AGENCY AND VIRTUAL BODY OWNERSHIP OF A VIRTUAL BAT´S AVATAR IN VR

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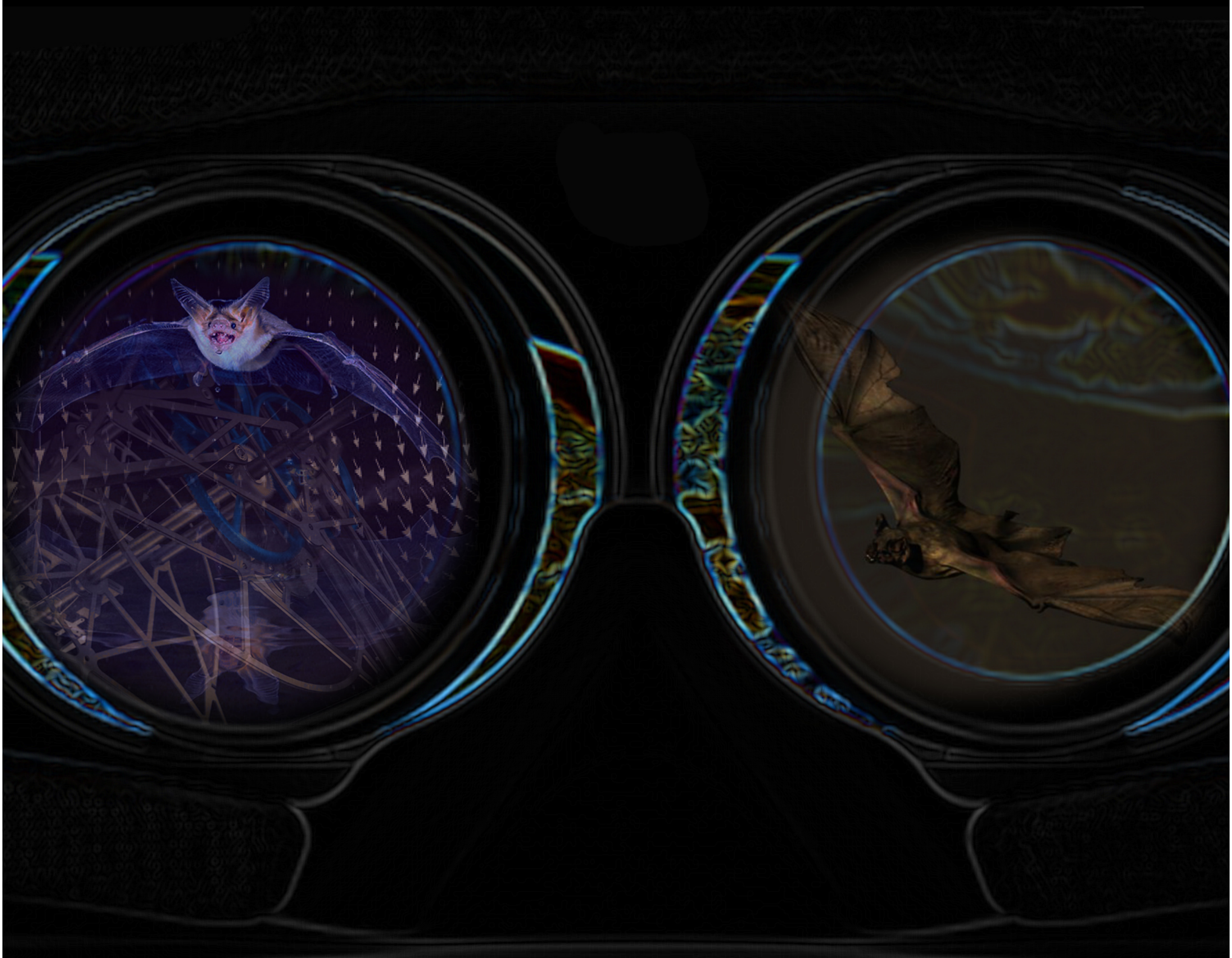

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3 INTRODUCTION

"There will be people crying in this, people falling in love, people falling over. For all sorts of reasons, this strikes at the core of being a human being. It's so compelling … this is as big an opportunity as the Internet."

This is how Dr. Jonathan Waldern (Arthur 2015) envisions the future of Virtual Reality (VR). Even though VR has been around more than 30 years, its purpose remains largely the same, namely, to create a sense of presence in virtual environments and make our brain believe that we are actually there.

VR is being used for many purposes, staring with gaming (Winchester 2015) and entertainment, such as film industry (Strange 2015)[1], and going further to medicine (for example treatment of different phobias, PTSD[2], pain management, surgical trainings, phantom limb syndrome, brain damage rehabilitation and many other (Carson 2015)), education, such as learning astronomy, for example (Yair, Mintz, and Litvak 2001), military (realistic trainings in different flight, vehicle, battlefield, boot camp simulators helps to mitigate unnecessary risk (Bymer 2012), (Blog 2009)), study of human perception, such as presence (Sanchez-Vives and Slater 2005), multisensory integration (Petkova, Khoshnevis, and Ehrsson 2011), locomotion (Nilsson, Serafin, and Nordahl 2013), spatial perception (Bruder, Steinicke, and Wieland 2011) and cognition (Maselli and Slater 2013), etc.

People have been dreaming about flying for centuries, starting from Greek legends about Icarus[3]. The first kite was constructed in China around 5th century B.C. by Mozi and Lu Ban. They were flat and rectangular. Some of the paper kites were used to deliver messages (Florian Ion Petrescu 2012) can be seen in the Figure 1.

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[1] "Sleepy Hollow VR Experience" (TV Show, Fox Network, started in 2013) has won Creative Art Emmy Awards of 2015 (Oculus VR u.d.).

[2] *"Post-traumatic stress disorder (PTSD) is a mental health condition that's triggered by a terrifying event - either experiencing it or witnessing it. Symptoms may include flashbacks, nightmares and severe anxiety, as well as uncontrollable thoughts about the event."* (Staff 2014)

[3] Icarus - the son of Daedalus, who created the labyrinth. Daedalus warned Icarus not to fly too close to the Sun, as it can melt the wings and neither too close to the sea, as it can dampen the wings. Albeit his father´s advice, Icarus was flying too high and fell into the sea.

FIGURE 1 CHINESE KITE, (MICHEL 2013)

FIGURE 2 DELTAPLANE (SEARCH U.D.)

During the renaissance period Leonardo da Vinci studied aerodynamics principles through birds flight, though his works were unknown for almost 300 centuries (Korn-Brzoza u.d.).

Fundamental concepts of aerodynamics were presented first in the 18^{th} century (Florian Ion Petrescu 2012). Since then mathematical analysis (Tennekes 2011), wind tunnel experimentations (Maderspacher 2008) and computer simulations (Pivkin, Hueso, and Weinstein 2005) formed the scientific background for physics of flight and other research. However sitting in the plane would not give you the same experience as flying like a bird, having a full motion control over your body and airflow around it. The closest one (in the real world) users can come to with is deltaplanes[4], shown in Figure 2.

VR makes it possible to create a simulation experience of a bird-like flight in the immersive virtual reality (birdly.zhdk.ch 2014). Somniacs together with Zurich University of Art and Design manage to construct a flying simulator "Birdly" applied in Immersive Virtual Reality (IVR), including audio, visual, tactile and olfaction feedbacks together with air blowing feedback in the flight direction. The harder you push the wing machine extensions the higher you fly due to drag and lift algorithm calculations, which is very close to the flying physics birds are using, also burning some energy, while involving muscle work. However, degrees of freedom on the shoulders are still missing, since the users can only flip with the wings up and down (SOMNIACS 2015).
Since the development of VR the effectiveness of exploration of the virtual world, movement in it and gestural input is one of the main priorities and topics of future development of this technology. The problem´s core is the discrepancy of interaction space, limited in size, and almost unlimited virtual worlds (Niels C Nilsson et al. 2013). Virtual reality motion platform like

[4] Non-motorized foot-launch aircrafts used in hang –gliding (Florian Ion Petrescu 2012)

Virtuix Omni[5], for example, or flight simulator Birdly, as shown in the Figure 3, are using a lot of space at home, thus, Virtuix Omni, for example, enables physically to control unnecessary forward drift[6]. However, it is unknown if forward drift would also be present during natural gestural input of flight control in VR. Researchers are trying to explore natural gestural inputs to control moments in VR, since consumer homes might lack space for such devices or they might be costly and therefore less attractive for consumers on the market.

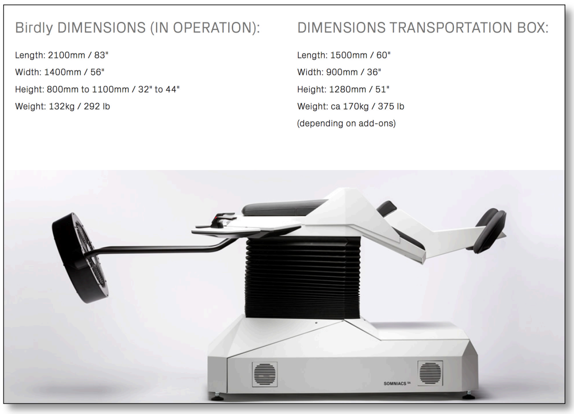

FIGURE 3 FLIGHT SIMULATOR "BIRDLY" (SA 2015)

Attempting to construct objects or mechanisms mimicking animals´ behavior in nature is known as biomimicry (Steph 2011). It is closely connected to biomechanics and some other fields of studies, like engineering and design. Planes constructions and physics are closely related to birds´ flight physics. However engineers are trying to construct faster planes with momentary rotational powers, which still has not been possible (Tennekes 2011).
Leonardo da Vinci noticed that bats are using different technique from birds, while flying (Korn-Brzoza u.d.). This idea has been developed further by constructing different models (Shirin Dadashi, et al. 2014) and simulators having in mind building a “perfect” plane. Understanding the bat flight is not only biologists´ first priority. Since Leonardo da Vinci experimented on bats (Korn-Brzoza u.d.), aviation and military has been attempting to build bat-like machines also for years. Some of the bats features still leave a mystery to us and have to be explored. Nevertheless the main feature, which is unique and separates bats from birds – is that bats are mammals and give birth to their young ones (BioExpedition Publishing u.d.). Bats, though, are the only existing flying mammals in nature (Altringham 2011).
Due to development of the technology it became possible to research bat´s flight. Understanding bat´s behavior would give an inspiration to create a vehicle that is able to maneuver in the urban-like environments due to their special ability changing rapidly direction

[5] Virtual Treadmill, developed for free movement in VR game
[6] Unintended Positional Drift (UPD) - is unintended physical motion in the virtual walking direction, which appears during movement in VR, when using walking-in-place locomotion (WIP).

of their flight and avoiding obstacles (Aerospace Computational Design Laboratory 2007). However, within VR field there has been no research done yet using bat´s flying algorithm and its potential influence on users.

