AIR WAR COLLEGE

AIR UNIVERSITY

HAND/FINGER TRACKING AND HAPTICS: THE NEXT PHASE FOR PILOT TRAINING NEXT?

by

Timothy A. Mach, Lt Col, USAF

A Research Report Submitted to the Faculty

In Partial Fulfillment of the Graduation Requirements

Advisors: Dr. Dennis Armstrong & Col Tony Millican

7 April 2019

DISCLAIMER

Biography

Lieutenant Colonel Timothy Mach is assigned to the Air War College, Air University, Maxwell AFB, AL. Lt Col Mach commissioned through the Air Force ROTC program as a Distinguished Graduate after earning a Bachelor of Science in Electrical Engineering from the University of Cincinnati in 1999. He completed Specialized Undergraduate Pilot Training at Laughlin AFB, Texas and went on to serve as an Instructor Pilot at Grand Forks Air Force Base, N.D. and Formal Training Unit Instructor Pilot/Chief of Wing Flight Safety at Altus Air Force Base, Okla., Assistant Director of Operations for the 21st Air Mobility Operations Squadron, Joint Base McGuire-Dix-Lakehurst, N.J., Executive Officer to the Commander, United Stated Air Force Expeditionary Center, Operations Officer, 100th Operations Support Squadron, Royal Air Force Mildenhall, UK, and Commander, 22d Expeditionary Air Refueling Squadron, Incirlik Air Base, Turkey. Most recently, he served as the Deputy Commander, 100th Operations Group, Royal Air Force Mildenhall, UK.

Abstract

The Pilot Training Next (PTN) program graduated its first class of pilots in August 2018. The pilots went through an experimental course which questioned the traditional paradigm the U.S. Air Force used for pilot training over the course of the last 70 years, with the use of virtual environments, biofeedback, artificial intelligence, and a wholesale re-invention of the model. However, one aspect lacking in the PTN program was the absence of interaction with the aircraft in the virtual environment. This paper examines the Simpson's 1966 model of the psychomotor domain of Bloom's Taxonomy through proprioception (sense of one's own bodily positions and motions) and kinesthesia (the human sense of position and movement) in relation to how students learn. It also looks at the benefits and drawbacks of hand and finger tracking and haptic feedback (human interaction with the external environment though the touch), including possible technical solutions for each. Finally, it recommends incorporating both into the PTN program and research the possibility of incorporating the PTN concept in other Major Weapon System (MWS) training programs.

Introduction

The Pilot Training Next (PTN) program graduated its first class of pilots in August 2018.[1] The pilots went through an experimental course which questioned the traditional paradigm the U.S. Air Force used for pilot training over the course of the last 70 years, with the use of virtual environments, biofeedback, artificial intelligence, and a wholesale re-invention of the model (i.e. as many 'reps' as the student would like) were primary features of the program. All as a way to address the problem of the current U.S. Air Force pilot shortage by producing pilots faster while expending less resources.[2] This was a watershed event for the U.S. Air Force, by producing pilots in only six months, versus the traditional 12-month timeline.[3] However, one thing lacking in the PTN program was the absence of interaction with the aircraft in the virtual environment, beyond Hands-On Throttle and Stick (HOTAS) inputs being virtually portrayed, because the lack of any type of hand and finger tracking and the environment not being programmed so the pilots could interact with virtual aircraft's switches, knobs, buttons, rotary dials, circuit breakers, etc.

So, it begs the question, as efficient as the program seems to be, can the training be improved to produce a better product, specifically, will incorporating hand and finger tracking and haptic feedback into the virtual environments make the training more effective? This paper will delve into the benefits and downfalls of hand and finger tracking and haptic feedback in virtual environments, specifically focusing on the PTN program, using the ideas of proprioception and kinesthesia to support learning in the psychomotor domain of Bloom's Taxonomy. Furthermore, we will discuss possible technical solutions for incorporating the tracking and feedback into the PTN program, and finish with some recommendations of whether hand and finger tracking and haptic feedback should be incorporated into the PTN program.

Background

The Pilot Training Next (PTN) program was based off the research conducted by two students at Air Command and Staff College in 2017, with the final results published in April 2018.[4] The premise behind the paper was to take a new look at applying the Targeted Learning Systems Theory (TLST), "a mixture of educational structures, learning theories, and technologies", to training programs within the Air Force, specifically Undergraduate Pilot Training (UPT).[5] Their focus was to take the TLST and challenge the traditional UPT training paradigm, a very regimented 49-week program consisting of academics, aircraft simulators, and flying about 300 hours in two different aircraft with a very specific order to the training. This has been the way the U.S. Air Force has trained pilots for over 70 years, in order to produce pilots faster thus increasing production throughput to help remedy the pilot shortage the U.S. Air Force is currently experiencing[6]. The study was funded and sponsored by Air University, and completed subjects were tested over a 1-week period at Columbus AFB, Mississippi, using the actual T-6A simulator (Figure 1) and the purpose-built Adaptive Flight Trainer (AFT).[7] The study concluded that by spending time flying an aircraft 1.5 hours in a Virtual Reality Learning Environment (VRLE), the AFT, it improved the subject's ability to fly in an actual simulator.[8] The study also showcased the TLST could possibly "reduce costs, adapt to new requirements, and create clarity from complexity from students."[9] For comparison, the total cost of the AFT was approximately $6,000[10] where the cost per T-6A aircraft is $4.27 million[11] and an additional $1,303 per hour to operate the T-6A.[12] Their research was fed directly into the PTN program as a baseline for their operations.[13]

