Psychomotor skills in consumer grade virtual reality

An assessment of which type of skills are suitable for simulator training

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ABSTRACT

Virtual reality simulators have been used for decades in the Aviation, Military and Medical industry for skill training. They have proved to be effective in skill transfer, and have contributed to safety, cost- and time-efficiency. Recently there has been a lot of focus on consumer grade VR. This paper looks into how this equipment can be utilized to provide the same benefits when training psychomotor skills. 8 guidelines have been compiled based on a literature review on this topic. These guidelines provide elements that should be avoided in consumer grade virtual reality simulators.

KEYWORDS: Virtual Reality, Simulators, Training, Psychomotor skills

1. INTRODUCTION

Virtual Reality(VR) has been a hot topic for many years and people have predicted a golden age of virtual worlds since the 1960s [1]. But VR has yet to make a breakthrough in most markets. The main problem has been that the technology is not accessible or affordable to the consumer market, which in turn has led to little research and development in this field [2]. However, the situation is now a lot different even compared to just a few years back. Today multi-billion dollar companies are investing in consumer grade VR technology, in terms of both software and hardware.

While this technology is new to the consumer market, it has existed in industries such as the Military and Aviation for several decades. VR simulators has been used as a training tools for pilots and soldiers, and has proven to be efficient in training effectiveness, cost and in terms of safety for the users.

This paper looks into how consumer grade VR equipment can be utilized for training of psychomotor skills. Firstly, there will be a literature review of equipment currently used for simulator training and the state of the art consumer grade VR equipment. Secondly there will be conducted a review of psychomotor skills. This will be used to assess what is possible to simulate, and which skills might be fit for simulator training.

1.1 The contribution of this paper

Virtual reality simulators have the possibility to save both time and money, and contribute to safety and efficient training for the users. As the availability of consumer grade equipment is increasing, it could be beneficial to investigate the possibilities and limitations with this equipment. This paper aims to contribute with a is a set of guidelines to assist the creation of consumer grade VR simulators for training of psychomotor skills.

1.2 Structure

The paper is organized into 7 sections. Section 2 looks into existing simulators and efforts at releasing consumer grade VR equipment. Section 3 is an assessment of fundamental requirements for creating realism in VR simulators. Section 4 is a review of psychomotor skills. Section 5 examines limitations and possibilities in current consumer grade VR equipment. Section 6 discusses which skills are fit for VR training and limitations with the current consumer grade equipment. The last section presents the guidelines that were constructed.

1.3 Definitions

The definition of VR according to the Oxford English Dictionary is; *A computer-generated simulation of a lifelike environment that can be interacted with in a seemingly real or physical way by a person, esp. by means of responsive hardware such as a visor with screen or gloves with sensors* [3]. This paper always refers to VR according to this definition, achieved through using head mounted displays or similar equipment.

Head mounted displays (HMDs) are worn on the head and provides the wearer with one display in front of each eye. The two displays provide the user with stereoscopic vision of a virtual environment.

Virtual environments (VEs) are three dimensional computer generated environments. In this paper VEs are always referred to as environments viewed though a HMD.

Virtual reality simulators (VRSs) and simulators are in this paper referred to as simulations of the real world or tasks within VR.

2. VIRTUAL REALITY SIMULATORS USED FOR SKILL TRAINING

In an interview with Jaron Lanier [4], often coined as the inventor of the term Virtual Reality, he said the following about the purpose of VR*; You can't really ask what the purpose of Virtual Reality is because it's just too big. You can ask what the purpose of a chair is because it's a small enough thing to have a purpose*. This paper focuses on VR as a tool for training psychomotor skills. The use of VR for training psychomotor skills is currently done in a series of fields, such as retraining of surgeons in the medical industry or soldiers in the military. In some educational agencies VRSs are even part of the mandatory curriculum, such as in civil flight. The following section looks into examples of existing simulators that have proven to be effective in skill transfer. Simulators which have proven to be time saving and cost efficient will also be evaluated. Lastly, attempts at releasing VR equipment to the consumer market will be assessed.