Researching flight potentials in immersive virtual environment using bat´s avatar might help to uncover the following factors, which should be taken into consideration during this research:

- If it is possible to create a Virtual Body Ownership (VBO) over a non-humanoid shaped avatar representation in the Immersive Virtual Environment (IVE). In principal this could be investigated by using any non-human avatar, but since bat is the only flying mammal, with anatomy closest to a human being, it would be natural to make a research, involving bat and not a bird.
- Another consideration is that bats are better in momentary changes of direction while flying than birds, which would also give an opportunity to create a better natural flying experience based on bat´s flying algorithm in VR.
- If the users would have a stronger connection to a 1st person perspective (as a self-attribution process) even when mirror effect is applied (seeing one-self as a bat in a virtual mirror in VR), taking into consideration that motor actions of the avatar are connected to the motor activities of the participant (using visuomotor correlations[7]).
- Would the sense of presence be delimitated if users would not see their virtual body, but feel their body through interactive movements in the immersive virtual environment. By interactive movements should be understood a control of the virtual avatar by natural gestural input, which would impact the change of scenery and sounds in IVE.
- And finally it would be also interesting to research if interactive movements would increase the sense of embodiment and if it is possible to split virtual body (as a shape) from its controlled by users movements in IVE.

In order to create a credible bat flight simulator it is necessary to understand bat´s flight and behavior, taking into consideration general aerodynamic laws of physics and basic mathematics behind so that the users would experience a realistic flight as close as possible to natural conditions.

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[7] Visuomotor correlation is a correlation between visual and proprioceptive sensations, inferring visual information based on motor function of the body.

3.1 INITIAL PROBLEM STATEMENT

Through previous researches we know that it is possible to establish VBO over a human-looking avatar (see section 4.7). However it is unclear if a non-human avatar body would have the same effect over the users if the users´ movements would be correctly mapped in the virtual world taking into considerations proper motor correlations. It is also unclear if the users would be able to achieve the same sense of presence effect in a non-human body as if being in a human-like virtual avatar body with the help of Virtual Body Ownership (VBO) illusion. VBO illusion is an illusion of owning virtual body parts (it might be only a virtual arm that users get a feeling of owning) or the whole body entity (virtual body), achieved by stimulated sensory input (by stimulating human senses).

In order to answer all these questions the first step should be to research and test if it is possible to create VBO illusion of a non-human body by testing self-attribution factors (the feeling that this particular body belongs to me) to a specifically designed virtual body without involving any controlled by users´ gestural inputs that would cause the movement of the virtual body. It is also essential to research the main parameters for building Virtual Body Ownership illusion over a non-human avatar shape so that it will be possible to use them when creating such an illusion.
Based on this discussion initial problem statement is the following:

Is it possible to obtain a believable VBO illusion through a non-human avatar shape?

4 ANALYSIS

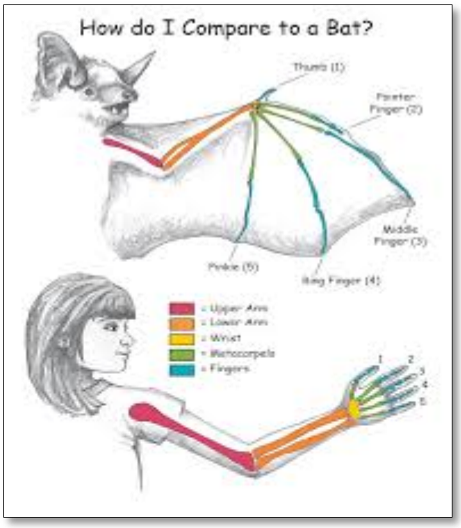
Since Virtual Reality makes it possible to experience different perceptual feeling it will be possible to create flight at least by involving a visual and proprioceptive senses as a starting point and further in the process add audition as well. In order to find out how to do this it is useful to investigate bat´s biological navigation system and get the have basic knowledge of bat´s anatomy and physics of flight.

Virtual Reality might make it possible to experience flight getting the sense of virtual body ownership or with other words owning bat´s virtual body as belonging to you, which might give a better chance for reaching a higher level of presence if virtual body ownership illusion would be achieved. For that purpose it would also be helpful to determine the main factors for embodiment in Immersive Virtual Environment.

Having this in mind, the chapter will concentrate on bat´s anatomy, physics of flight, bat´s flying locomotion and the main aspects of VR field as well as the problem of embodiment in VR, and discuss interactive gestural input at the end.

4.1 BATS ANATOMY

Bats anatomical structure is very similar to humans, as shown in Figure 4. Bat´s wing is a remarkable result of evolutionary process (Fenton et al. 2014). Their wings are also called “hand-wing” (chiropteria) (John. E. Hill and Jame Smith 1984), (Myers 2015).



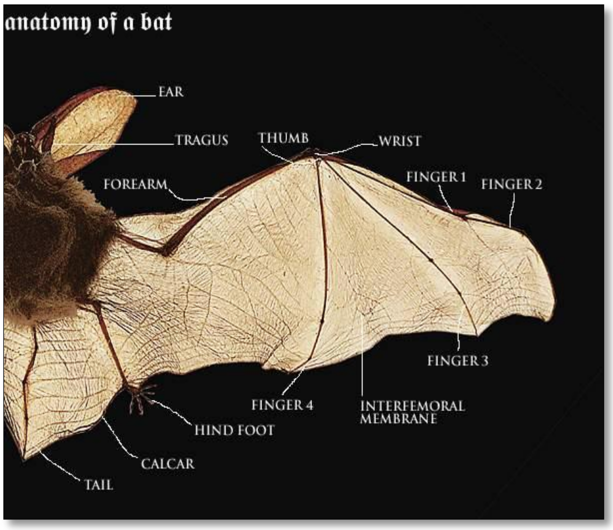


FIGURE 4 SIMILARITIES OF WING AND HAND**(SIZE N.D.)** FIGURE 5 BAT´S ANATOMY (SEATTLETIMES 2002)

Bat´s wing have a structure of the forelimbs of other mammals. The closest, very long and thin limb to the body is humerus, followed by radius, which is also very long and thin, but stronger than humerus, since it has to support the wing, and finally ulna, which is reduced in size.
The wrist is also similar to other mammals, but less flexible, shown in Figure 5. It supports a certain motion, when flying. Thumb is used for climbing, food handling and fight. The rest of the digits, usually 2 to 5, support the wing. One of the largest is metacarpal, consisting of 1 to 3 phalanges.

The wing membrane is an extension of the body´s skin, containing blood vessels and muscles, which control the wing flight curve. Wings have long muscles embedded in the skin, however they are not attached to any bones. Their flying cycle consists of upstroke and downstroke (middle stroke is not taken into consideration) (Iriarte-Diaz et al. 2011), as shown in the Figure 6.

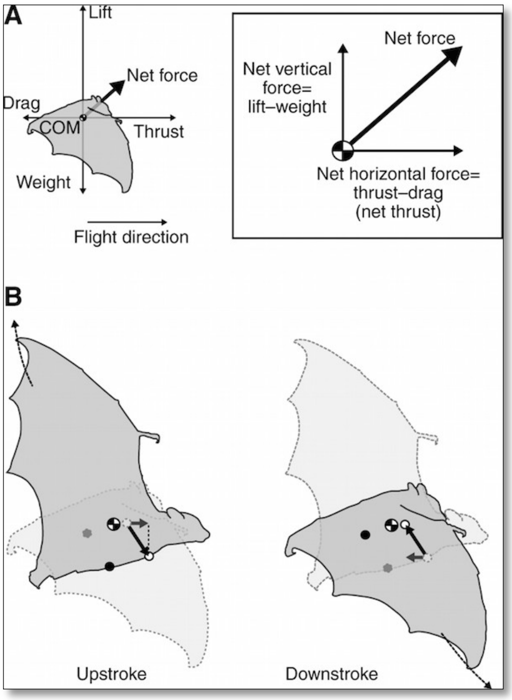


FIGURE 6 BATS´ FLYING CYCLE **(IRIARTE-DIAZ ET AL. 2011)**

According to the research these muscles influence (they contract) on the downstroke during flight. With the help of electrodes insertion, they could show evidence of the muscles activity. Besides that, injecting bat´s muscle array with Botox, the researches could determine the difference in their usage on the downstroke flight (Cheney et al. 2014).
The membrane also joins bat´s legs. Some species of the bats don´t have any tails at all. Bat´s body is covered with hare, but some have hairless wing membranes (John. E. Hill and Jame Smith 1984), can be seen in the Figure 7.