Figure 1: T-6A Texan II Simulator[14]

The first class graduated the PTN program in August of 2018, and became fully accredited USAF pilots in six months[15]: under half the time it takes with the traditional UPT training program.[16] The training program consisted of time spent in the Virtual Reality (VR) flight trainer (Figure 2) and flying in an actual T-6A, while it completed all the same training objectives in a traditional UPT program syllabus. The students conducted training in basic contact flying procedures, instrument flying, formation, and then some more specific Combat Air Forces or Mobility Air Forces training after they were paired according to their abilities around the 4-month point.[17] The training was not necessarily in a specific building-block fashion as in the traditional UPT program syllabus.[18] One example of this is the students were flying formation on their third flight in the aircraft, where it would take several months before they would do this in the traditional UPT syllabus.[19] Additionally, the VR flight trainer devices were available to the student pilots when they were on their own personal time, at a 2:1 ratio of students to training devices.[20] This additional access allowed the students to have extra time in the VR environment to practice what they had learned in the formal PTN syllabus, just as traditional UPT students would utilize a paper cutout taped to a wall to chair fly, "a visualization technique in which a student imagines executing a series of tasks from a desk chair, to introduce initial flight concepts."[21] However, VR provides visual reactions to student control inputs including adding power and seeing gauges move and hearing engines spool up, or pulling back on the stick and seeing the horizon drop, unlike chair-flying where you have to imagine the reaction to imaginary inputs, shown in Figure 3.

Figure 2: VR Flying Trainer[22]

Figure 3: Chair Flying[23]

The benefits of the PTN program is definitely clear, as the students could fly almost 90% of their first aircraft sortie compared to about 10% in a traditional UPT sortie,[24] and they were able to solo on their seventh to eighth ride compared to their 13th or 14th.[25] PTN began their next class in January 2019 using the lessons learned from the first iteration by "learning from those failures, tweaking the processes, and ultimately improving the learning environment."[26] One drawback to the current program is the lack of hand and finger tracking and haptic feedback in the VR flight trainers.[27] In UPT, students spend many hours in a traditional simulator, learning the switchology, "the setting of switches on panels",[28] of the aircraft. This is not done currently in the VR flight trainers at PTN because the fidelity of the aircraft models in the VR flight trainer is not detailed enough to interact with the switches and buttons and there is no use of hand and finger tracking in the program.[29] An example is the *Go For Launch: Mercury* simulation where you control switches in the Mercury space capsule, but have a hard time actually determining where the controls are dues to the low fidelity simulation and there is no haptic feedback associated with the switches. These omissions limit the level of training that could be accomplished in the VR flight trainer, as the muscle memory and limb awareness associated with moving switches and pressing buttons in the aircraft is an important part of the learning process. This muscle memory as we call it, has its basis in a few different ideas of learning theories, specifically the psychomotor domain through proprioception and kinesthesia.

The psychomotor domain is one of three domains listed under the Bloom's Taxonomy, along with the cognitive and affective domains.[30] The psychomotor domain consists of actions that "emphasize some muscular or motor skill, some manipulation of material and objects, or some act which requires a neuromuscular coordination."[31] In 1971, Simpson developed one of three classifications for the psychomotor domain, and her descriptions best suit the importance of bringing in finger and hand tracking and haptics into the virtual environment. Simpson's original levels of learning are perception, set, guided response, mechanism, and complex overt response from her 1971 study, with the recommendation for further study into a possible sixth level, shown in Table 1.[32] The lowest level is perception: "the process of becoming aware of objects, qualities, or relations, by the way of the sense organs" and "it is the central portion of the situation-interpretation action chain leading to purposeful motor activity."[33] Next, set "is a preparatory adjustment or readiness for a particular kind of action or experience."[34] Thirdly, guided response "is the overt behavioral act of an individual under the guidance of the instructor."[35] Mechanism is when the "learned response has become habitual."[36] Finally, complex overt response is when "the individual can perform a motor act that is considered complex because of the movement pattern required", "a high degree of skill has been obtained", and "the act can be carried out smoothly and efficiently, that is, with minimum expenditure of time and energy."[37] The virtual environment can allow subjects to practice the skills necessary to achieve the different levels of Simpson's psychomotor domain classification, similar to the current UPT and other U.S. Air Force Major Weapon System (MWS) training programs. While the psychomotor domain is the overall learning theory, this paper will focus more specifically on principles of proprioception and kinesthesia.