2.1 Link Trainer

One of the first products which could be considered a VR simulator, is the Link Trainer, a flight simulator developed during the nineteen twenties. It was the result of a drive by the American military to make new and efficient ways to train pilots for the world war 2. The Link Trainer is a mechanical machine, which is fixed to the ground and equipped with aircraft instruments. The simulator acts similar to a flying aircraft but has no displays. The purpose of the Link Trainer was to train pilots in instrument flying, and was a forerunner in showing the efficiency of simulator training [5].

2.2 LapSim

LapSim [6] is a VRS made for training of surgeons in laparoscopic surgery. The LapSim has proven to be efficient in skill transfer, and has since its release in 2001 been used to train thousands of surgeons. Ahlberg et al. [7] did a study to assess the efficiency of proficiency-based VR training, in this simulator. The study consisted of a VR-trained group and a control group, where the VR-trained group was trained in the LapSim until a predefined level of performance was reached. The study concludes that; *all new laparoscopists should train on the simulator until they reach the established proficiency level, before performing laparoscopically on patients*. This study shows promising result for the simulator, as the VR-trained group performed with a significantly higher score, a more homogeneous performance and with consistently fewer errors, compared to the control-group.

2.3 DentSim

DentSim is a preclinical simulator made for the dental industry [8]. The simulator consists of a mannequin with a dentoform and a dental hand piece, which are tracked by an infrared camera. Information about progress and performance is displayed on a monitor, through real time image processing. Feedback from an instructor is therefore not necessary after every preparation, thereby enabling the trainees to carry out up to twice as many dental preparations in the simulator, compared to training in traditional laboratories. As a result, trainees were able to learn dental procedures faster, and at the same time reaching the same level of skill as with other training methods [9]. A similar experiment by Kikuchi et al. [10] was conducted to compare performance in metal crown preparation for dental trainees both using and not using the DentSim. They found that trainees training in DentSim improved over time and received a significantly higher score than those who did not. This was caused by the simulators embedded feedback system, which gave the trainees a better understanding of which actions were needed, leading to better development of skills.

2.4 Commercial simulators

An evaluation of several medical simulators, including both DentSim and LapSim, by Ruthenbeck and Reynolds [11] found that many simulators are very efficient in skill transfer. Most of these simulators are part trainers, which focuses on a few aspects of a skill, and are limited to specific training scenarios. The majority of these simulators also used custom or heavily modified hardware along with very complex software applications. As a consequence, the simulators are often inflexible and hard to adapt to new scenarios, which renders most of them unfit for reuse. This is also common for most other simulators, as they are often customized for specific training scenarios, such as the Link Trainer.

However, the biggest problem for consumers is the cost of these simulators. In order to make VR simulators available to consumer market, both hardware and software would have to be affordable, and at the same be easy to obtain and customize [2]. This could enable consumers to acquire simulators for a range of task.

2.5 Efforts at releasing VR to the consumer market

During the 1990s, there were several attempts at releasing VR equipment to the consumer market. One of the earliest was *The Power Glove*, which was released in 1989. *The Power Glove* was a hand motion controller, used to track the users hand motion and to control objects on the screen on the Nintendo Entertainment system. However, one of the initial flaws with the system was the poor interface, as both the hardware and software were hard to use, and offered few possibilities for customization. Secondly the equipment was expensive. As a result, this attempt at releasing VR to the consumer market was an economic failure for Nintendo [2].

Similar products have also suffered the same fate, such as Virtual Boy, a portable gaming-console able to display 3D-graphics. The console had apparent technical shortcomings and a lack of valuable content [12]. Similar to The Power Glove, the cost of the equipment compared to the value it offered to the consumer was not in compliance, resulting in failure.

2.6 VR hardware

Since the 1990s, no mentionable releases of consumer grade VR equipment have been made. However, when Oculus VR launched a successful Kickstarter campaign in 2012 to found their VR HMD named Oculus Rift, several big companies has started to invest in this technology. Since 2012, several releases of affordable consumer grade VR equipment has occurred. Some of these are; Google Cardboard by Google, HTC Vive by HTC and Valve Corporation, PlayStation VR by Sony and Samsung Gear VR by Samsung. All of these are VR HMDs made primarily for media consumption, mainly games and 3D video.