FIGURE 7 NATTERER`S BAT, SEEN IN ARGONNE CAVE (VERDUN, FRANCE), (MILLER 2012)

Researches have found out that some of the bats species are using their tails as a helping tool when lifting and thrusting. With the help of a video footage they were able to find out that bats are fanning their tails during down strokes and collapsing them during upstrokes (Adams, Snode, and Shaw 2012), which also could be seen in a bat slow motion flight footage (Science 2011). The main goal of flight is to minimize physical forces of Gravity during the upstroke and maximize air-displacement during the downstroke, as shown in the Figure 8. Bats can also control the flight direction with their tails, as the same research showed. Tail membranes are also important part of navigation and hunting (Adams et al. 2012).

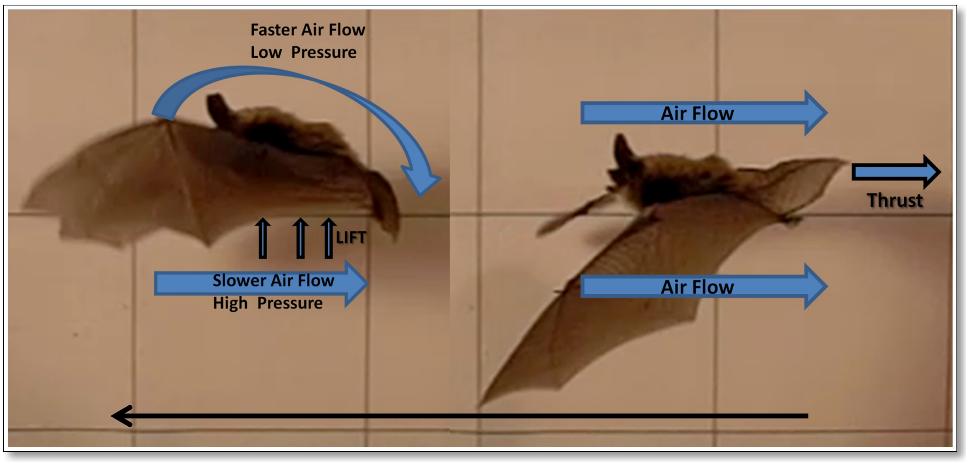


FIGURE 8 FLIGHT MOVEMENTS, RETRIEVED FROM: (BLOGS U.D.)

Bats do have both day- and nighttime visions. It is considered that they see in black and white gamma, however details of objects are missing in their visual system. In order to be able to get the details of the objects and to orientate themselves in the dark bats are using echolocation scope. Echolocation is orientation through the analysis of the emitted sound pulses (echo). When they have to catch a prey they simply generate the sound and their cochlea system analyses emitted impulses of the sound waves. The sound itself is generated in larynx of the bat, though Rousettus (mega bat) does it by clicking the tongue (Altringham 2011). Their pinna acts as a horn. The larger pinna they have the better low frequencies have been transmitted. Through echolocation bats decode:

- Target direction (echo frequency)
- Distance (pulse-echo time delay)
- Angular direction (ear amplitude difference)
- Velocity and trajectory (pulse-echo frequency change)
- Target size and shape (echo frequency)

Bats emit sounds only while they produce upbeat with their wings in order to reduce physiological cost (Wilkinson n.d.).

Bat´s locomotion of flight differs from birds´ (bats are the only flying mammals, as was explained in section 4.1). The main principals of their locomotion will be explained in the next section.

4.2 BAT´S FLYING GAIT

Birds´ size and the wingspan influence the flying gait – bigger birds fly faster than the smaller ones (Alexander 2002). The same is applied for the bats. In general larger animals have less drag drift to overcome for a given amount of lift production.

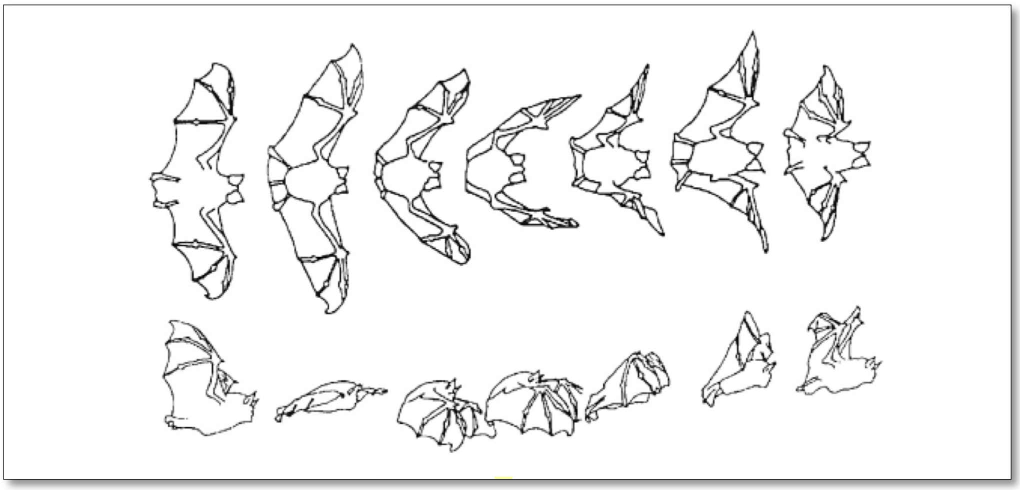


FIGURE 9 BAT´S FLYING GAIT (ALTRINGHAM 2011)

The whole flying gait is shown in the Figure 9.

Scientists have discovered that nectar feeding bat (very small in size) hovers in the air (in the wind tonnel filled with fine fog), using the same aerodynamic mechanism as insects. They have placed the animals in a wind tunnel, where feeders have been installed with sweet water, fog, lasers and high-speed video camera capturing wing kinematics and Digital Particle Image Velocimentry cameras capturing fog particles. The result of the experiment made it clear that air vortex[8], formed above the wing, increases lift to 40% through out the stroke, which allows bat hover in the air. The air flow reduces the air pressure above the wing, which provides a bat with advantage to use muscles and long fingers, changing the bend of the wing. By controlling air flow, bats can hover making fifteen strokes per second (Maderspacher 2008).

4.3 VR, TECHNOLOGICAL IMMERSION AND PRESENCE

There are many definitions of VR. One of them has technology as foundation, which capture attention, as it is close to the topic of this research: " *VR is an alternative world filled with computer-generated images that respond to computer movements. This simulated environments are usually visited with aid of an expensive data suit which features stereoscopic video goggles and fiber optic data gloves*" (Biocca and Delaney 1995).

The goal of VR is full immersion into VR environment, achieving the sense of presence or "being there" (McMahan 2003), which could be done through technological immersion(Slater 2003a). Technological immersion should be understood as incorporation of the human senses and sensorimotor channels into VR system (Slater and Usoh 1994).

Presence could be created and full immersion achieved only when all human senses are incorporated into the system (Biocca and Delaney 1995). Slater states that presence, being a subjective reaction (since it is it is our mind that sets it into this illusory motion as presence) to multisensory integration of a given level of technological immersion, which is objective – the more senses are incorporated into the system, the higher presence is (Slater 2003b). It is a psychological sense of "*being there*" in IVE, as users present in IVE, which they would consider as places visited rather than images seen, would be more engaged into it than to a physical world reality (Slater, Steed, and Usoh 2013).

It should be noted that our physical body acts as an anchor to physical reality. Physical body and its self-location (being inside the body and knowing that the body is mine) is a border between objective reality (*being here*) and subjective perception of presence (*being there*), which stimulates neurons objectively by technology and perceived subjectively by the mind. Furthermore, presence as subjective phenomenon is a process of constant undergoing

[8] Swirling air begins at the leading edge of the descending wing , and bypasses it back to the front edge, when the wing moves up again.

changes due to the fact that it is an experience of perceptions and sensations, feelings and emotions through time and in space of our subjective image of the world.

Slater and Usoh define 3 points that reveal trace of presence:
1) Presence can be both objective (behavioral phenomenon or the extant of behavioral similarity to the real world) and subjective ("being there") description of the user´s state with respect to IVE ("place like")
2) It is an increasing function of immersion
3) The extant to which "Plot"/scenario can remove users from everyday reality and place them into an alternative self-contained world
(Slater et al. 2013).

Slater suggests that presence is a form ("like being there", for example in theatre, when listening to a music system at home), however, it does not include emotional involvement or emotional response, since it is only user´s degree of interest in it (Slater 2003b). That is why technological immersion can cause subjective perceptual differences among users, since our cognitive system differs from one another as a reaction to presence by the same immersive system. Although no matter how much we would like to create impossible surrealistic scenarios in VR the real physical laws should be preserved, as physically we are still located in the real world (Slater 2003a).

Since the higher purpose of the VR system is to achieve full immersion and through that presence, an Immersive Virtual Reality (IVR) system should be defined here. IVR is a "*system relying on high fidelity tracking and multisensory displays to facilitate natural perception and interaction with computer generated environment*" (Niels Christian Nilsson, Serafin, and Nordahl 2013).

An ideal IVR system should include high quality visual images, determined by position and orientation of the tracking system, tactile, force-feedback, heat and smell feedbacks (Slater 2009). Immersive system, depending on degree of immersion (system characteristics (Slater 2009)) should be characterized by sensory-motor contingencies (SC) it supports. *SC*s are *carrying actions to perceive Immersive Virtual Environment* (IVE). They can be valid (actions inside IVE) and non-valid (from outside of IVE). Due to that systems could be characterized as immersive or non-immersive(Slater 2009).

