assembly task was undertaken during each of the three trials and covered the manual assembly and installation of six parts to a car door locking mechanism, window lifter, and cover plate shown in Figure 4a, with Figure 4b showing the trainee performing the task. A single experienced trainer from

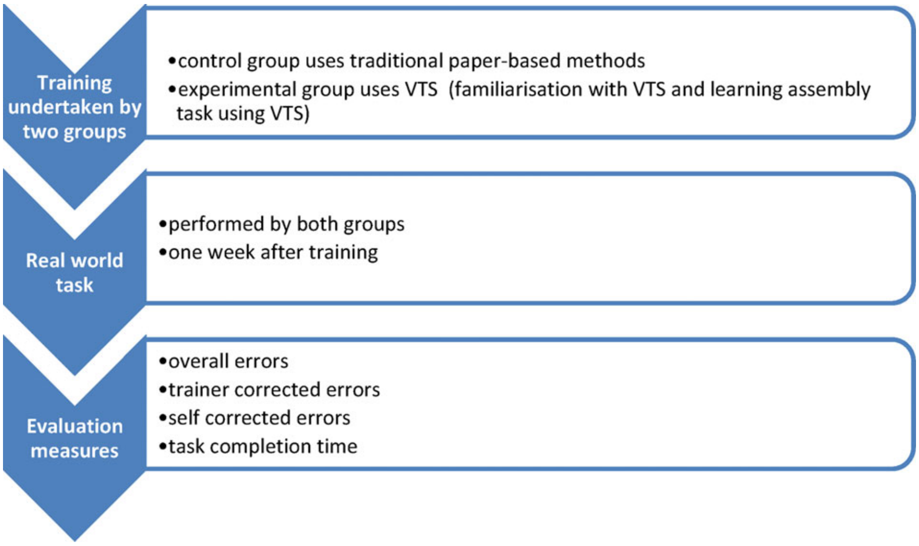

Figure 3 Summary of the methodology for Study 1.

Figure 4 Experimental evaluation. Assembly task performance in Study 1. The parts of the assembly procedure for Study 1 (a). The trainee performing the real-world assembly in Study 1.

the OPEL plant oversaw the training and real-world assembly task. Performance measures were collected during all three trials of the real-world assembly task in the form of overall errors, trainer-corrected errors, self-corrected errors, and task completion time and documented by experts from the research team. Trainer-corrected errors were defined as an intervention by the trainer when a wrong action was taken or when the participant specifically asked for assistance usually because they could not remember the next step, part, or position of a part. Self-corrected errors were defined as when the participant recognized that they were making an error (for example, when they picked up a wrong part but realized this before finishing the assembly action) and corrected it without any interference from the trainer. Overall

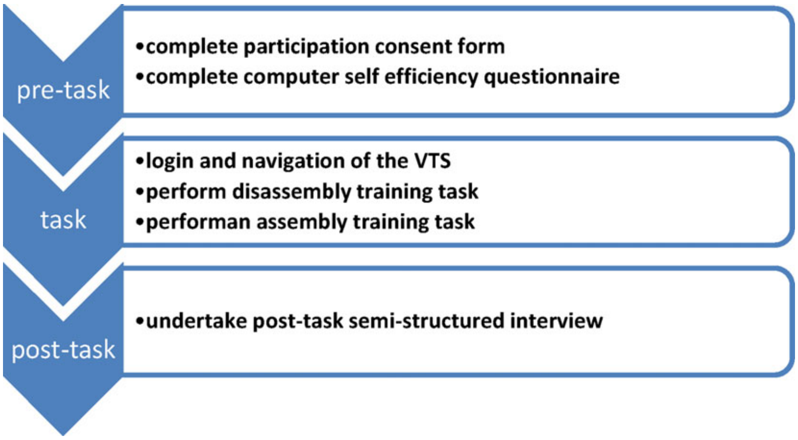

Figure 5 Summary of the methodology for Study 2.

Figure 6 Participant performing task within the VTS in Study 2.

errors were defined as the sum of the trainer-corrected errors and the self-corrected errors. Task completion time was defined as the time taken to perform the real assembly task, from the time the trainer requested the participant to start until the final part was assembled.