Category or 'level'	*Behavior descriptions*	'Key words' (verbs which describe the activity to be trained or measured at each level)
Perception	*awareness*	recognize, notice, touch, hear, feel, choose, describe, detect, differentiate, distinguish, identify, isolate, relate, select
Set	*readiness*	arrange, prepare, get, begin, display, explain, move, proceed, react, show, state, volunteer
Guided Response	*attempt*	imitate, try, copy, trace, follow, react, reproduce, respond
Complex Overt Response	*expert proficiency*	coordinate, fix, demonstrate, calibrate, construct, dismantle, display, fasten, fix, grind, heat, manipulate, measure, mend, mix, organize, sketch

Table 1 – Simpson's 1966 Model of the Pyschomotor Domain[38]

According to Bales, proprioception is the "sense of one's own bodily positions and motions."[39] It is the ability to determine where your limbs are without physically seeing their specific location, or more importantly the awareness of one's limbs in a space. Also, Bales states that proprioception provides "information on body forces and motion through muscles, tendons, and joints."[40] An example of proprioception is the classic roadside sobriety test, where you close your eyes and must touch the tip of you index finger to the tip of your nose.[41] Even though this is a non-standard field sobriety test because officers can't determine why the subject is unable to perform the maneuver, the subject must be aware of the movement and placement of their arm all the way through their index finger to accomplish this effectively.

Kinesthesia is often used as a synonym for proprioception, but it is a distinct and separate idea and defined by Avizzano et al. as "the human sense of position and movement, which is created from proprioceptive cues arising from the receptors in the muscles and joints."[42]

Although they sound the same, the focus of kinesthesia is the actual movements of the muscles and not so much the awareness of the actual position in space. Kinesthesia research shows that humans have an uncanny ability to remember positions of their limbs for long periods of time.[43] Also, surgical studies show kinesthetic training helps students learn complex motor skills by physically performing the motions, because it creates the muscle memory needed making it automatic.[44]

Hand/Finger Tracking

In virtual reality currently, hand tracking is done with various types of controllers, which present a model of where your hand should be. The controllers also give you the option to point or grasp an object by pressing buttons on the controller for controlling the fingers as a group, but not individually. While this mimics the movement and position of your hands and fingers, they are not actually tracked, thus making the movements still a very mechanical representation and not very smooth. This basic level of involvement fills the need in most situations currently, because it is very hard in practice to get accurate hand and finger tracking in a virtual environment due to limitations in technology and the complexity of the hand and fingers. Hand and finger tracking, with all the different joints involved and multiple planes of motion occurring at the same time, is a challenging technological problem to solve. A 2016 study by Abraham et al. identified "the fast motion, lack of visible textures, and severe self-occlusions of finger segment," which make tracking the hand and individual fingers difficult.[45]

One benefit of having hand and finger tracking in a virtual environment is the increase in immersion and the greater feeling of presence individuals have in the environment. Immersion and presence are two terms which are common to the virtual reality world but need some defining to understand them better. Kim et al. defines immersion as the ability for a user to experience the environment in which virtual reality is placing them in and stimulates emotions in the user, so they feel what they would in the real world.[46] Per Chertoff and Schatz, there are many different definitions of what presence actually is, and no one can come to an agreement on just one definition,[47] but they define presence as "that human–computer *je ne sais quoi* that theoretically enhances the intended outcome of a system.[48] In other words, the act of being there in a virtual environment is the same as being there in a real-world environment. The best virtual environments give users both immersion and presence as if they were in the real-world place and time specified by the virtual environment.

There are a few studies which show having better visual tracking increases a user's immersion and presence in a virtual environment. Menelas and Benaoudia referenced that vision dominates the other sensory channels in spatial perception, so having accurate hand and finger tracking makes the environment that much more real to the user.[49] They also stated that an increase in visual tracking makes the implementation of haptics even more effective as it relates to not only to the visual picture but gives you an associated feel that goes along with this, thus increasing psychomotor learning.[50] Kim et al. concluded without accurate visual tracking, there is less presence felt in the virtual environment, which induces less concentration in the user for completing tasks.[51] Sheets et al. supposes a student pilot's act of chair-flying, defined as "close their eyes and visualize all the steps and actions they would take to execute a training maneuver", improves the kinesthetic performance because it speeds up the preparatory planning stages prior to taking an action, thus increasing the learning objective.[52] This increased immersion and presence can make switchology in the cockpit easier to learn in the virtual environment as the student will learn through proprioception and kinesthesia, as well as how to orient themselves in the space provided in the aircraft because the interaction with the switches can be visualized.[53] The better feel of immersion and presence can help the students raise the level of learning to the complex overt response level in the psychomotor domain.