These products are very different in terms of interactivity. The simplest versions, like Google Cardboard and Samsung Gear, only allow for head tracking, with three rotational degrees of freedom; roll, yaw and pitch. While the more advanced versions also allow for interaction with the VEs through input controllers. The most advanced consumer grade VR equipment as of October 2016 must be considered to be the HTC Vive, which enables a room-scale VR in six degrees of freedom, namely; roll, yaw and pitch and translation in all directions.

2.7 VR software

Many successful commercial simulators are built with open source software [11]. However, these are usually modified to the specific needs of the simulator, which is often time consuming. Custom simulators are also often associated with high maintenance cost.

However, 3D game engines, such as Unity and Unreal, supports most of the new VR equipment and are in addition free to use. Both provides the user with the ability to use visual scripting, allowing for programming simple simulator behavior without extensive technical knowledge. As long as a user has the necessary hardware, e.g. HTC Vive or Oculus Rift and a suitable computer, setting up a VE ready for development can be done in just a few steps [13, 14]. Furthermore, the Physic engines, which are built into the game engines, makes simulating forces, collisions and basic interactions as simple as checking a box or adjusting values with a slider. The Unity Asset store and Unreal Engine Marketplace provides a great variety of free or inexpensive assets to the user. Additionally, there exist other communities that offer free assets, so there is often no need to create content from scratch.

3. ACHIEVING REALISM

Bowman and McMahan [15] argue that simulator training will only be as effective as the simulation is realistic. Creating a realistic simulation is a matter of matching the real world experience, and is the key to a successful VRS. However, there exist several types of realism. Which type of realism that is important, varies based on the skill that is taught. This section is a discussion of skill transfer and visual, interaction and tactile realism, and to which degree each can be achieved with consumer grade VR equipment.

3.1 Skill transfer

Rose et al. [19] evaluates several factors for efficient skill transfer from VR to the real word. Firstly, the importance of similarity between sensory characteristics, or in other words external stimuli and feedback to the user. An example is mismatch in feedback, which can lead to compromised skill transfer if not simulated realistically.

Secondly the importance of similarity between motor characteristics, as the same motoric actions should be possible and give the same results in both VR and in the real world.

Mismatch of feedback could consequently result in negative skill transfer, meaning that the user would perform worse than he initially would, or that bad habits are transferred to the real world.

Rose et al. also states that making tasks equally difficult is important, as skill transfer could be compromised if the cognitive load differs between the tasks. If a task requires less cognitive effort in VR, the user could experience a deficiency in cognitive capacity when transferring to the real world. This implies that the cognitive load of the task in VR should not be lower than the cognitive load in the real world.

3.2 Visual realism

Visual realism is usually easy to achieve. The state of the art graphic cards today, has great rendering capabilities and are able to render photorealistic VEs in real time. In spite of this, Herrington et al. [16] argues that high fidelity visual realism is not always necessary. However, it is making the user perceive the simulation as real and authentic that is important. An example is animated movies, which by many can be experienced as just as real as movies with real actors. Well-designed simulations are able to immerse the user and when the initial suspension of disbelief has occurred, the screen-resolution and level of visual realism is to some extent unimportant.

3.3 Interactions realism

Simulating interactions are in most cases possible, but often difficult. They are one of the fundamentals in making VR simulators effective in skill training. Interaction between the user and the VE is usually done with an input-controller, where the controller usually defines the key interaction mechanics. Achieving interaction realism is a matter of simulating realistic results from the users actions. Clicking a button in VR, should ideally be experienced the same way as clicking a button in real life.

3.4 Tactile realism

Feedback to the user in terms of the tactile experience is one of the major challenges in VR simulations [17]. Cues from tactile realism can be separated into three categories; kinesthetic, haptic and cutaneous, which is sense of force, vibrations and texture respectively. Enabling the user to sense the application of force, kinesthetic cues, in a VE is difficult, since properties such as weight and volume is limited to the physical world. Unlike visual and interaction realism, tactile realism can only be achieved through the use of external devices. As a result, most medical simulators use custom haptic devices [11]. These are devices that allow for tactile interactions between the user and a computer. However, they usually only allow for a limited amount of degrees of freedom, firstly because the devices has to be mounted somewhere in the psychical world and secondly because this makes creating simulations easier. An example of a widely used haptic device is the Phantom OMNI [18]. This device is able to move in 6 degrees of freedom, but is very limited in terms of range of motion. It provides both kinesthetic and haptic cues to the user, and has proven to be efficient in many part task medical simulations.