3.2. Study 2—Training Efficiency and Acceptance Based on Subjective Measures

To complement the results of the objective study, feedback from a group of real end users (assembly workers, trainers, and managers) from the OPEL plant in Rüsselsheim, Germany, were recorded and used to elicit the benefits and limitations of the VTS.

3.2.1. Participant Selection

Real end users from the OPEL plant were screened as potential participants to establish their demographic information and computer skill level based on a 10-point Computer Self-Efficacy Scale that measured the participant's opinion of their capability regarding computer-related knowledge and skills (described in Section 3.1.1.). From this screening, seven men were selected for the user role of trainee based on their availability, broad age range (average age 40.43 ± 13.04 years with a range between 21 and 54 years), and computer skill level.

3.2.2. Apparatus

The apparatus used in this study was identical to that given in Study 1, described in section 3.1.2.

3.2.3. Study Procedure

Study 2 was undertaken to establish the efficiency and acceptance of the end user to the VTS with Figure 5 showing a summary of the study procedure, which was completed within 2 hr. All the participants that undertook the subjective study first completed the pretask paperwork and the computer self-efficiency questionnaire (adapted from Compeau & Higgins, 1995) used for the participant selection process. This was followed by the performance of three different tasks within the VTS, which the participants were allowed to proceed through at their own pace. The first task involved access, login, and navigation of the VTS. The second task involved performing a virtual disassembly task (a skill required because when new cars come into the assembly line the doors of the car are taken off and reinstalled in a later stage). The third involved performing the same virtual assembly task as in Study 1, with the

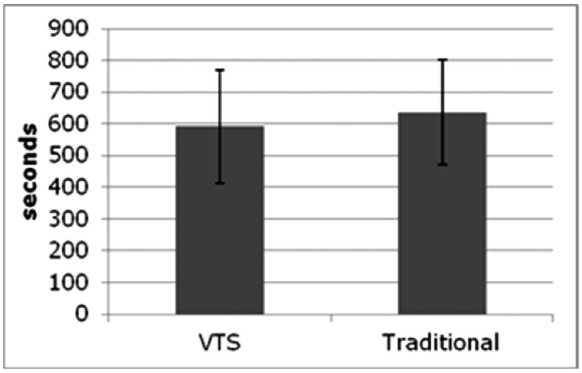

Figure 7 Average task completion time in seconds for the VTS trained and the traditionally trained groups, with the standard deviation represented by the error bars.

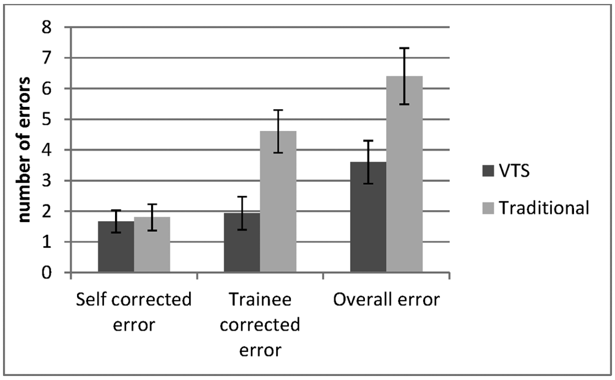

Figure 8 Average overall error, self-corrected error, and trainer-corrected error for the VTS trained and the traditionally trained groups, with the standard deviation represented by error bars.

exception that no time or error measurements were recorded. The study concluded with a semistructured interview that aimed to encourage the participants to discuss what they liked and disliked about the system and how it compares to traditional methods of training. Each study took less than 45 min and was observed by VISTRA project experts of OPEL, the University of Nottingham, and DFKI (German Research Center for Artificial Intelligence). Figure 6 shows the participant undertaking a task within the VTS.