Any ideal immersive system could simulate and recreate actions from any non-immersive system. For example, sitting in front of a computer even using an audio system is not the same as sitting in front of a display in an immersive system – these systems are non-symmetric. That is why *immersion* here should be defined as *property of valid physical actions* (Slater 2009), which are possible within the system users can take that might result in perceptual changes or even changes of the environment. The level of immersion in such a system is determined by its physical properties. That is why in accordance to the level of technological immersion these VR systems can be also classified as the first-order system, which is the ideal one, second-order system, containing the valid actions as a subset of the first-order system, and so on (Slater 2009).

On the other hand immersion as property of valid physical actions could be described from presence point of view. IVE simulates a real, physical reality transforming the sense of place through non-invasive alterations of body senses. The environment can create new experiences based on existing ones, where people are responding on the events - perceiving them as real - with their body actions. In VR theory there are two requirements (two orthogonal components) that should be taken into consideration for a successful perception of IVE. These components are place illusion ("pi", which is responsible for presence at a place/location in the IVE) and plausibility illusion ("psi", the illusion that the scenario is actually occurring). These two components combined together are responsible for achieving a specific level of realism in IVE, where users respond to the system as if the illusion is real (Slater 2009).

Pi is based on sensorimotor contingencies and shows how the world is perceived, while Psi indicates to what is perceived, it is the amount and extent of the events, the system is able to produce that directly relates to the user. In other words, Pi is believability illusion with the events, referring directly to users that are occurring and are true; while Psi is valid actions, consisting of sensorimotor actions, resulting in changes to images in all sensory modalities and effectual actions, taken in order to effect changes in the environment (Slater 2009).

Establishing VBO illusion (considering a specific virtual body as belonging to a user) also contributes to the sense of presence, as the user might feel more present when he or she would have a virtual representation of oneself inside IVE and full control over this virtual body; that is why self-representation in the IVE should also be believable.

4.4 HMD, MOTION TRACKING SYSTEM AND LATENCY

When visual interaction with IVE occurs through Head-Mounted Display (HMD), it provides users with stereoscopic view of computer-generated images, what could also be called a binocular vision. As soon as users turn their head in the real world the view in the virtual world changes accordingly due to real-time tracking of HMD. One of the problems of modern HMDs is latency they come with, from low to high, depending on the technical specifications. Latency is a delay between user´s input and the display response, as shown in the Figure 10.

Users motion can be mapped to a virtual body in VR with the help of tracking (also in real-time) through either optical or non-optical systems (Boger 2014). Optical systems rely on camera inputs, like Microsoft Kinect[9], for example, or infrared tracking point systems. Non-optical systems might be gyroscopes (Microsoft 2015)[10], as an example.

Different factors play a certain role when choosing the system, such as how reliable the system should be, meaning how accurate tracking one needs, refreshing rate, the desired tracking area, as acoustic tracking system, for example, might not give the most accurate results (Boger 2014), as they do not provide with very accurate results, take time to calibrate, noise should be excluded, update rates are not high, etc.

Motion mapping can be done either by tracking rigid body though markers attached to the limbs of the real physical body and computing the virtual body movements using inverse kinematics, or by tracking the full body movements with real-time motion capture system and applying the resulting motion to the virtual body (Kortum 2008).

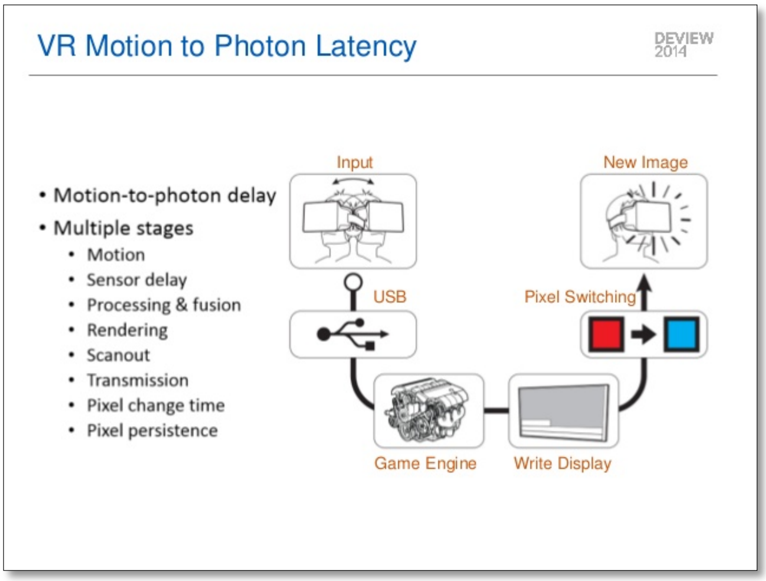


FIGURE 10 MOTION TRACKING LATENCY (SLIDESHARE 2014)

If the response time from user input into the system is very low the realism of the virtual world is reduced and therefore presence might get a negative influence. The less complicated the scene is the less latency susceptible the process is, however CPU and GPU influences the workload as well. During the scanout process (transfer of the rendered scene to HMD) a pixel, emitting photons, is shown out immediately as it arrives on the display. After the pixel has been shown for a while display has to stop emitting these photons before the next frame is

[9] Kinect´s sensor tracks position and rotation through three-dimensional space.

[10] Gyroscope is a device that measures or maintains orientation of an object.

shown. The longer the show time for these pixels is the further away they get from the correct position of the HMD, resulting in smear of the image (Abrash 2012).

There are discussions about the acceptance of the largest number of delay. Sherman and Craig mean that the most acceptable delay is 100 msec. (Sherman and Craig 2003), though Carmack and Abrash mean that 50 msec. is still noticeable by the users although it will be responsive, but 20 msec. is acceptable (Carmack 2013). Abrash also states that 20 or more msec. are "*too much for VR*", while 15 msec. or as low as 7 msec. might be a threshold for an acceptable latency (Abrash 2012).

Sherman and Craig suggest several ways to reduce latency; two of them are the following: by reducing the time information is sent from the input device to the computer, or by reducing the amount of render-frame time (Sherman and Craig 2003). However the frame rate can never be faster than what HMD supports, while trying to reduce latency that is why one of the solutions might be, instead of reducing latency, simply create faster frame rates. Another solution to this problem is to build faster HMD. For example, instead of 60 Hz display (here, the total latency would be 34 msec.) one should develop 120 Hz display, which would decrease display latency to 8 msec. and the overall latency to around 12-14 msec. (Abrash 2012).

4.5 INTERACTION WITH VR SYSTEM

Interaction, in general, is a two-way communication, in contrast to "cause and effect", which is a one-way communication[11].

One-way communication occurs when there is only one object that performs an action and the other one is being affected by it. In a two-way communication process both objects have possibility to affect each other´s state, but under condition that they both perform an action influencing the state of each other (Farrell et al. 2000). As an example – a user has to press a button, which turns on a TV (one-way communication), on the other hand when TV is on it shows a picture to the user (two- ways communication). In this example a TV is a stationary object.

Interaction in IVE could be also found between active agents (Crawford 2011) and IVE, when agent is changing the environment. It can also be between agents and stationary object or mobile object as well as between several active agents.

In the IVE there are two types of objects to interact with: stationary and mobile. A mobile object is an object that changes its´ position within time and space.

[11] "Dialectical Materialism" A. Spirkin, Chapter 2: "The System of Categories in Philosophical Thought", 1983, https://www.marxists.org/reference/archive/spirkin/works/dialectical-materialism/ch02-s06.html

In order to have interaction within IVE with stationary and mobile object the users should be able to control a virtual avatar through tracking body movements (Slater and Usoh 1994).

Mimicking the real world movements is a naturalistic approach in interactive VR, against magical approach, like for example, locomotion vs. teleportation. Direct approach allows mapping real physical movements of the users to the IVE, while indirect one brings into the scene different help to interact with VR in the form of widgets [12] (for example: toggles, buttons, devices etc.).

Interaction with the system and its narrative context allows engaging users into the IVE and the events in real-time, as VR system is a real-time system. Users control the system with the help of gestural inputs or might also control it with the voice commands or react to sounds, if it is an audio IVE.

The virtual environment is manipulated as soon as it receives gestural input from the user. Direct manipulation of the environment happens when a self-motion illusion occurs, which entails minimum requirements, such as space, cost, safety features and technical possibilities (Riecke 2006). Nonetheless self motion illusion generates very convincing sensation of movement on behalf of a stationary user illuminating the problem of spatial constrains (Niels Christian Nilsson et al. 2013).

The sensation of actual movement through the environment (or self-motion) is accompanied by optic flow, which estimated the direction and speed of self-motion (Lappe, van den Berg, and Bremmer 1999). Optic flow can be described as a pattern of apparent motion of objects or surfaces in VR, caused by relative motion between a user and a scene. Optic flow in VR provides users with cues about the direction and speed of the environment (Warren et al. 2001).

4.6 EMBODIMENT IN IMMERSIVE VIRTUAL ENVIRONMENT

Embodiment is used in different contexts according to multidisciplinary adoption in broad application areas and thus depending on conceptualized viewpoint considering the field of study. In cognitive science and psychology it is the brain representation of the body and its alterations under specific conditions; in robotics it is the way of delegation of virtual agents and robots that have the real physical representation (Kilteni, Groten, and Slater 2012).

[12] https://developer.leapmotion.com/gallery/widgets

J. Varela described embodiment as a necessity of physical body experiencing sensory-motor processes, which result in cognition. Embodiment experience is problematic to replicate, due to "*impossibility of dissociating the body from one´s self*" (Varela, Thompson, and Rosch 1991).

In VR the problem of embodiment has been also discussed (Biocca 1997, 1999). Biocca discussed that self-presence is the main factor of embodiment of one´s self representation (Biocca 1997). Kilteni defined the sense of embodiment as "*assemble of sensation that arise in conjunction of being inside, having and controlling a body*"(Kilteni, Groten, et al. 2012). Slater also claims that the virtual body is the critical contributor to the sense of being in the virtual location (Slater et al. 2010). Furthermore he explains that oneself in a body has spatial representational characteristics, which are location inside the body, self-attribution (for example, the body, in which one perceives one´s self inside one´s own body) and that the "*body obeys the intentions of one´s self under enactment*" (Slater et al. 2010). This leads to several components that are essential in IVE – sense of self-location, sense of Body Ownership (BO) and sense of agency (Kilteni, Groten, et al. 2012).

