Study Of The Transfer Of Procedural And Motor Skills Using Virtual Reality For Training Industrial Maintenance And Assembly Operations

Jorge Rodríguez Arce, PhD

September, 7th 2012
The design, implementation and evaluation of a set of multimodal learning strategies in order to study the use of a VR training system for transferring procedural and motor skills in the context of industrial maintenance and assembly operations. Conclusions and future research
Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
Industrial Maintenance and Assembly (IMA) operations.

- Knowledge of specific procedures for each machine.
- Knowledge of the movements and forces that should be applied.
- Complex and need a lot of practice.
IMA OPERATIONS AND THEIR SKILLS

Procedures \rightarrow \text{procedural skill (what – when – how)}

 Movements and forces \rightarrow \text{fine motor control skill}
We remember ...

10% of what we read
20% of what we hear
30% of what we see
50% of what we see, read and hear
70% of what we say
90% of what we say and do

Learning by doing
Doing the physical task

Level of involvement

Verbal information
Visual information
Passive
Active

Doing a training presentation
Participating in a discussion
Watching a demonstration
Seeing it done on location
Watching a video
Looking at an exhibit
Looking pictures and diagrams
Hearing presentations
Reading manuals

introduction | objectives | experiments | IMA-VR platform | final assessment | conclusions & future research
TRADITIONAL LEARNING METHODS

- **Methods:**
  2D drawings, reading a manual, watching a video, following a presentation in a classroom

- **Drawbacks:**
  Required travel
  Time consuming
  Constraints such as: time, costs, availability
Multimodal Training Systems
introduction | objectives | experiments | IMA-VR platform | final assessment | conclusions & future research
• It is not necessary to use the real scenario.

• VR brings extra information that is not available in the real world.

• Practice under the approach of learning by doing.
Learners become dependent on features of the use of VR systems.
There are not many works that have studied the efficiency and performance of training based on VR systems for IMA operations.

- **SHARP**
  Dual-handed haptic assembly system

- **MIVAS**
  Multimodal Immersive Virtual Assembly System

- **HIDRA**
  Haptic Integrated Dis/Reassembly Analysis
Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
1. Analysis of the **training** of the motor and procedural skills involved in the IMA operations.

2. Study of the **risk of the use of VR** for training.

3. Study of the **cognitive elements** that can **improve** the VR **training process** in IMA operations.

4. Design and implementation of a **VR training system** for training procedural skills.

5. Study of the **usability** and the **transfer of skills** involved in a real IMA task with **expert technicians** using a VR training system.
• Exp 1 & 2 – fine motor skill transfer – learning 3D trajectories with accuracy.

• Exp 3 – fine force skill transfer – learning patterns of forces.

• Exp 4 – procedural skills – learning a procedural task.

• Exp 5 – observational learning – improve the training time.

• Exp 6 – transfer study (SIDEI, Italy) – real IMA task.
## Objectives and Experiments

<table>
<thead>
<tr>
<th>Objectives</th>
<th>Experiments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Exp 3 – learning of patterns of forces.</td>
</tr>
<tr>
<td></td>
<td>Exp 4 – learning a procedural task.</td>
</tr>
<tr>
<td>2. Study of the risk of the use of VR.</td>
<td>Exp 4 – use of multimodal aids in a controlled way.</td>
</tr>
<tr>
<td>4. Design and implementation of a VR training system.</td>
<td>All the experiments.</td>
</tr>
<tr>
<td>5. Study of the usability of the VR system with expert technicians.</td>
<td>Exp 6 – transfer study in Sidel.</td>
</tr>
</tbody>
</table>
Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
• **Goal:**
  Evaluating the use of some multimodal training strategies for the transfer of fine motor skills.

• **Experimental task:**
  Learning a 3D trajectory with accuracy.

• **Hypothesis:**
  The use of visual-haptic feedback allows the creation of a useful mental model about fine motor tasks.
Exp 1 - Experimental Conditions

1. Visual feedback (V)
2. Haptic feedback (H)
3. Visual-haptic feedback (VH)
Introduction

Familiarization

Training

Test and subjective evaluation

EXP 1 - PROTOCOL
- Each trajectory was recorded.
- DTW algorithm.