The benefits of visual tracking of the hand and fingers are very apparent, but there are limitations to implementing this, as the accuracy of the hand and finger tracking and the accuracy of the interaction with the virtual model must both be very good. The initial Sheets and Elmore study, conducted for PTN, found that the hand and finger tracking was difficult using the Leap Motion (discussed in a later section) tracking system because it would lose the lock on the hand when the hand was not in the sensor's field of view.[54] This was also shown when PTN was starting their first class as the Leap Motion system was unable to detect the twisting of a knob in the virtual environment, and it also dropped the tracking of the hands when they were not in the sensor's field of view.[55] Although with a different system, Abraham et al. ran into issues with tracking the hand due to its complexity as well as "lighting conditions, skin color detection, rapid hand motion, and self-occlusions."[56] Additionally, the virtual environment must be accurate enough to produce realistic switches and subsequent effects, so the user can accurately maneuver to interact with the switches. If not, Oberhauser and Dreyer propose that task completion takes much longer, and you lose out on the kinesthetic and proprioceptive learning because the movements and limb awareness are different that the real-world.[57]

Haptic Feedback

The word haptics was first introduced in 1931 and is derived from the Greek words *haptikos*, meaning "able to touch", and *haptesthai*, meaning "able to lay hold of".[58] Today, haptics relates to "the study of touch and the human interaction with the external environment though the touch."[59] The sense of touch is developed and explored at an early age in human development, and as early as 5 months old, babies are placing items in their mouth to get the sense of what they feel like and to gain an understanding of the environment around them.[60] This continues and develops as we get older and we continue to use haptics to serve as a "window into our representations in memory."[61] The sense of touch "is a critical factor in how people physically perceive and feel the world around them."[62] In relation to virtual reality, haptics are interface devices which provide either force feedback (simulating object hardness, weight, and inertia) or tactile feedback (simulating surface contact geometry, smoothness, slippage, and temperature).[63] It involves active touch in the virtual environment, defined by Minogue and Jones as deliberately choosing "his or her actions in the exploration and manipulation of an object."[64]

Without haptic feedback, any interaction in the virtual environment will lead to a gap between the virtual environment and physical world which is crucial to ensuring the virtual environment will be an effective training platform for the pilot training students.[65] Menelas and Benaoudia referenced that by incorporating haptic feedback into simulations, it allows the simulation to be more realistic and the user to feel a more efficient level of involvement in the simulation.[66] PTN already utilizes haptic feedback in their virtual environment, but it is not through the use of the models themselves, but through physical mockups of the throttle, stick, and rudder pedal setup in the VR flight trainer.[67] The actual controls provide tactile feedback as well as proprioceptive and kinesthetic learning as the students learn how much motion, input to the physical aircraft controls, translates into control of the aircraft, and how they are represented spatially in a physical T-6A cockpit. This is invaluable to ensuring the student pilot retains the physical movements that directly translate into flying the aircraft and is one of the main purposes for having a simulator or a VR flight trainer.

There is a benefit to having more haptic feedback built into the VR flight trainer. It is an increased level of motor skills training, because it provides a fully virtual cockpit where you can push buttons and flip switches. Dargar et al. purports it provides a more realistic setting, so students can learn by performing these actions at a slower pace, instead of having to do this training in the actual aircraft.[68] One part of this cements the physical movements into muscle memory and allows the student to learn the proper sequence of steps in the checklists, because of the ease of gaining repetition in the virtual simulation, thus enabling proprioceptive and kinesthetic learning at the complex overt response level of the psychomotor domain.[69] Menelas and Benaoudia's research, from the medical field, show that haptic feedback improves the usefulness of virtual training, increasing both a surgeon's proficiency and their confidence in performing surgical procedures.[70] Using laparoscopic surgery as an example, it showed that without haptic feedback in a virtual environment, the level of performance was limited compared to the group which had haptic feedback, and also improved surgeon's cataract performance by 32%.[71] Additionally, Döor et al. supposes the lack of haptic feedback increases the time it takes pilots to accomplish tasks in a virtual environment.[72] The repetition also enables movements to become automatic instead of having to physically think about them, getting to the automatic response subset of the complex overt response classification suggested by Simpson.[73] The benefit of the motions being automatic is it shifts the processing from the cognitive level, thus speeding up the actual motions and allowing more of the mind's processing time to be devoted to something else and helps the student pilot by reducing the amount they are affected by distractions and interruptions.[74]

Another aspect of haptics is the Just Noticeable Difference (JND), also known as Weber-Fletcher Law, which "is a measure of the minimum difference between two stimuli which are necessary in order for the difference to be distinguishable."[75] JND is used in haptics to describe the amount of force or level of feedback which is discernable by the individual, and the level is not the same between different individuals.[76] These feedback levels are important because they can help determine the haptic feedback device needed in a virtual environment, which is discussed later in the paper. Additionally, with having a fully detailed virtual environment, the usability of the switches and buttons in the cockpit greatly decrease if the right amount of haptic feedback associated with each of the features is not there, thus decreasing feeling of presence and the potential learning.