Although the main two components – BO and Agency – has been known and researched for a long time in psychology, it is not the case in VR. Virtual Body Ownership has been discussed a lot, however agency did not get that much attention in the field of VR (Kilteni, Groten, et al. 2012). This concept has been discussed only during the past three years and it is still remaining unclear if by Virtual Body Ownership the researchers mean embodiment or only BO, which apart from the virtual body also includes "*visuomotor correlations*" or other sensorimotor correlations.

Before going further into the concept of self-perception in VR it should be understood how brain distinguishes between biological body, its parts and external world objects.

Cognitive neuroscience studies multisensory integration, while psychology concentrates on self-identification. In order to be able to interact with IVE one might want to have a representation of an own biological body there – a virtual avatar, by using multisensory integration system trying to achieve Virtual Body Ownership (VBO) (Kilteni, Groten, et al. 2012; Maselli and Slater 2013). One could say that in VR there are two types of embodiments (out-of-body experience): psychological (3d Person Perspective) and physical (1st Person Perspective). Through representation of the biological body in the virtual avatar form VR allows to realize embodiment in a controlled way by manipulating the body structure and size, morphology, dissociating egocentric visual perspective from the body, using role of multimodal information in spatiotemporal terms for body perception (Denisova and Cairns n.d.; Kilteni, Groten, et al. 2012; Normand et al. 2011; Slater et al. 2010).

4.6.1 THE SENSE OF SELF-LOCATION AND ITS SPATIAL REPRESENTATION

Self-location has a psychological matter. It is a perceptual sense of being inside the body (or can be inside the environment, depending on the coordinate system, described underneath).

Space can be peripersonal (the space within arm´s reach) and extrapersonal (out-of-body reach), which allows to create a coordinate system, represented by allocentric (external space) and egocentric (internal space) locations. Allocentric heading representation defines the angle of ego´s axis of orientation, relative to external reference direction (Klatzky 1998).

Based on this coordinate system self-location and presence might be presented as complimentary concepts. Together they constitute one´s spatial representation. Since self-location is a representational variable of oneself inside the body (avatar body), presence, on the other hand, might be another variable, representing location inside the environment (IVE), which can be with or without an avatar body.

However self-location depends on:

- An egocentric visuospatial perspective. That is why 1st Person Perspective (1PP) supports sensory believability and acceptance of self-localization inside the avatar body as well as brings immersion into a higher level in 1st Person Shooter Games (Nacke and Lindley 2008).
- Vestibular signals provide information about translation and rotation of body, in addition to orientation with respect to gravity
- Our skin acting as a border to the external environment, that is why tactile input plays another significant role in self-location (Kilteni, Groten, et al. 2012).

4.6.2 THE SENSE OF BODY OWNERSHIP AND AGENCY

Our body is the source of experienced sensation, which combines bottom-up and top-down processes (Wolfe et al. 2008).

Sensory information that reaches the brain belongs to bottom-up process. It can be visual, tactile, proprioceptive and vestibular. The study of Rubber Hand Illusion (RHI) is a perfect example of this process that studies the dominant sense in our body (Botvinick and Cohen 1998; Petkova et al. 2011).

Top-down process operates with sensory stimuli in the brain and is a cognitive process. As an example of it could be different studies on the sensation of resemblance of a rubber hand to a real hand and the difference in spatial configuration (Petkova et al. 2011).

4.6.2.1 BODY OWNERSHIP

The best way to explain what is Body Ownership (BO) is to understand the constitution of one´s self-attribution – how do you know that it is your body – the body that is "*my own*" and has always been presented in "*my life*" (Tsakiris 2010). Self-attribution includes attribute of ownership and agency.

BO awareness is a "*sense that one´s own body is a source of sensation*". Its structure depends on afferent signals coming from the senses and being felt through both active and passive movements (Tsakiris, Prabhu, and Haggard 2006). The sense of *self* does not have temporal limitations.

Awareness of one´s self – body and actions, is fundamental for the sense of self-consciousness (Asai 2015). Touch (tactile stimulation), proprioception (passive movements) and action (active movements) all together constitute body awareness (Tsakiris et al. 2006).

BO is reflective – realization of one´s movement and recognition of it. Movement is an action, which could be voluntary (action, performed by oneself or active movement) and involuntary (passive movement). Body awareness should be understood as proprioceptive awareness, since the body senses its movements as it has cross-referenced relationship with actions. It is a cycle process of sensory feedback modulating an action, meaning that when we take an action, the motor command is calculated based on the current state of the body (its sensory feedback) to achieve the desired state (Tsakiris et al. 2006; Wolpert 1997).

During voluntary movements the sense of BO is created by sensory feedback that is why it is suggested in the literature that voluntary movements structure BO (Haggard 2005; Wolpert 1997).

Knowing that body has been moved, but not producing this movement by oneself, would infer only BO and not agency, since this movement is involuntary and you are able to only sense the movements, but you are not a creator of these movements(Tsakiris, Schütz-Bosbach, and Gallagher 2007).

BO is characterized by multisensory integration, in particular by interaction between vision and somatosensation (Kennett, Taylor-Clarke, and Haggard 2001; Taylor-Clarke, Kennett, and Haggard 2002).

RHI experiment, described in section 4.7.1, proved that multisensory signals interacting with BO generate the sense of self (the observer accepted external limb as a part of his own body). It also showed that temporal and spatial visuo-somatosensory synchronicity is important when establishing BO. However, minor spatial asynchronicity patterns are acceptable, if they don´t influence the perception of BO. Several experiments showed that measuring BO with proprioceptive drift[13], which drives the sense of agency, was necessary for establishing BO over an external object (Asai 2015).

4.6.2.2 AGENCY

Agency is "*the sense of intending and executing actions*" (Tsakiris et al. 2006), feeling the control of body movements and making an impact on the external environment through these movements (Tsakiris, Longo, and Haggard 2010). It is generated by efferent signals, as motor commands coming from the brain precede voluntary movements (Tsakiris et al. 2006).

Since BO was one of the parts that constitute self-attribution (described in 4.6.2.1), agency is another one. It is a awareness of movement cased by the user (Graham and Stephens 1993). This happens only under the condition of voluntary movements (active movements) – when you are in control of your own actions (Tsakiris et al. 2007; Tsakiris 2010).

The sense of agency is realized through motor commands, sent to the muscles.

Since BO is created by the sensory feedback, and agency is initial motor commands, the sense of agency does infer BO, though BO does not infer the sense of agency (Haggard 2005; Tsakiris et al. 2007; Wolpert 1997), since BO does not infer active movements, but it could be felt through them, as it has proprioceptive awareness. Based on this statement Tsakiris means that not all objects can be experienced as a part of the body, because there is no functional reason for such an object to be a part of the body, unless it´s a neutral object used by the body as a tool (Tsakiris et al. 2007).

Another detail of agency is that, besides that it is present in active movements, users have to have a full control over their actions implying free will (Kilteni, Groten, et al. 2012), which is understandable, since it involves active voluntary movements.

Due to there is only one perception of "*I*", needed for self-recognition, in real life it is difficult to split agency from BO, as they always work together (Asai 2015; Tsakiris et al. 2007).

RHI experiment also proved interaction between BO and agency, which was established during it. When experimenting with RHI, Tsakiris could also prove an interaction between the sense of agency and BO (Tsakiris et al. 2006). Nonetheless it had also been proven, that synchronous tactile feedback generated proprioceptive drift locally for the specific finger that was stroked (that was an indication for BO present), while active movement of a single digit produced proprioceptive drift for the whole hand and not only locally for this specific finger (that was an indication for agency present). This spread across the fingers was an evidence of motor activity that generated BO, which gave him a possibility to conclude that agency structures BO,

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[13] When the observer's hand seems to drifts towards the rubber hand (from the observer's point of view).

especially since in primary motor cortex different body parts representation are overlapping each other (Tsakiris et al. 2006).

At the same time this experiment showed that deviation from synchronicity is acceptable. It is due to the fact that, consequences of people´s making active movements are temporarily attracted to the action itself, which is called “intentional *binding effect*”. It leads to a paradox of asynchronous active movement being perceived as more synchronous than they actually are (Tsakiris et al. 2006).

On the other hand Gallagher discovered that agency required movements but not necessarily the body itself (Gallagher 2000). Asai was able to conduct three experiments, where he tried to prove that BO elicits proprioceptive drift. The results proved that explicit agency without explicit BO can elicit a proprioceptive drift. Asai was only able to measure the feelings during his experiments and came to the conclusion that the sense of self was constructed from representation of one´s own body together with its actions (Asai 2015).

As a conclusion of agency section it should be noted that even though in theory agency functions together with BO (when one performs a voluntary action) it had been proven that agency “*overrides*” BO or BO “*inhabits*” movements (Tsakiris et al. 2007; Tsakiris 2010). In experimental conditions, though, there were found no proof that it is possible to dissociate agency from BO. Ehrsson and Kalchert wanted to prove that agency enhances BO, unfortunately no conclusive evidence was achieved (Kalckert and Ehrsson 2012).

4.6.3 VIRTUAL BODY OWNERSHIP AND VIRTUAL AGENCY

The Virtual Body Ownership (VBO) is an illusion, where healthy users believe that artificial body (avatar) is their own physical body (Maselli and Slater 2013). It is characterized by multisensory integration. The illusion is based on the altered representation of the whole body in IVE and is supported by the Rubber Hand Illusion paradigm from the study of body perception. It proved that for creation of the full VBO illusion visual perspective and visuotactile stimulations are necessary factor (Maselli and Slater 2013). On the other hand, it was experimentally proven that visuotactile stimulations are not as important as visuomotor correlation[14] (Slater 2014).