DTW error: 16.7

DTW error: 81.6
• The H and VH groups obtained the best performance.

• The VH groups is more independent from the trajectory’s characteristics.

• No significant differences among the trajectories (F=2.40, p=0.106).

• Subjective evaluation, from 1 (the worst) to 7 (the best):
  - VH = 6.25
  - H = 5.0
  - V = 4.0
EXP 1 - CONCLUSION

- **Visual feedback** facilitates the development of a mental model of the trajectory.

- **Haptic feedback** promotes understanding of some of the characteristics of the task and resolves whatever visual discrepancies may exist.

- **Initial hypothesis:** the use of visual-haptic feedback allows the creation of a useful mental model about fine motor tasks. → it is valid.

• **Goal:**
  Evaluating the reduction of feedback for the transfer of fine motor skills.

• **Hypothesis:**
  The reduction in feedback during the learning process does not damage the transfer of fine motor skills → *It is rejected.*

• **Conclusion:**
  The use of system-maintained feedback is better because it reinforces and corrects the references of the trainees regarding the task.

• **Goal:** Evaluating the use of some multimodal training strategies for the transfer of fine force skills.

• **Experimental task:** Learning a pattern of forces.
EXPERIMENTAL CONDITIONS

1. Punctual Visual Feedback (VFp)
2. Punctual Audio Feedback (AFp)
3. Punctual Haptic Feedback (HFp)
4. Contextual Visual Feedback (VFc)

Punctual Visual Feedback (VFp):
- Trainee
- Tutor

Pitch
Visual Feedback (VFc)

Treble

Wrong

Good

Opposite Force

Low
Introduction | Familiarization | Training | Test
EXP 3 - PERFORMANCE MEASURES

- Variable patterns
  - DTW.

- Constant patterns
  - Difference between the tutor and participant’s patterns.
• The participants trained with the contextual condition obtained the best performance in both cases.

• Significant differences among the training conditions in both cases (F=4.62, p=0.006) (F=109.3, p=0.001).

• People had problems to understand the information provided by the punctual conditions.
• **Contextual information** approach results in better performance than the punctual information approach.

• **Initial hypothesis:** the use of contextual information for transferring fine force skills results in better performance than the use of punctual information. → it is valid.

EXP 4 - GOAL, TASK AND HYPOTHESIS

- **Goal:** Evaluating the use of direct and indirect aids for the transfer of procedural skills.

- **Experimental task:** Learning an assembly procedure.

- **Hypothesis 1:** The use of direct aids in a controlled way results in better performance than the use of indirect aids for the transfer of procedural skills.

- **Hypothesis 2:** The use of multimodal feedback in a controlled way does not create dependence in the transfer from the VE to the real world.
EXP 4 - EXPERIMENTAL CONDITIONS

“Indirect aids” group
> cognitive load

“Direct aids” group
< cognitive load

STEP 30/75
**Introduction**

**Familiarization**

1st day

1. **Trial 1** – automatic help
2. **Trial 2** – requested help
3. **Trial 3** – trial and error
4. **Trial 4** – trial and error

**Test**

2nd day
• Task execution time: time to perform the real task.

• Correct steps: number of bricks assembled in its correct position without the use of the instruction book.

• Steps with aids: number of bricks assembled in its correct position with the use of instruction book.

• Steps with non-solved errors: number of bricks assembled in a wrong position or number of missing bricks.
In general, there are not significant differences between both groups. People from the “direct aids group” solved more errors without the instruction book.

<table>
<thead>
<tr>
<th>Performance measures</th>
<th>Indirect aids group</th>
<th>Direct aids group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Task execution time (min)</td>
<td>17.9</td>
<td>18.6</td>
</tr>
<tr>
<td>Correct steps (%)</td>
<td>62.11</td>
<td>60.49</td>
</tr>
<tr>
<td>Steps with aids (%)</td>
<td>36.56</td>
<td>37.54</td>
</tr>
<tr>
<td>Steps with non-solved errors (%)</td>
<td>1.33</td>
<td>1.96</td>
</tr>
<tr>
<td>Number of consults</td>
<td>27.4</td>
<td>28.2</td>
</tr>
<tr>
<td>Number of errors corrected without the book</td>
<td>20.7</td>
<td>28.6</td>
</tr>
</tbody>
</table>
• The use of direct aids could reduce the training time.
Transition from the VR system to the real task.