With all the learning upsides to including haptics in a virtual environment, there are some downsides to doing this. With regards to applying haptics to the PTN program, the fidelity of the aircraft models in the VR flight trainer needs to be increased, because overall today's virtual reality systems are not designed for detailed, fine-tuned tasks.[77] The VR flight trainer is limited in what it provides, with regards to a real cockpit, with just the stick, throttle, and rudder pedals, with everything else being in the virtual environment.[78] The students can see and read the gauges and instruments, but cannot interact with anything else in the virtual environment. The models used will need to be developed with much higher precision, regarding the placement of all the buttons and switches, but will also need the various buttons and switches to function with the corresponding actions for each individual item. The increase in fidelity has a greater cost associated with it, because of the level of detail needed to program the model.[79] Additionally, the Alessi hypothesis suggests that at some point the increase in fidelity of the model does not have any benefit in training at all, so you can go all out making the perfect virtual model, but in fact there could be something much less perfect that accomplishes all of the training objectives.[80]

Dargar et al. also concludes that for novice learners, the lower fidelity may actually work better because the complexity of the model itself does not compete for the learner's attention.[81]

Another downside to haptics is the greater amount of feedback, in relation to the real-world, the size of the haptic devices must increase. Depending on the level of feedback required, haptic devices can range from just fingertip devices to major exoskeletons which encompass the entire hand and forearm. Point-based devices provide some sort of tactile feedback,[82] usually in the form of a vibration, where the exoskeleton could provide force-feedback and tactile feedback,[83] because the exoskeleton realistically simulates the muscular resistance you would feel when manipulating objects.

The benefits and downsides are clear, but without accurate visual tracking of the hand and fingers, haptics just add confusion to the interaction in the virtual environment. According to Kim et al., the lack of haptics, when a subject is interacting in the virtual environment, can lead to a gap between the environment and the real-world, but having haptics increases the subject's sense of presence and immersion reducing the perceived gap.[84] Additionally, Oberhauser and Dreyer found that interacting with individual switches can be a challenge without haptics, as the subject can see the interaction with the switch but receives no feedback from the action.[85] So, there is no reinforcement of the motion, making the usability challenging.[86]

When you add haptics to visual tracking of the hand and fingers, the benefits are very clear. Menelas and Benaoudia purport haptics can strengthen the information provided by the visual channel, by reinforcing the feedback mechanism provided to the subject.[87] Furthermore, Kim et al. show that including haptics with the visual tracking provides higher presence and immersion when interacting with objects in a virtual environment because of the subject's increased concentration levels.[88] The haptic feedback also increases the subject's limb awareness, because of the spatial perception associated with receiving the haptic feedback during interactions with the virtual environment, per Menelas and Benaoudia.[89]

Possible Solutions

Haptic feedback with hand and finger tracking technology is coming of age. There are numerous solutions on the market and some currently in development which provide simple vibration, via fingertip thimbles, to full-fledged force feedback on every single joint in the fingers and hand, via exoskeletons, and can incorporate hand and finger tracking within the devices or they can be separate.[90] The biggest question is what is the right type of technology to utilize which fits within the constraints of the PTN program? One drawback of the PTN program is the student pilots perform many complicated maneuvers with their hands, interacting with the throttle, control stick and instrument panel, all in a limited amount of space inside the T-6A cockpit. This limits the type of devices to ones that are not too bulky for the student pilot to wear because according to Pacchierotti et al., the wearable device should be "small, easy to carry, comfortable, and it should not impair the motion of the wearer"[91], which eliminates almost all exoskeletons, and pushes more towards a fingertip device or a traditional glove-type device.

A fingertip device normally needs a separate tracking system because of the need to place the wireless transmitter, feedback mechanism, and power source in a small form-factor on the fingertip, per Perret and Vander Poorten.[92] There are numerous fingertip devices on the market, but they can be bulky on the end of the fingertips and could limit motion[93], which may not meet the needs of the PTN program because of the bulkiness. Kim et al. developed a device for their research based on an Arduino circuit board and a Bluetooth transmitter, with vibration and thermal feedback located in the finger tip for under $33, but it needed the Leap Motion tracking system to get both tracking and haptic feedback.[94] The Leap Motion system is an "industry leading markerless hand tracking technology"[95] which continues to improves its hand and finger tracking using an external sensor with 180 x 180 degree field of view, usually positioned on a head mounted display.[96] This tracking technology is already being utilized by Vertex Solutions for an AC-130 Gunship crew trainer enabling the crewmembers to interact with switches in the aircraft,[97] and was also tested by PTN as they were developing the program, but ran into issues with the tracking.[98] The combination of the fingertip device and Leap Motion can be very cost effective, as the Leap Motion is a proven technology and the proposed fingertip device by Kim et al. is inexpensive[99], but it still may not serve the purpose of the PTN program because of the possible bulkiness of the system.

The traditional glove solutions usually provide both tracking and haptic feedback contained within the same unit. The biggest constraint here is that gloves need to fit to the subject's hand, so either one size adaptable to all or multiple sizes of the glove, which possibly drives up the cost of acquisition and development.[100] The glove would be an addition to the current VR flight trainer setup with the HOTAS so students still have the feel of a stick and throttle, as this would be extremely difficult and bulky to simulate. There are two traditional gloves, discussed by Perret and Vander Poorten in a recent conference paper, which look like they will mimic the wearing of traditional flight gloves in the aircraft, thus meeting the requirement to fit in the T-6A virtual cockpit without hindering the student's movement. The AvatarVR™ by Neurodigital Technologies uses Inertial Measurement Units (IMUs) for each of the fingers and the hand, and provides vibration spots for all five fingertips, three on the palm, and two on the back of the hand, giving both tracking and haptic feedback to the subject.[101] The SensoGlove™ by Senso tracks the fingers and hands with IMUs and provides vibration feedback under the last phalange of each finger, but also measures grip pressure.[102] The benefit to each of these is they are already commercially available, and combine the hand and finger tracking with the haptic feedback into one device, but the downside is you need to have multiple sizes of the gloves available.