3.5 Simulating materials

Mechanical interfaces interacting with homogeneous materials are the most common feature in medical simulators [11]. For instance, are VR training often applied to medical procedures using external instruments, e.g. minimal invasive surgery. The reason for this is generally because this does not involve direct contact with the patient, which would require the surgeon to rely on cutaneous cues. On the contrary, this is often seen in dentistry, where VR simulators, e.g. DentSim, often involve the use of physical mannequins. While soft and heterogeneous materials, such as soft tissue, is difficult to simulate, the use of mannequins allows the surgeon to experience kinesthetic, haptic and cutaneous cues.

4. PSYCHOMOTOR SKILLS

Psychomotor skills are actions involving movement, coordination, manipulation, dexterity, grace, strength and speed, based on the definition by Simpson [20]. This is a subcategory of motor skills, as they do not include all muscular actions, e.g. reflexes such as breathing or hiccups. Psychomotor skills are also defined as muscular actions based on external stimuli, such as sounds or the position of an object. Examples of psychomotor skills are shooting at a target with a gun or making a penalty kick in football. This section is a review of psychomotor skills, providing ways to divide them into categories and stages.

4.1 Different categories of psychomotor skills

Smith and Ragan [21] provides three different ways of categorizing psychomotor skills. Firstly, psychomotor skills can be divided into discrete and continuous skills, indicating to which extent a skill can be fully mastered. An example of a discrete skill is the ability to click a button, which a person can or can not do. Additionally, serial skills is a subcategory of discrete skills, relating to a series of skills required to form a major skill, for example the ability to write a series of letters in order to complete a full word. An example of a continuous skill is the ability to run, which is a skill that can always be improved.

Secondly, psychomotor skills can be categorized based on the extent external factors that are affecting the execution of a skill. This results in the categories; closed and open skills. Closed skills are not actively influenced by external factors, e.g. juggling. As for open skills, continuous adjustments are required, e.g. team sports, where a persons action are depending on other players. These categories are also called self-paced and externally paced skills, referring to which extent a person initiates the task or action [22].

Finally, psychomotor skill can be categorized into type 1, 2, 3 and 4 skills. However, this only applies when the skill includes the use of one or several objects, and referrers to weather the person, object or both are at rest or in motion. If both the person and the object is at rest, the skill is categorized as a type 1 skill. As for type 2 and 3 skills, the object or person is in motion respectively. However, if both the person and the object are in motion, the skill is categorized as a type 4 skill. As far as difficulty is concerned, difficulty generally increases when motion is introduced. Naturally, type 4 skills are generally more difficult than type 2 and 3 skills, which again are generally more difficult than type 1 skills.

4.2 Stages of psychomotor skill acquisition

Acquiring psychomotor skills consists of two different sub- tasks. The first is learning the muscular movements required to do the skill. The second is decision making, learning to plan the sequence of muscular movements required to achieve the wanted result. Fitts et al. [23] describes the acquisition of a motor skill as a continuous process, consisting of two different phases; the early phase and the intermediate phase.

In the early phase learners are taught instructions, enabling them to create a cognitive map of how to execute a skill. An example is when a baseball instructor is telling a learner how to swing the baseball bat in order to hit the baseball. In brief, the learners are though decision making, enabling them to know when to do what. This phase also involves the completion of a few preliminary trials, to give the learner an overview of what is to be taught. Alternatively, this phase is called the cognitive phase, emphasizing the fact that the user only has a verbal understanding of the skill.

At the intermediate phase the learner has acquired a verbal understanding of how to execute a skill, but has yet to learning how to perform it. In general, this is done through practice, gradually learning muscular movements and the sequence of which they are to be executed. This phase is also referred to as the associative phase, as learners at this stage are forming associations to external cues, e.g. assessing the speed of the baseball in order to know when to swing the baseball bat. During this phase, the learner is still reliant on following a cognitive sequence of plans, in order to do the correct muscular movements. In other words, the learner is transferring verbal knowledge into physical skills.