There are not significant differences between the trial 4 and the real task.
• The use of direct aid in a controlled way:
  - allows the learning of procedural tasks, and
  - avoids that people become dependent on the VR system.

• *Initial hypothesis 1:* The use of direct aids in a controlled way results in better performance than the use of indirect aids for transferring procedural skills. \( \rightarrow \) *It is rejected.*

• *Initial hypothesis 2:* The use of multimodal feedback in a controlled way does not create dependence in the transfer from the VE to the real world. \( \rightarrow \) *It is valid.*
• **Goal:**
  Evaluating whether replacing part of the physically active training with observational learning improved training efficiency.

• **Hypothesis:**
  Integrating observational learning into virtual training systems can enhance training efficiency.

• **Conclusion:**
  The results provide insights on training time is reduced with the addition of an observational learning phase.

Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
EXP 6. GOAL AND HYPOTHESIS

- **Goals:**
  - Evaluating the use of the IMA-VR platform as a training tool with expert technicians.
  - Comparing the training with the IMA-VR platform and the use of one traditional training method.

- **Hypothesis:**
  Since the IMA-VR platform is focused on transferring the procedural skills then this system can replace the traditional learning methods without decreasing the performance of the task.
EXP 6. EXPERIMENTAL TASK

1) Belt Roller

2) Two Level Sensors

25 steps and 6 sub-tasks

3) Support Plate

4) Electronic Board

5) Actuator Cover

6) Clamp
EXP 6. EXPERIMENTAL CONDITIONS

• **GROUP 1 – VR:**
  • Performing twice the virtual task with the IMA-VR platform.

• **GROUP 2 – Control-VR:**
  • Watching twice the instructional video demonstrating the task.
MORNING

- Capability test
- Introduction
- Familiarization
- Training

AFTERNOON

Test and subjective evaluation
## Measures

<table>
<thead>
<tr>
<th>Measures</th>
<th>Video</th>
<th>IMA-VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants Age</td>
<td>32.90</td>
<td>31.50</td>
</tr>
<tr>
<td>Participants Experience (in years)</td>
<td>4.00</td>
<td>3.80</td>
</tr>
<tr>
<td>Level of ability in IMA tasks (range from 1 to 5)</td>
<td>3.70</td>
<td>3.60</td>
</tr>
<tr>
<td>Training Time (in minutes)</td>
<td>4.43</td>
<td>8.47</td>
</tr>
<tr>
<td>Performance Time (in minutes)</td>
<td>8.72</td>
<td>8.75</td>
</tr>
<tr>
<td>Average of non-solved errors in the real task</td>
<td>0.10</td>
<td>0.40</td>
</tr>
<tr>
<td>Average solved errors in the real task</td>
<td>0.20</td>
<td>0.10</td>
</tr>
<tr>
<td>Percentage of correct steps</td>
<td>98.80</td>
<td>98.00</td>
</tr>
<tr>
<td>Score from 1 (the worst) to 5 (the best)</td>
<td>N/A</td>
<td>2.90</td>
</tr>
</tbody>
</table>

In general there are not significant differences.
• The IMA-VR platform is a useful tool for training IMA operations.

• The IMA-VR platform is an efficient alternative to the current learning methods.

**Initial hypothesis:**
The IMA-VR platform can replace the traditional learning methods without decreasing the performance of the task.

→ It could not be totally validated at this time.

Overview

introduction
objectives
experiments
IMA-VR platform
final assessment
conclusions and future research
GENERAL CONCLUSION

• Multimodal aids in a controlled way enable the transfer of procedural skills and does not create dependency.

• The IMA-VR platform can be an alternative option to the traditional training methods.
• Further research should focus on:
  – More experiments should be done in order to validate the use of the IMA-VR as a training tool.
  • What kind operations can be trained?
  • What is the best profile of the trainees?
• **Experiment on procedural tasks with non-experts.**

• **Goal:**
  - Evaluating the multimodal strategies of the IMA-VR platform to define the best training protocol for the final assessment.