Recommendations

The PTN program is making huge strides in way the U.S. Air Force thinks about pilot training. Incorporating hand and finger tracking and haptic feedback is the next logical step to increase the learning for the student pilots through the psychomotor domain. Although they can be accomplished separately, the full advantage will not be seen unless the tracking and feedback is done simultaneously. It will enhance the student pilot's ability to perform at the mechanism and complex overt response levels of the psychomotor domain, using proprioception and kinesthesia in the virtual environment, which will translate directly to the real-world application of those skills. Additionally, although a few different types of tracking and haptic feedback devices were introduced, more thorough research needs to be accomplished to determine what is the right mix of technology and commercial off the shelf technology.

Additionally, the PTN model, with the tracking and haptic feedback incorporated, should be investigated for inclusion into the U.S. Air Force's MWS training programs. Incorporating this into both the Formal Training Unit (FTU) for initial and upgrade training, as well as continuation training for aircrew members at home station, is a way to possibly reduce the cost and the timeline of training and improves the learning potential of the student through the psychomotor domain. Also, a VR flight trainer for an MWS is a lower cost option for pilots to knock to rust off or practice challenging scenarios they may on missions prior to actually flying the mission.

Conclusion

The PTN program challenged the U.S. Air Force's traditional pilot training paradigm using virtual environments and was successful in graduating its first class of pilots in 2018.[103] The lack of hand and finger tracking and haptic feedback is a limitation in the current design of the program and raises the question: should it be incorporated into the PTN program? Through the course of this paper, we have looked at the benefits and drawbacks of hand and finger tracking and haptic feedback, as well as the associated learning theories. Incorporating these into the program will increase the student pilot's ability to learn in the psychomotor domain, through proprioception and kinesthesia, allowing the program to become more effective. The exact technical solutions will come to fruition with more research, but the proposed solutions of a fingertip device with Leap Motion or a glove-like device are a good starting point.

Notes

(All Notes appear in shortened form. For full details, see the appropriate entry in the bibliography.)

[1] Major Van de Water, 3 October 2018.
[2] Sheets, "Abstract to Action", 1.
[3] Major Van de Water, 3 October 2018.
[4] Sheets, "Abstract to Action", 1.
[5] Ibid.
[6] Ibid.
[7] Sheets, "Abstract to Action", 2.
[8] Ibid., 76.
[9] Sheets, "Abstract to Action", 76.
[10] Ibid., 24.
[11] AF.mil, "T-6A Texan II.
[12] Roth, "Fiscal Year 2018", 2.
[13] Sheets, "Abstract to Action", 74.
[14] Weseman, " CAP Cadets Take Flight".
[15] Major Van de Water, 3 October 2018.
[16] Lewis, "Pilot Training Next", 7.
[17] Major Van de Water, 3 October 2018.
[18] Ibid.
[19] Ibid.
[20] Ibid.
[21] Lewis, "Pilot Training Next", 3.
[22] Hawkins, "PTN Innovations".
[23] Roth, "Fiscal Year 2018", 2.
[24] Hawkins, "Pilot Training Next Cadre Discuss".
[25] Lewis, "Pilot Training Next", 7.
[26] SSgt Pons, "Flying Training Reimagined".
[27] Major Van de Water, 3 October 2018.
[28] "Submit Dictionary Words".
[29] Major Van de Water, 3 October 2018.
[30] Simpson, "Educational Objectives in the Psychomotor Domain", 60.
[31] Ibid., 62.
[32] Ibid., 62-67.
[33] Ibid., 62.
[34] Ibid., 64.
[35] Ibid., 65.
[36] Ibid., 65.
[37] Ibid., 66.
[38] Sideeg, "Bloom's Taxonomy", 166-167.
[39] Bales, "An Ergonomics Investigation", 1.
[40] Ibid., 5.
[41] "Finger to Nose Test".