Additionally, Smith and Ragan [21] mentions a third phase, called the autonomous phase. As a rule, the learner is considered to have reached this phase when expert performance in a skill is achieved. During this phase the learner is no longer reliant on cognitive effort to execute a skill, which is called; reaching automaticity. An example of this is when someone is driving a car and suddenly realizing they have reached their destination, without being able to recall driving. In general, the learner is able to automatically respond to cues when they have reached the autonomous phase of skill acquisition.

5. EXAMINATION OF CONSUMER GRADE VR EQUIPMENT

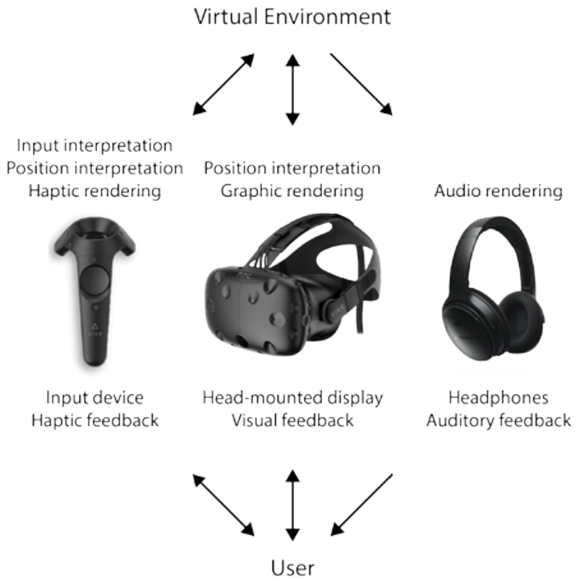

Figure 1: Interaction loop between the user and the VE. Based on Bowman and McMahan [15] Figure A.

Figure 1 shows a typical interaction loop between a user and the VE in VR. In this example, the computer is used to track the position of the HMD and position and inputs from input device. As a result, the computer is able to provide the user with feedback, in terms of haptic, visual and auditory feedback. This section evaluates the possibilities and limitations with current consumer grade VR equipment, with the HTC Vive [24] used as a reference.

5.1 Tracking system

Tracking systems are used to read the positions of VR hardware. The tracking system used with the HTC Vive, are able to track an area with a diagonal of maximum 5 meters, resulting in a maximum area of approximately 3.54 x 3.54 meters. Accordingly, the user is able to move around freely within these limits. However, activities that require a larger area than this would need another solution than free movement. One possibility is low friction platforms, similar to treadmills, such as the Virtuix Omni [25]. These devices allow the user to move around unrestricted. However, Harlaar et al. [26] suggests that treadmills coupled with VR induce unnatural walking behavior. Additionally, they point out that walking on treadmills while in a VR can make subjects uncomfortable. Other alternatives for movement are transitions, flying and teleportation, which are widely used in current VR games [27].

Kreylos [28] has done a thorough examination of the HTC Vives tracking system. From the examination he concludes that the controllers are tracked at a rate of 1000 Hz and the HMD at 370 Hz. However, the tracking data is only updated at a rate of 250 Hz and 225 Hz, when using OpenVR. Consequently, the expected delay from users input to systems output is approximately 4.4 ms for the HMD and 4.0 ms for the controllers. Additional latency will occur depending on the simulation program, where latency usually increases with the simulators complexity. Allison et al. [29] finds that the acceptable level of latency varies greatly between tasks. For instance, the acceptable latency for virtual object manipulation is 33 ms, while the acceptable latency for flight simulators can be up to 240 ms. A rule of thumb is that lower latencies are required when motion increases. In addition are high latencies associated with decrease in both performance and the feeling of presence, and can lead to unwanted effects, e.g. motion sickness.

Kreylos [28] also finds that the expected tracking accuracy is about 2 mm. In reality this is a lot less noticeable, as algorithms are used to compensate for tracking inaccuracies.