• **Experimental Task:** an assembly procedure composed of 23 steps grouped in 5 sub-tasks.

1) Level Sensors  
2) Fix Support Plate  
3) Place Electronic Board  
4) Place Actuator Cover  
5) Place Clamp
Final performance of the trainees

Non-experts

<table>
<thead>
<tr>
<th>Video</th>
<th>IMA-VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steps with non-solved Errors: 23.0%</td>
<td>14.8%</td>
</tr>
<tr>
<td>Steps with Solved Errors: 71.3%</td>
<td>79.1%</td>
</tr>
<tr>
<td>Steps With Aids: 4.3%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>

Experts

<table>
<thead>
<tr>
<th>Video</th>
<th>IMA-VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steps with non-solved Errors: 0.8%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Steps with Solved Errors: 98.80%</td>
<td>98.00%</td>
</tr>
<tr>
<td>Steps With Aids: 0.4%</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

Correct Steps
• Further research should focus on:
  – More experiments should be done in order to validate the use of the IMA-VR as a training tool.
    • What kind operations can be trained?
    • What is the best profile of the trainees?
  – The implementation of other cognitive and motor skills.
  – The implementation of the training in diagnosis methods.
Gracias por su atención.

¿Alguna pregunta?
OTHER IMA OPERATIONS

- Learning trajectories
  - Weld
  - Clue a part

- Learning forces
  - Tighten a fragile part
  - Assemble a fragile part
<table>
<thead>
<tr>
<th>Cognitive Skills</th>
<th>Sensori-motor skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perceptual observation</td>
<td>Bimanual coordination</td>
</tr>
<tr>
<td>Attention management</td>
<td>Interpersonal coordination</td>
</tr>
<tr>
<td>Control flexibility</td>
<td>Balance control</td>
</tr>
<tr>
<td>Decision making</td>
<td>Postural control</td>
</tr>
</tbody>
</table>
- Preliminary capability test: no significant differences in technical capabilities between groups.
IMA-VR STRATEGIES

Strategy 1 – Observational learning.

Strategy 2 – Current action aid.

Strategy 3 – Step level aid.

Strategy 4 – Sub-task level aid.
1. **Screwing/unscrewing**: Trainees can use different types of screwdrivers and screws in order to fix several components, such as, supports, sensors, motors, etc.

2. **Tightening**: Trainees can use different types of wrenchs and nuts in order to tighten a screw. The operation can be simulated using other intermediate steps, such as, the use of lock washers.

3. **Plugging/unplugging**: Trainees can simulated the operation to plug/unplugged cables, from example, to connect the data signal of a motor into an electronic board.

4. **Managing pieces with one hand**: Trainees can simulated the operation to place pieces by hand, for example, to place a electronic card in a support plate or to place the cover of a machine.
• To compare the data with previous studies
  – As result of my research previous works only analysed the training of 2D trajectories with haptic devices using a normal screen as visual feedback, then I want to study what happen with the learning of 3D trajectories.

• Technicians are not familiarized with VR technologies.

• There are some studies that support the idea of the 3D technology can cause headache in some people.
EXPERIMENT 7

- Expert vs non-expert technicians

- Easy vs complex task
  - Easy – same task than in Sidel
  - Complex – more steps, more operations and more complex scenario
<table>
<thead>
<tr>
<th></th>
<th>Video</th>
<th>IMA-VR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participants Age</td>
<td>34.9</td>
<td>23.2</td>
</tr>
<tr>
<td>Participants Experience (in years)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Participants Skills in IMA tasks (range from 1 to 5)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Training Time (in minutes)</td>
<td>20</td>
<td>24.56</td>
</tr>
<tr>
<td>Performance Time (in minutes)</td>
<td>13.04</td>
<td>13.30</td>
</tr>
<tr>
<td>Average number of Non-solved errors in the real task</td>
<td>5.1</td>
<td>3.7</td>
</tr>
<tr>
<td>Average number of Solved errors in the real task</td>
<td>1.1</td>
<td>0.5</td>
</tr>
<tr>
<td>Percentage of correct steps</td>
<td>71.3</td>
<td>79.13</td>
</tr>
</tbody>
</table>