Maselli and Slater define some building blocks of the full body ownership illusion that include the following adopted factors in their experiment (Maselli and Slater 2013):

[14] Visuomotor correlation is a correlation between visual and proprioceptive sensations, inferring visual information based on motor function of the body.

- Visuotactile stimulation and head-based visual sensorimotor cues are independent factors if 1PP is present
- Visual perspective (1 PP) is critical for establishing full VBO illusion
- Body appearance has to be realistic seen from 1PP, including humanoid shape and realistic clothing

They also point out that previous studies showed that non-humanoid shaped objects failed to be accepted as a proxy extension of the body. They pointed out to one of Tsakiris´ experimented compared a wooden no-hand-shaped object and wooden hand-shaped object with the rubber hand striking it synchronously with the participants´ real hand (one of the modifications of RHI), which did not produce positive results towards BO in the first two conditions. This experiment drove a conclusion that only corporeal objects, containing the information about the body structure, can maintain coherent sense of BO (Tsakiris, Carpenter, et al. 2010). Substitution of the body for a wooden block did neither give any results for obtaining BO (Lenggenhager et al. 2007; Petkova and Ehrsson 2008). However, the view of the human-shaped manikin experiment did not completely dampened the illusion, due to visuotactile component, present in the experiment (Petkova and Ehrsson 2008).

Physical body experiences complex sensations from different senses, such as vision, touch, proprioception, motor control and vestibular sensation (Maselli and Slater 2013), working together, establishing the sense of VBO. In particular, there is a correlation between visual impressions of movement and somatic sensation. Correlation between vision and proprioception plays a significant role in self-identification used in mirror or video-recordings (Bailenson, Blascovich, and Guadagno 2008) or in infant identification of the congruent vs. incongruent visual and somatic feedback of own movements (Ehrsson 2012). Slater states that visuomotor correlation is one of the most important factor for linking physical and virtual body movement, what is even more prior than synchronous feedback (Slater 2014), which might undergo minor alterations as described in section 4.6.2.2. The most substantial evidence of congruent multisensory experience is RHI, which results in three-way interaction between vision, touch and proprioception and could prove that central body representation is dynamic due to continuous update on the basis of available sensory inputs from different modalities (Botvinick and Cohen 1998). Identification of different body parts undergoes the same process. Although around 30% of population is "*immune*" to RHI due to individual differences, depending on the weight distribution of integration process between the senses (Ehrsson 2012).

Since it is arguable if it is possible to totally dissociate BO from agency in physical reality as they work together, VBO might be possible to split from Agency in IVR.

By agency is meant bodily motor control actions and intentions (since it is a top-down process) in IVE, including the subjective experience of such actions under the condition of synchronization of visuomotor correlation.

As mentioned before VBO requires an avatar – an external artificial virtual proxy, which would represent users´ body in IVE. As the sense of agency normally would imply body ownership (knowing of being in control of one´s own body), it should not be different for agency either. However, knowing that virtual body has been moved by involuntary action might infer only VBO, not agency. On the other hand moving the virtual body without proprioceptive experience, might even exclude VBO, which has to be tested, as it might be difficult to relate to a non-corporeal object, which would be a non-human avatar having anatomical differences. The explanation for this phenomenon, as I see it, lies in sensorimotor contingencies, which is the set of valid physical actions (see section 4.3), possible within immersive system, which might result in perceptual changes (changing the sense of VBO) or changes of the environment (changing the sense of presence). However, not introducing users to the perfect 1st order system as described in section 4.3, might result in perceptual limitations and therefor limitations of full VBO illusion. For example, if a user would hit a tree in IVE, depriving him from tactile feedback, would not give realistic enough sense of being there, the same might be for other senses, which awareness of VBO includes. On the other hand motor movements, correctly mapped and implemented into the system, might still produce agency, which would be motor linked to the real physical body and therefore might still support agency input from the real physical body. Based on these assumptions it should be tested if agency might override VBO in IVE or if it might enhance the sense of VBO.

Albeit described above questions, it has been already proven that having VBO in IVE creates the sense of presence for the users anyway (Maselli and Slater 2013). Taking into consideration that presence is a form not a content – a reaction to multisensory integration of technological immersion (see section 4.3) it would be interesting to find out if agency might increase presence even more that VBO and which degree of presence it is possible to achieve by only having VBO and excluding agency.

In active applications like games or simulators, having only VBO present might not be enough to achieve the highest sense of presence.

Although users might experience the sense of presence inside IVE even without having an avatar body, by only operating through the 1 PP camera movements, instead of having and moving the body as 1 PP, thus when avatar is not involved in any specific active tactile movements, like touching objects, for example, or dragging them in the environment, where visual feedback is necessary for the users in order to observe motor actions of their virtual body and the result of it. However, the level of presence is unclear, when the virtual body is absent but agency is present and therefore needs to be tested as well. The best possible way of testing it might be testing VBO in absence of agency and as a control condition the sense of VBO in presence of agency.

In conclusion of this discussion differences in terminology should be noticed between perception and cognition field of study and VR. In the first one it is clearly distinguished between agency and BO, which structures embodiment or body awareness. In relation to VR field there might be some confusion, due to the usage of term VBO, which does not clearly involve the sense of agency, if one looks at its definition at the beginning of the paragraph. Furthermore, it has been defined throughout almost all lately articles that VBO should include not only 1 PP with humanoid-shaped realistic avatar body, but also visuotactile information and visuomotor correlations, which is even more important than visuotactile feedback. The last two terms should be understood as – visuotactile – belonging to the sense of VBO; visuomotor correlation, on the other hand – belonging to the sense of agency, which would give a possibility to split the two different terms: VBO and agency.

And the last one, but nonetheless important point that should be discussed - is human-shaped avatar, which according to Kilteni and Slater influences the enhancement of VBO illusion (Kilteni, Groten, et al. 2012). They state that virtual body obeys certain structural and morphological constrains, like similarities between the biological body and the avatar, as VBO might be highly susceptible to individual differences. They speculate if individualized avatars might strengthen ownership by increasing body and self-recognition (Kilteni, Groten, et al. 2012). This might be true in relation to VBO, though might be discussable if agency is considered, which as well needs testing. As was mentioned in in section 4.6.2.2, if an object is neutral and used by a body as a tool, there is a functional reason for such an object to be a part of the body. Since it was possible to accept (and mostly important control) an extra limb by VBO– a tail – (Steptoe, Steed, and Slater 2013), which is unnatural for the human biological body due to its absence, it might be possible to accept another non human-shaped appearance, but only if it would be possible to keep visuomotor correlation between the movements of that different than human-shaped virtual avatar and the movements of the biological body or in other words agency should be correctly mapped in order to create a possible embodiment over a non humanly-shaped virtual avatar in IVE.

4.6.4 THE ROLE OF PERSON PERSPECTIVE IN VR

Visual perspective is an important factor for establishing full VBO illusion (Maselli and Slater 2013). Through Person Point of View (POV) users interact with IVE. There are many numbers of applications, allowing changes of POV, depending on the situation and preferences (Denisova and Cairns n.d.).

3PP gives users possibilities to act more as observers and gives a wide field of view, when needed, serving as exploratory tool (Taylor 2002).

In terms of VR 1PP leads to a higher sensation of presence (Slater et al. 2010).

Another experiment conducted in VR and Augmented Reality described benefits of 3PP, where POV was switched between 1PP and 3PP (Salamin, Thalmann, and Vexo 2006). The results showed that both POV were useful, depending on the situation. According to this experiment, 3PP might be used when displacing actions or interactions with the moving objects, while 1PP might be used, when looking down or interacting with nonmoving objects in the environment. Furthermore it showed that users were better at evaluating distances and anticipating trajectory of mobile objects, while using 3PP due to large field of view (Salamin et al. 2006).

Maselli and Slater also noticed that 3PP is not an actual illusion but a form of self-recognition as a mirror-like image (Maselli and Slater 2013).

4.6.5 SPATIAL AND TEMPORAL SYNCHRONICITY

Albeit some alteration might be applied to the spatial positioning of the limbs, it is important to keep temporal congruency of the visual, tactile and proprioceptive signals applied in the peripersonal (egocentric) space, proved by RHI experiment and its variations (Botvinick and Cohen 1998; Kalckert and Ehrsson 2012; Kort and Dickinson 2006; Olivé and Berthoz 2012). The RHI showed that any alterations from synchronous visuotactile feedback are crucial in extension of the body part. In several experiments measurements were obtained where the asynchronous sensorimotor trials showed to decrease the VBO illusion. Some minor alterations, however, in a spatial position is acceptable (Banakou, Groten, and Slater 2013). The physiological proof of synchronicity can also be compared to psychological self-perspective **"***The movements of the subjective "I" need not be exactly coupled to oneself***"** (Bailenson et al. 2008).

4.7 STATE OF THE ART

In this section there will be presented several cases, which could be used as background knowledge in both VR field and psychophysics. At the end of this section there will be presented measurements the researchers are using in order to test body external proxy, VBO, agency and presence.

4.7.1 RUBBER HAND ILLUSION

Originally RHI illusion was studied by Botvinick and Cohen (Botvinick and Cohen 1998). One of the participants' hands was hidden from the sight and replaced by the rubber hand, which could be seen by the participants. The posture of the rubber hand was similar to the posture of the real hand. Both (rubber and the real) hands were stroked simultaneously. Synchronously strokes indicated acceptance of the rubber hand as belonging to the participants´ body with the touch originating from the rubber hand itself. When the strokes were asynchronous or when spatial touch inconsistencies between the stroking the hands were present, this illusion was perceived with less or no extent of acceptance of the rubber hand as belonging to the participants´ body.