[42] Avizzano, “Motor Learning Skill Experiments”, 198.
[43] Ibid.
[44] Pinzon, “Skill Learning from Kinesthetic Feedback”, 1.
[45] Abraham, “Hand Tracking and Gesture Recognition”, 1.
[46] Kim, “Study on Immersion and Presence”, 1.
[47] Chertoff, *Handbook of Virtual Environments,* 861.
[48] Ibid.
[49] Menelas, “Use of Haptics to Promote Learning”, 4.
[50] Ibid.
[51] Kim, “Study on Immersion and Presence”, 13.
[52] Sheets, “Abstract to Action”, 13.
[53] Döor, “Virtual Cockpit Simulation”, 2.
[54] Sheets, “Abstract to Action”, 30.
[55] Major Van de Water, 3 October 2018.
[56] Abraham, “Hand Tracking and Gesture Recognition”, 2.
[57] Oberhauser, “Virtual Reality Flight Simulator”, 275.
[58] Minogue, “Haptics in Education”, 318.
[59] Ibid.
[60] Ibid., 321.
[61] Ibid., 326.
[62] Bales, “An Ergonomics Investigation”, 1.
[63] Minogue, “Haptics in Education”, 318.
[64] Ibid., 332.
[65] Kim, “Study on Immersion and Presence”, 2.
[66] Menelas, “Use of Haptics to Promote Learning”, 2.
[67] Lewis, “Pilot Training Next”, 4.
[68] Dargar, “Towards Immersive Virtual Reality”, 2.
[69] Ibid., 2.
[70] Menelas, “Use of Haptics to Promote Learning”, 8
[71] Sheets, “Abstract to Action”, 13-14.
[72] Döor, “Virtual Cockpit Simulation”, 5.
[73] Simpson, “Educational Objectives in the Psychomotor Domain”, 66.
[74] Dargar, “Towards Immersive Virtual Reality”, 4.
[75] Bermejo, “Survey on Haptic Technologies”, 3.
[76] Ibid.
[77] Bales, “An Ergonomics Investigation”, 17.
[78] Lewis, “Pilot Training Next”, 4.
[79] Major Van de Water, 3 October 2018.
[80] Dargar, “Towards Immersive Virtual Reality”, 5.
[81] Ibid.
[82] Ibid., 10
[83] Ibid., 11.
[84] Kim, “Study on Immersion and Presence”, 2.
[85] Oberhauser, “Virtual Reality Flight Simulator”, 267
[86] Ibid.
[87] Menelas, “Use of Haptics to Promote Learning”, 3.

[88] Kim, “Study on Immersion and Presence”, 13.
[89] Menelas, “Use of Haptics to Promote Learning”, 4.
[90] Pacchierotti, “Wearable Haptic Systems”, 581.
[91] Ibid.
[92] Perret, “Touching Virtual Reality”, 3.
[93] Bermejo, “Survey on Haptic Technologies”, 4.
[94] Kim, “Study on Immersion and Presence”, 9-10.
[95] Lang, “Leap Motion Releases Major Tracking Update.”
[96] “Technology”.
[97] “Bohemia Interactive Simulations”.
[98] Major Van de Water, 3 October 2018.
[99] Kim, “Study on Immersion and Presence”, 4.
[100] Perret, “Touching Virtual Reality”, 2.
[101] Ibid., 3.
[102] Ibid.
[103] Lewis, “Pilot Training Next”, 2.

Bibliography

Abraham, Lizy, Andrea Urru, Niccolò Normani, Mariusz P. Wilk, Michael Walsh, and Brendan O'Flynn. "Hand Tracking and Gesture Recognition Using Lensless Smart Sensors." *Sensors (Basel, Switzerland)* 18, no. 9 (August 28, 2018). doi:10.3390/s18092834.

AF.mil. "T-6A Texan II." AIRMAN Magazine. Accessed April 7, 2019. https://airman.dodlive.mil/2019/01/28/t-6a-texan-ii/.

Avizzano, C.A., J. Solis, A. Frisoli, and M. Bergamasco. "Motor Learning Skill Experiments Using Haptic Interface Capabilities." In *Proceedings. 11th IEEE International Workshop on Robot and Human Interactive Communication*, 198–203. Berlin, Germany: IEEE, 2002. doi:10.1109/ROMAN.2002.1045622.

Bales, Delaney. "An Ergonomics Investigation of the Application of Virtual Reality on Training for a Precision Task." *Master's Theses and Project Reports*, June 1, 2017. https://digitalcommons.calpoly.edu/theses/1757.

Bermejo, Carlos, and Pan Hui. "A Survey on Haptic Technologies for Mobile Augmented Reality." *ArXiv:1709.00698 [Cs]*, September 3, 2017. http://arxiv.org/abs/1709.00698.

"Bohemia Interactive Simulations." Accessed December 15, 2018. https://bisimulations.com.

Chertoff, Dustin, and Sae Schatz. "Beyond Presence - How Holistic Experience Drives Training and Education." In Handbook of Virtual Environments: Design, Implementation, and Applications, Second Edition, edited by Kay M. Stanney and Kelly S. Hale, Vol. 2nd ed. Human Factors and Ergonomics. Boca Raton: CRC Press, 2014. http://search.ebscohost.com/login.aspx?direct=true&db=nlebk&AN=835658&site=ehost-live&scope=site&custid=airuniv.

Dargar, Saurabh, Rebecca Kennedy, WeiXuan Lai, Venkata Arikatla, and Suvranu De. "Towards Immersive Virtual Reality (IVR): A Route to Surgical Expertise." *Journal of Computational Surgery* 2, no. 1 (May 7, 2015): 2. doi:10.1186/s40244-015-0015-8.

Döor, Kai - Uwe ; Schiefel, Jens ; Kubbat, W. "Virtual Cockpit Simulation for Pilot Training," 2001, 9. http://www.dtic.mil/dtic/tr/fulltext/u2/p010789.pdf.

"Finger-to-Nose Test." Accessed January 7, 2019. http://www.fieldsobrietytests.org/fingertonosetest.html.