5.2 Head-mounted display

HMDs are used to track the users viewpoint and display the appropriate image based on their position. The HMD used with the HTC Vive, see Figure 1, has a resolution of 1080x1200 pixels per eye, a refresh rate of 90 Hz and a field of view of 110 degrees. In general, most people are only able to see a frame rate of 50 Hz [30]. This implies that a frame rate of 90 Hz should be sufficient for most tasks.

The HMD does support stereo depth cues, but does not support focus cues. Lenses commonly used in HMDs have a focal distance of 2 meters [30]. This means that in ranges closer than 1.2 meters, depth-of-focus effects can appear. Thatte et al. [31] suggests that this could lead to discomfort in the long run, but more importantly to deficiency in depth perception.

Current consumer grade HMDs also suffer from deficiency in peripheral vision, as field of view is usually 110 degrees. This is only about 60% of the eyes possible field of view, which is approximately 180 degrees.

5.3 Controllers

The controllers are the users way of interacting with the VE. However, they can be considered to be restricting compared to the real world. An obvious limitation with the current consumer grade VR controllers is the reduced ability for finger movements. This is caused by the controllers, which are restricting the users hands, and thereby their finger dexterity. Still, the HTC Vive controllers, see Figure 1, provide the users with three main ways of interacting with the VE. The first ability is to push a trigger with the index fingers. The second ability is to grab or squeeze by pressing with the middle- ring- and little-finger. The third ability is a more arbitrary action, where the user has a clickable touch pad positioned under the thumb.

Another limitation is the types of feedback available to the user. For the most part, the trigger, buttons and touch pad provides feedback in terms of tactility. Apart from this, the only available feedback is haptic feedback in terms of vibrations. However, many VR games are currently taking advantage of the haptic possibilities of the controller, and are using the vibrations to simulate force. An example is seen in the mini game called *Longbow*, within the game *The Lab* [32]. This is an archery game, where the player has to defend a castle by shooting arrows at targets. Evangelho said the following about the mini game; *Longbow just feels magical. Audio cues combined with the Vive's motion controller haptics to create an illusion of resistance in your mind. You feel like you're really pulling back on the string and letting the arrow fly* [33]. This suggests that vibrations could be used as a compensation for the shortcomings of other types of feedback.

6. DISCUSSION

Consumer grade VR equipment has several limitations when it comes to simulating the real word. This section assesses possibilities and limitations for psychomotor skill training with this equipment. Limitations in regards to both hardware and software will be assessed. The findings in this section are presented as guidelines.

6.2 Limitations with consumer grade VR hardware

Consumer grade VR equipment has many technical shortcomings. Firstly, the current HMDs used in consumer grade VR has a deficiency in field of view compared to regular sight. This means that cues that usually appear in the peripheral vision can be weak or not appear at all. Tasks that require the user to keep an overview over several objects or a large area can therefore be inappropriate to learn in VR. This is because important cues can easily be overlooked. An examples of such a skill is driving a car in traffic, as driving requires the learner to keep an eye on many things at once. These could be incoming cars and traffic signs, which are cues that are crucial for learning this particular skill.

- Skills should not require learner to keep track of several objects at once or monitor a larger area. All objects that are monitored should be within the HMDs field of view.

Skills that are reliant on focus cues are also not ideal for training in consumer grade VR, as current HMDs are not able to display these cues. At distances closer than the HMDs lens focal distance, there is a chance that negative depth-of-focus effect can occur. Examples of skills that require accurate depth estimations at a close range are manual stitching and sculpting. However, if the user has sufficient cues for evaluating distance, this should not be a problem.

- Skills that require focus cues or accurate depth estimations at a range closer than the HMDs lens focal distance should be avoided.

Consumer grade VR are not able provide kinesthetic or cutaneous cues. As a result, skill which are dependent on these cues are unfit for simulator training. An example is weightlifting, which directly involves reacting to kinesthetic cues. However, this does not mean that all skills involving these cues are unfit, as discussed in section 5.3, it is possible to simulate some of these cues using other types of feedback. If haptic feedback is coupled with e.g. visual or auditory feedback, realistic experiences can be achieved. Examples of kinesthetic cues which could be simulated are contact between objects, e.g. by using sound and vibration to simulate the kinesthetic cue of the controller hitting a virtual object. Nevertheless, efforts to do this would require validation to evaluate efficiency of skill transfer. Skills that require touch sensitivity, cutaneous cues, such as reading braille, are currently not possible to simulate in VR. If this also includes interactions with soft and heterogeneous materials, they are even more difficult to simulate, and should be avoided if possible.