Scientists also proved that the illusion does not occur when:

a) Anatomical constraints are violated (when the rubber hand was located outside of the participants´ personal space).
b) When the posture was impossible.
c) When it did not represent the main topological features of the hand.
d) When visuotactile stimulation was substituted by other stimuli.

Based on the experiment the main principal of the RHI is the following:

Spatial configuration component corresponds to visuoproprioceptive information. Furthermore, spatial location encoded by vision is compared with the one encoded by proprioception. Based on that real physical body´s spatial location, which does not always correspond to the position of the physical body, can be altered. The fake hand does not necessarily need to have a realistic look (can be plastic, or elongated, etc.). However, the most important factor of the RHI is synchronicity of the visuotactile stimulation. Due to visual representation it is possible to enhance the strength of the illusion (Botvinick and Cohen 1998). After the experiment the participants tend to say that the position of their biological hand were closer to the rubber hand as it really was. This over/under estimation of the hand location is called *proprioceptive drift* – the difference between the pre- and post-experimental position estimation (Kilteni, Groten, et al. 2012).

The conclusion of this experiment is that the sense of ownership over an external object can be obtained by convergence of bottom-up processing of congruent multimodal perceptual cues and top-down prior internal body representation with anatomical constrains of body shape and visual perspective. The same conditions are valid for the whole body (Botvinick and Cohen 1998).

Besides the fact that RHI elicits 1)*visuotactile contingencies* between the seen and the felt strokes, providing the sensation that the rubber hand is part of the participants body and 2) *proprioceptive drift* towards the rubber hand; RHI is also elicited with 3)*synchronous visuomotor correlations*, when the artificial body parts has been see to move synchronously with the biological hidden hand (Kalckert and Ehrsson 2012; Tsakiris et al. 2006).

As a variation of the RHI illusion another experiment was conducted, where two rubber hands were placed side-by-side and brushed simultaneously and synchronously with participants own hidden hand with a "twin-brush". This lead to sensation of receiving both touches and as a result getting a feeling of owning both rubber hands by test participants. The conclusion has been made that the brain is capable of hand representation in two equally probable locations simultaneously (Kalckert and Ehrsson 2012).

4.7.2 THE CONCEPT OF BODY OWNERSHIP AND ITS RELATIONS TO MULTISENSORY INTEGRATION

In the article Ehrsson describes one experiment that went beyond the borders of 1PP. This experiment resulted in self-identification with the 3PP VBO, even feeling the sense of touch on their back. It proved that VBO and the sense of touch can be projected to a body out of intrapersonal space to an extrapersonal space, observed from a 3PP, which directly contradicts spatial constrains of the RHI. One of the likely reasons for this is the resemblance to a self-recognition process as when seeing oneself in the mirror or in a video recording.

Ehrsson concludes that humans' perceptual system learned spatial mirror transformation in a way where it is possible to associate somatic events from one's own body to the visual events on the body, which is in the distance (mirror) from intrapersonal space (Ehrsson 2012).

4.7.3 HUMAN TAILS: OWNERSHIP AND CONTROL OF EXTENDED HUMANOID AVATARS

RHI experiment showed that it is possible to extend human biological body to external objects and tools, such as rubber hand, due to the plasticity of the human brain´s representation of an updating body schema (neural system, where space coding for action is centered). Proprioceptive and visuomotor system are dynamically updating constantly, depending on allocentric factors of peripersonal position of the biological body.

VR technology makes it possible to transform the users´ sense of place by replacing visual field with stereoscopic and perspective-correct imagery that can also present transformations of the immersed user´s body. VR gives unlimited possibilities to extend and alter virtual bodies (Steptoe et al. 2013).

The conducted experiment considered a possibility of acceptance of an extra virtual limb as belonging to the virtual body of the participant. Special gestural inputs (hip movements to the left and right) were involved, in order to control a tail. The participant's task was to play a game in VR and collect all the circles (it was also possible to collect circles with the tail). In order to enhance the feeling of VBO, fire was used in the game as one of the obstacles. The fire could burn the virtual body as well as the virtual tail. The participants tried to avoid the fire on the tail by controlling the virtual tail via the hip movements. The experiment showed that the correct gestural input of the extended limb combined with a game context, a 3PP, humanoid looking avatar and synchronous gestural input of the body movements (legs and arms) are necessary, in order to accept an external virtual limb (controlled by hip movements) as belonging to the body and to get the sense of overall VBO (Steptoe et al. 2013).

4.7.4 THE ROLE OF INTERACTION IN VIRTUAL EMBODIMENT: EFFECT OF THE VIRTUAL HAND REPRESENTATION

This study explores agency and interaction with IVE through manipulation of the virtual objects (as the first condition of the experiment) together with VBO by changing the level of realism exposing the virtual hand to different dangerous situations (as the second condition of the experiment). Test subjects were supposed to place their virtual hand to a specific location marked on a virtual table. Danger helped to measure how much were pest subject able to expose their virtual hand to risk and danger, as fire and spinning saw. Furthermore the researchers studied interaction of the virtual embodiment. Though interactions techniques used in the study dis not include physically based simulations. There were two research questions presented in this study:

1. *"Does the virtual representation of the hand alter the sense of agency?*
2. *Does the virtual representation of the hand alter the sense of ownership?"*

The virtual hand was presented in 3 different conditions having different levels of realism and was tracked by the Leap Motion:

a) Abstract - low level of realism, presented as uniformly shaded sphere, controlled by the hand palm.
b) Iconic – medium level of realism, where two states of animations was included (open, closed)
c) Realistic – high level of realism, where full animation was provided, including forearm.

Within subject design was used. Quantitative data acquisition methods were applied as well as questionnaire as qualitative methods, shown in Figure 11, where ID with A indicates agency and ID with Q indicates body ownership.

ID	Question
A1	I felt as if the virtual representation of the hand moved just like I wanted it to, as if it was obeying my will.
A2	I expected the virtual representation of the hand to react in the same way as my own hand.
A3	The task was (1 difficult, 7 easy) to perform.
A4	I felt like I was able to interact with the environment the way I wanted to.
A5	I felt that the interaction with the environment was realistic.
A6	I felt like I controlled the virtual representation of the hand as if it was part of my own body.
O1	I felt as if the virtual representation of the hand was part of my body.
O2	I felt as if the virtual representation of the hand was someone else's.
O3	I felt that I was losing the control of my hand when the virtual hand was not responding properly.
O4	I thought that the virtual representation of the hand could be harmed by the virtual danger.
O5	I felt that my real body was endangered during the experiment.
O6a	Did you try to avoid the virtual obstacle (fire) while performing the task?
O6b	Did you try to avoid the virtual obstacle (brick) while performing the task?
O6c	Did you try to avoid the virtual obstacle (barbed wire) while performing the task?
O7	I felt my own hand tickling whenever the virtual representation of the hand went through a virtual obstacle.
O8	I felt that the virtual representation of the hand was able to go through the virtual obstacles.

FIGURE 11 QUESTIONNAIRE USED TO MEASURE VBO AND AGENCY (ARGELAGUET AND ANATOLE N.D.).

It had been concluded that agency percept was stronger in a less realistic virtual hand representation due to efficiency of control (degrees of freedom) provided to test subjects, while perception of VBO was increased together with the level of realism (Argelaguet and Anatole n.d.).

4.7.5 THE ROLE OF THE SOUND IN THE SENSATION OF OWNERSHIP OF A PAIR OF VIRTUAL WINGS IN IMMERSIVE VR

This article is taken as an example of audio representation of the wings and an impact on the ownership and agency perception and acceptance of the body of an external proxy through synchronized random sounds of the wings.

Four sound conditions were presented to test subjects:

1. No self-produced sound activated;
2. Body sound only;
3. Body and Wings sounds were presented;
4. Asynchronous (from body movements) wing sounds were generated including randomized delay between 0 and 500ms.

The sound of the wings was Foley recorded using umbrella and heavy blanket. Overall there were 5 different sounds recorded and applied randomly in the experiment being attached as animation event in Unity 3D. The sound was activated when "*wing tips were fully extended in their downward stroke position*".

Test subjects had a training session in order to get used to the environment and getting a "*training session*" to get used to control the wings. They had to fly or walk from one obstacle to another. Animation was played in loop as soon as motion capture system activated by the tracker on the shoulder, providing also a small amount of lift. Though lift was also restricted by the invisible to the test subjects collider object as a "roof". Animation was not synchronized with the test subjects´ shoulder movements. One of the drawbacks of this experiment was limited field of view, which did not give the test subjects a very good look at their wings and therefore did not provide them a good audio-visual sensation of synchronous movements.

The researchers used within subject design for this experiment. Quantitative measurements helped to define the amount of agency and ownership. Likert scale was given as 1 – "*complete disagreement*" to 7 – "*complete agreement*".

The questions used in the experiment were the following:

Ownership	*1. I felt as the body I saw in the virtual environment might be my own body*
	2. I felt as if the wings were a part of the body that I saw in the virtual environment
	3. At times during the period spent in the virtual environment, I imagined that I had real wings
	4. I considered the wings to be as much of a part of the body as the arms and the legs were
Agency	*5. Not considering the wings, the movements to the body I saw in the virtual environment seemed to be my movements*
	6. I could easily move the wings to where I wanted
	7. The wings seemed to move from around on their own
	8. I learned how to control the wings more accurately as the flight course went on
	9. There were times during the flight course when moving the wings came naturally to me

FIGURE 12 QUESTIONNAIRES (SIKSTRÖM, DE GÖTZEN, AND SERAFIN 2014)

Results showed a slightly significant difference between no sounds at all or the sounds from the upper body and the sound of the body and the wings, indicating that test subjects accepted the wings as a part of their body sonically (Sikström et al. 2014).