Hawkins, Dan. "Pilot Training Next Cadre Discuss Lessons Learned, Way Forward." U.S. Air Force, September 19, 2018. http://www.af.mil/News/Article-Display/Article/1638707/pilot-training-next-cadre-discuss-lessons-learned-way-forward/.

Hawkins, Dan. "PTN Innovations Move to Undergraduate Pilot Training." U.S. Air Force, March 14, 2019. https://www.af.mil/News/Article-Display/Article/1784958/ptn-innovations-move-to-undergraduate-pilot-training/.

Kim, Mingyu, Changyu Jeon, and Jinmo Kim. "A Study on Immersion and Presence of a Portable Hand Haptic System for Immersive Virtual Reality." *Sensors (Basel, Switzerland)* 17, no. 5 (May 17, 2017). doi:10.3390/s17051141.

Lang, Ben. "Leap Motion Releases Major Tracking Update and New Demos to Show It Off." Road to VR, June 11, 2018. https://www.roadtovr.com/leap-motion-releases-major-tracking-update-and-new-demos-to-show-it-off/.

Lewis, Jennifer, and Joyner Livingston. "Pilot Training Next: Breaking Institutional Paradigms Using Student-Centered Multimodal Learning." Orlando, FL, 2018.

Major Scott Van de Water (Pilot Training Next Deputy), interviewed by author, 3 October 2018.

Menelas, Bob-Antoine J., and Rabah Syphax Benaoudia. "Use of Haptics to Promote Learning Outcomes in Serious Games." *Multimodal Technologies and Interaction* 1, no. 4 (December 1, 2017): 31. https://doaj.org.

Minogue, James, and M. Gail Jones. "Haptics in Education: Exploring an Untapped Sensory Modality." *Review of Educational Research; Washington* 76, no. 3 (Fall 2006): 317–48. http://search.proquest.com/docview/214115027/abstract/AD3FA82EA5546D6PQ/1.

Oberhauser, Matthias, and Daniel Dreyer. "A Virtual Reality Flight Simulator for Human Factors Engineering." *Cognition, Technology & Work; London* 19, no. 2–3 (September 2017): 263–77. doi:http://dx.doi.org/10.1007/s10111-017-0421-7.

Pacchierotti, C., S. Sinclair, M. Solazzi, A. Frisoli, V. Hayward, and D. Prattichizzo. "Wearable Haptic Systems for the Fingertip and the Hand: Taxonomy, Review, and Perspectives." *IEEE Transactions on Haptics* 10, no. 4 (October 2017): 580–600. doi:10.1109/TOH.2017.2689006.

Perret, Jérôme, and Emmanuel Vander Poorten. "Touching Virtual Reality: A Review of Haptic Gloves." In *ResearchGate*. Bremen, Germany, 2018. https://www.researchgate.net/publication/324562855_Touching_Virtual_Reality_a_Review_of_Haptic_Gloves.

Pinzon, David, Roberto Vega, Yerly Paola Sanchez, and Bin Zheng. "Skill Learning from Kinesthetic Feedback." *The American Journal of Surgery; New York* 214, no. 4 (October 1, 2017): 721–25. doi:http://dx.doi.org/10.1016/j.amjsurg.2016.10.018.

Roth, John P. "Fiscal Year (FY) 2018 Department of Defense (DoD) Fixed Wing and Helicopter Reimbursement Rates," October 3, 2017. https://comptroller.defense.gov/Portals/45/documents/rates/fy2018/2018_b_c.pdf.

Sheets, Travis H., and Matthew P. Elmore. "Abstract to Action: Targeted Learning System Theory Applied to Adaptive Flight Training." Maxwell Air Force Base, Alabama: Air Command and Staff College, April 18, 2018. www.dtic.mil/dtic/tr/fulltext/u2/1053015.pdf.

Sideeg, Abdunasir. “Bloom’s Taxonomy, Backward Design, and Vygotsky’s Zone of Proximal Development in Crafting Learning Outcomes.” International Journal of Linguistics Vol. 8, (April 26, 2016): 158–86. doi:10.5296/ijl.v8i2.9252.

Simpson, Elizabeth. “Educational Objectives in the Psychomotor Domain.” In *Behavioral Objectives in Curriculum Development: Selected Readings and Bibliography*, edited by Miriam B. Kapfer. Englewood Cliffs, New Jersey: Educational Technology, 1971.

SSgt Pons, Chip. “Flying Training Reimagined as First PTN Class Graduates.” Air Education and Training Command, March 8, 2018. http://www.aetc.af.mil/News/Article/1593411/flying-training-reimagined-as-first-ptn-class-graduates/.

“Submit Dictionary Words.” Accessed December 8, 2018. http://nws.merriam-webster.com/opendictionary/.

“Technology.” Leap Motion. Accessed January 9, 2019. https://www.leapmotion.com/technology/.

Lt Col Weseman, Andreas K. “CAP Cadets Take Flight.” Joint Base San Antonio, January 24, 2014. http://www.jbsa.mil/News/News/Article/599231/cap-cadets-take-flight/.