- Kinesthetic and cutaneous cues should not be a key element for learning the skill, unless the cues can be simulated using available types of feedback.

Tracking in the HTC Vive is accurate to approximately 2 mm. This is not accurate enough for fine motor tasks such as threading a needle. However, for most tasks this is presumably precise enough not to be noticeable. For some skills, the required accuracy depends on the skill of the learner, e.g. aiming with a gun. In this case, the current accuracy would be acceptable for a beginner, but not precise enough for an expert. However, as the accuracy is not exact, errors relating to this should always be expected.

- Skills that require a high level of precision should be avoided.

Finger movement is limited while using input controllers in consumer grade VR. As a result, skills that are based on finger dexterity is not fit for VR training. Examples of such skills are playing a piano and knitting, since the fingers are prevented from naturally pushing the piano keys or holding knitting needles. Exceptions are skills that can be adapted to the use of controllers.

This could be using the trigger to simulate a gun or the grip buttons to pick up objects.

- Finger dexterity should not be a key element for learning the skill. Unless the skill can be adapted to the use of the controllers or other custom input devices.

Movement is limited when using VR equipment. The most apparent restriction is the maximum movement area of 3.54 x 3.54 meters. Alternative movement methods are transitions, flying and teleportation or the use of a treadmill. These come with the drawback of not being available in the real world, and are therefore unrealistic. Movement in VR can also induces discomfort for users. Skills learned in VR should therefor ideally be stationary. Type 3 and type 4 psychomotor skills should as a consequence be avoided.

- Type 3 and type 4 psychomotor skills should be avoided. Unless movement is not a crucial part of skill transfer.

6.2 Limitations with simulation software

Current simulation software has several deficiencies compared to the real word. Firstly, a simulation can never be identical to a task in the real world. Consequently, negative skill transfer can occur. Users should therefore not aim to reach the autonomous phase in a skill from training in VR. If the simulator is not validated, the learner should preferably only practice while in the early phase of skill acquisition, to prevent that bad habits are picked up and brought to the real world.

- If the simulator is not validated, the learner should not aim to reach automaticity in a skill from VR training. The learner should preferably only practice while in the early phase of skill acquisition.

Open, or externally paced skills could really benefit from VR training. This would allow for customized training, as the same event can be simulated multiple times. These could be skills that are dependent on certain weather conditions, e.g. flying a plane in a storm or driving a car on a slippery surface. However, for many open skills, human factors are involved. These are usually difficult to simulate, as they are very unpredictable. A simulator made for skills such as football or dancing, would therefore never be entirely realistic. The implementation of such factors is also difficult. Open skills should therefore be carefully evaluated before learned in VR.

- If not validated, training open skills involving human or other unpredictable factors should be avoided.

7. CONCLUSION

The purpose of this article was to assess which psychomotor skills are suitable for simulator training. The result from this assessment is a set of 8 guidelines, which elaborates on the limitations with the current state of the art consumer grade VR equipment. These guidelines are presented below;

Guideline 1: Skills should not require learner to keep track of several objects at once or monitor a larger area. All objects that are monitored should be within the HMDs field of view.

Guideline 2: Skills that require focus cues or accurate depth estimations at a range closer than the HMDs lens focal distance should be avoided.

Guideline 3: Kinesthetic and cutaneous cues should not be a key element for learning the skill, unless the cues can be simulated using available types of feedback.

Guideline 4: Skills which requires a high level of precision should be avoided

Guideline 5: Finger dexterity should not be a key element for learning the skill. Unless the skill can be adopted to the use of the controllers or other custom input devices.

Guideline 6: Type 3 and type 4 psychomotor skills should be avoided. Unless movement is not a crucial part of skill transfer.

Guideline 7: If the simulator is not validated, the learner should not aim to reach automaticity in a skill from VR training. The learner should preferably only practice while in the early phase of skill acquisition.

Guideline 8: If not validated, training open skills involving human or other unpredictable factors should be avoided.

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