4. RESULTS

4.1. Study 1—Training Effectiveness Based on Objective Measures

An independent samples *t*-test was conducted to compare the different measures obtained from both groups during the three real trial stages. The statistical results of the effectiveness evaluation gives the data collected for the dependent variables for task completion time (TCT), overall errors, trainer-corrected errors, and self-corrected errors for both the VTS and traditionally trained groups. Figure 7 shows the results for task completion time of the two groups, and Figure 8 shows the results obtained for overall errors, self-corrected errors, and trainer-corrected errors. Table 3 shows the average statistical results of the study.

Significant difference (accepted at $p < .05$) was recorded for overall error and trainer-corrected errors between the VTS group and the control group, although no significant differences were recorded for task completion time and self-corrected error.

4.2. Study 2—Training Efficiency and Acceptance Based on Subjective Measures

During the study, positive aspects of the VTS system were identified and noted. All of the participants enjoyed the experience with one participant commenting that *it was like a game* while another stated that *it was fun and comparable to reality*. The participants felt that it was simple to use and better than paper-based training for practicing the sequence of the whole assembly process. The participants liked the visualization, with one stating specifically that he liked that the different parts were in different colors.

Theme-based content analysis (TBCA) was used to analyze the issues raised by the participants about the VTS. TBCA is a qualitative evaluation method that provides information on the opinions of a number of participants, by grouping these opinions into meaningful categories or themes (Neale & Nichols, 2001). The results are listed next and summarized further in the text.

The results identified three main issues, which all relate to the quality of the instructions:

- Extra instruction required concerning the Wii controller and relating to its use
- Instructions for discarding the screw were insufficient
- Instructions for moving the whole body to change the view area were inadequate

On-screen and verbal instructions were given on the use of the Wii controller at the start of the evaluation. However, 85% of participants stated that the instruction concerning the use of the buttons on the Wii

TABLE 3. The Average Measures Taken During the Real World Assembly Task for the VTS and the Traditionally Trained Group

	VTS group	Traditionally trained group	Statistical significance ($p < 0.05$)
Task completion time	M = 592s; SD 178.30	M = 636s; SD 165.03	t (28) −0.697, p = 0.491
Overall error M	M = 3.60; SD 2.720	M = 6.400; SD 3.542	t(28) = −2.428, p = 0.022
Self-corrected error	M = 1.67; SD 1.397	M = 1.80; SD 1.656	t (28) = −2.238, p = 0.813
Trainer-corrected error	M = 1.93; SD 2.086	M = 4.60; SD 2.694	t (28) = −3.031, p = 0.005

controller during the self-calibration stage and navigation through the menu was insufficient. In addition, the instructions to control the field of view using the arrow buttons on the Wii controller were also inadequate.

Verbal instructions were given at the start of the study on the procedure of the task, including the method for discarding the virtual screw. However, 71% of participants stated that discarding the screw, after detaching it from the part, was an issue. The screw needed to be disposed at the lower right-hand side of the screen and the participants were leaving the screen at a point that was too high and consequently became frustrated. A screenshot of the working view showing the screw is shown in Figure 9.

Verbal instructions were also given on the process of moving the body to change the on-screen field of view at the start of the study. However, 71% of participants found this option difficult to control because of the vague instructions, preferring to use the arrow buttons on the Wii while staying static to change the on-screen view.

One of the general principles for interaction design is to promote user-interface design that minimizes the user's memory load by making instructions visible or easily retrievable and related to the current context (Nielsen, 1994). These issues are to be sent to the developers of the VTS and used in further development to bring the system in line with this general principle.

5. DISCUSSION

This paper reports on a study that aimed to evaluate the effectiveness and efficiency of the first prototype of the VTS developed for the VISTRA project, using real end users from the OPEL automotive industry. The investigation involved two studies: 1) a study that objectively evaluated the performance of participants after they had VTS training to establish the effectiveness of the system and 2) a study that elicited the subjective opinions of experts in the assembly procedure to establish the efficiency of the system and to identify usability issues for further development.

The objective evaluation compared a group of participants that had undergone VTS training with a group that had undergone traditional training. The results showed that although there were no significant differences between the groups for task completion time or self-corrected errors, the VTS-trained group made fewer trainer-corrected errors and overall errors when compared to the traditionally trained group. These findings suggest that the VTS has the ability to provide training that produces a greater retention of procedural knowledge and therefore requires less intervention from the trainer. This is an important finding for employees of the OPEL plant because any stoppage of a production line due to mistakes made in assembly cost the company time and money. This suggests that, if the VTS can provide training to a level at which fewer errors are made, it has the potential to be an effective and efficient training tool within the automotive industries.

The overall results of the subjective evaluation showed that most of the participants enjoyed the experience, found it simple to use, liked the visualizations, and commented that it was more enjoyable than traditional training. This shows real potential for acceptability of virtual training. Nevertheless, a number of usability issues were identified, with the three main issues relating to the quality of the virtual instructions. These issues should be the focus of future development to improve the effectiveness and efficiency of the system, taking into consideration the general principles for user interface design and promote recognition over recall. Future advancement virtual training technology has the potential to contribute to the reduction of resources required by industry for training.

This paper has used multiple measures to provide evidence of the effectiveness and efficiency of the VTS. The study has found that by using error as a performance measure, the accuracy of the task performed

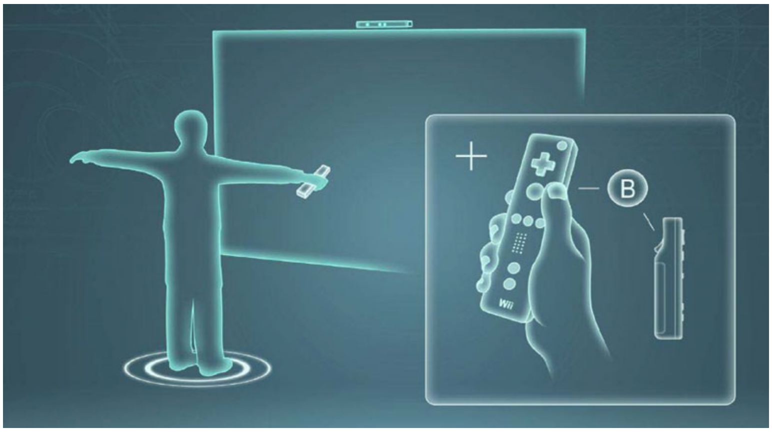

Figure 9 On-screen instructions of the self-calibration instructions.

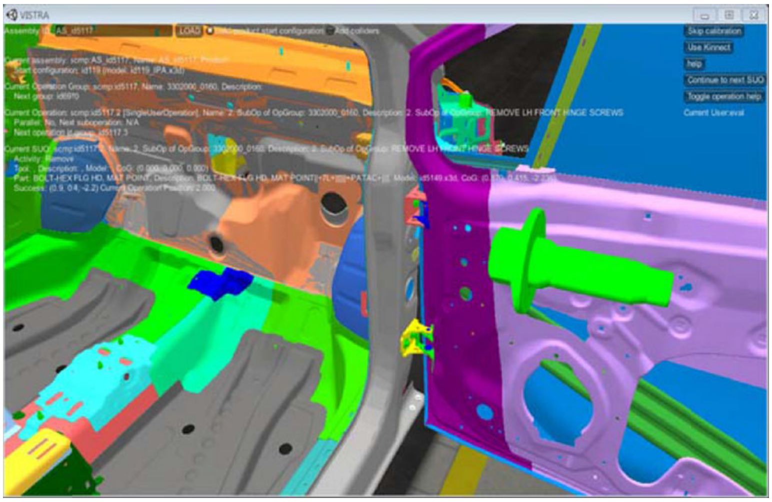

Figure 10 Working view with screw needing to be disposed of at the bottom right hand side of the screen.

and the competency of the trainee in performing the task, can be established. Subjective methods contribute to establishing efficiency of the VTS by identifying the benefits of the system; however, by also extracting user-based issues, the limitations can also be identified and used for further improvement.

6. CONCLUSION

In order for virtual training systems to be fully accepted as a valid tool within the automotive industry, research needs to provide evidence of efficiency and effectiveness for training. This paper has begun to establish the effectiveness and efficiency of the first prototype VTS by using objective and subjective measures. However, this study also identified a number of issues that will be considered in the next round of development and improvement.

ACKNOWLEDGMENTS

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