4.7.6 VIDEO ERGO SUM: MANIPULATING BODY SELF-CONSCIOUSNESS

In this experiment a self-attribution only with visuotactile stimulation occurred. An Out-of-body experience was tested, where the participants identified themselves with a mannequin (3PP) projected 2 meters in front of them and dressed the same way (Lenggenhager et al. 2007).

The conciseness self is localized within bodily borders. Particular neurological conditions (as out-of-body experience) might lead to disturbances of the bodily self-consciousness. The experiment was conducted on healthy test subjects. It showed that during multisensory conflicts, participants were able to mislocalize themselves towards an extracorporeal position of a global self (outside their body borders). In other words participants were able to mislocalize themselves to a virtual avatar body, which was shown on the screen. The results showed that synchronicity is very important in the process of identification of oneself to a virtual avatar body, when extracorporeal position leads towards the position of virtual avatar, which has another position than participants´ position. It was possible to conclude that illusory self-location showed that body self-conciseness and selfhood can be dissociated from one´s physical body position (Lenggenhager et al. 2007).

4.7.7 THE PERSPECTIVE MATTERS! MULTISENSORY INTEGRATION IN EGOCENTRIC REFERENCE FRAMES DETERMINES FULL-BODY OWNERSHIP.

The experiment showed a possibility to establish VBO over a manikin body in IVE, using HMD. Asynchronous visual and somatic stimulation, replacement of the mannequin by a block of wood, representation of the mannequin two meters in front of the participant (outside of the near-person space) were the controlled conditions of the experiment. These conditions eliminated or strongly reduced the VBO (Petkova and Ehrsson 2008).

In the later experiment Petkova was able to prove that it was possible to create a real or a "genuine" VBO illusion, which was not just a general form of self-recognition as when seeing yourself in a mirror or on a video recording, by integrating visual and somatic stimuli (Petkova et al. 2011). It was proved that the multisensory integration process - producing the sense of corporeal self - operated in an egocentric frame of reference.

The main findings about establishing VBO were (nearly the same for creating the RHI):

- Temporal congruency of the visual and tactile signals applied in peripersonal space (within reaching distance).
- The virtual body has to have a humanoid shape.
- First person visual perspective is essential, that is why it is different from (Lenggenhager et al. 2007) where 3PP was used. However, it might be possible that the strength of the illusion in 3PP (Lenggenhager et al. 2007) was reduced due to a far distance of the intrapersonal space, since RHI states that the bodily part should be inside this space and the posture should match. This means that egocentric frame of reference is important for the establishment of the corporeal (bodily, somatic) sense of self.

For measurements questionnaires were involved. For creation the feeling of fear virtual knife was used to cut virtual belly of the avatar, and that is why it was possible to measure skin conductance responses. This illusion preserved spatial and temporal congruent principles (Petkova et al. 2011).

4.7.8 AGENCY

It was investigated here how voluntary actions (active, self-induced actions), like motor agency, influence participant´ s proprioceptive body awareness (the experience of where a specific body part is situated in space). It was tested using the RHI, where researchers identified three conditions:

- Tactile stimulation of one finger by using a paintbrush
- Passive movement of one finger. They used a string attached to a plastic ring, which was placed on the participant's finger.
- The participant moved one finger voluntarily (active movement).

They also included other factors such as synchronous and asynchronous display of the showed image (the image substituted for the actual *rubber* hand). In the asynchronous case, the image was delayed. There was a natural, small delay of 100ms in the synchronous case, which was not noticed by the participants. The delay in the asynchronous case was on 567ms.

The results showed that "*the sense of body ownership generated by voluntary action transfers well from one finger to another*" (Tsakiris, Longo, et al. 2010). EMG electrodes placed on the hand helped to measure if there was any muscle contractions involved.

It was concluded that even though one can feel BO, this sensation is often fragmented and is based on ownership of individual body parts, whereas agency gives a "*coherent sense of bodily self*" (Tsakiris, Longo, et al. 2010). This means that action is needed, in order to create unification of the sensation one has of the bodily self. Another study by Tsakiris et al. supported this result, as it showed that experiencing agency gave the participants more unified awareness of the body, and therefore gave more unified sensation of their body (Tsakiris, Longo, et al. 2010; Tsakiris et al. 2007).

4.7.9 THE BUILDING BLOCKS OF VBO

There were conducted some experiments, where participants saw themselves from the back (other cases front-chest) of their virtual body. Synchronous stroke of the participants' back triggered a sensation of "*seeing their own perceived body from a distance*". However, the true body being present from the front was perceived as an "empty shell" or a "disowned body" (Maselli and Slater 2013).

In a different experiment there was a manikin presented as a virtual body from a 1PP, which made it possible to elicit a feeling of artificial body ownership. Synchronous stroking proved positive results of inducing this illusion (Petkova and Ehrsson 2008).

When HMD was used in the experiment it was possible to conclude that the *field of view* influences the VBO illusion of a 3PP (mirror with both synchronous and asynchronous visuotactile stimulations). Petkova, on the other hand, in her experiment, used only a static field of view and could not achieve same results as Maselli and Slater, who used continuous dynamic field of view (Maselli and Slater 2013; Petkova and Ehrsson 2008). Furthermore, the virtual body in Maselli and Slater's experiment had a realistic human body appearance (skin texture and clothes), while Petkova used a plastic mannequin as they argued their case (Maselli and Slater 2013). As a result of these findings, Maselli and Slater proposed the building blocks of full body illusion that includes visual perspective, human-like body appearance, visuotactile stimulation and visual sensorimotor contingencies provided by an HMD with tracking and an updated field of view of the display in accordance with the tracking position, as in a physical reality of the world (Maselli and Slater 2013).

The following experiments were conducted:

- *Experiment 1:* It examined the effect of visuotactile and visual sensorimotor stimulation with possible interactions of each other, including synchronous vs. asynchronous visuotactile stimuli.
- *Experiment 2:* It attempted to account for a critical factor of a visual perspective (1PP vs. 3PP).
- *Experiment3:* It examined the level of realism and the influence of a real-looking human avatar vs. a plastic mannequin.

In total there were six conditions present and a between group 2x2 design adopted (Maselli and Slater 2013).

Touch was presented as mechanical vibrations through a haptic vest. It was implemented as a bouncing ball on the virtual body along a prerecorded path.

After each test, the participants answered a 6-point scale questionnaire. The choice of the even number of points on the Likert scale was used to get a forced answer on if the participants agreed or disagreed on a particular question, though considering the differences in the intensity of experienced sensation. "My body" was used to state VBO. "Clothing" item was also used to test the feeling of VBO. Maselli and Slater mean that wearing the same clothes as avatars ´ provides this feeling as a substitute factor.

Physiological factors:

In order to measure physiological factors, the participants were exposed to a continuous threat during the experiments. *Heart Rate Deceleration* (HRD) was in particular used to measure stress and anxiety levels, as it had been used before to measure psychological correlation of the full BO illusion. These feelings were presented by a continuous over time threat (separating legs from the body over time of 10 seconds). EEG signals were sampled at the rate of 256 Hz. GTech biological analysis was made by g.BSanalyze (Maselli and Slater 2013).

Results:

Experiment 1:

Multimodal contingencies: No significant differences between the 4 conditions with respect to the sensation of BO ("mybody"). Touch item detected a significant difference. Furthermore, asynchronous visuotactile feedback was simply perceived as being wrong. A head-tracking factor played a significant role. The participants had a desire to move in the environment, which indicated a sense of VBO. VBO turned to be an independent factor in both conditions. This means that the feeling of VBO depended neither on visuotactile nor on head tracking modes signals. HRD did not show any significant difference.

Experiment 2:

Perspective (mybody from 1PP and 3PP): mybody – significant difference as well as clothing. HRD – no significant difference.

Experiment 3:

Bodily Appearance: No significant difference was found between the two groups. Participant samples were expanded to 36 and a significant difference was found between the two groups despite asynchronous visuotactile stimulation and mannequin appearance (sense of VBO was present). HRD – no significant difference (probably to intrinsic HRD difference between participants).

Conclusion:

The main focus of the experiments was on visuotactile, visual (head-based) sensorimotor stimulation, visual perspective and body appearance. The findings were the following:

- 1st person perspective is crucial.
- Physical body should be moved synchronous with avatar using same gestures and posture. Due to that there is no need for head-based sensorimotor cues.
- Level of realism: skin texture and clothing strengthens the illusion of VBO.
- Multisensory and/or sensorimotor contingencies can influence the level of VBO.
- When a 1PP with realistic looking body is involved, asynchronous visuotactile cues might be perceived as correct.

However, if the degree of spatial overlap (between the real and virtual body) and/or of visual realism (of a fake body) is not high enough, congruent multisensory and sensorimotor cues are necessary to trigger the illusion (Maselli and Slater 2013).

4.7.10 QUALITATIVE AND QUANTITATIVE MEASUREMENTS OF THE OF SENSE OF EMBODIMENT (SOE) IN VR

It has been advised to measure SOE on a continuous scale from non- to a maximum degree, instead of “I felt vs. I did” with Yes and No answers, due to its subjectivity – the difference of the potential intensity of the BO sensation. The same continuous scale was also applied for the sense of self-location and agency. Unfortunately only little is known about the contribution of these components and their relationship between each other. Apart from splitting the components while measuring the SOE, it is possible to measure physiological, emotional and behavioral consequences, for example, the concept of self-presence (Biocca 1997), while researching Cyborg´s Dilemma, or, for example, alterations in the behavioral and emotional pattern towards a virtual representation of one´s self (Lee and Nass 2005). As Lee proposed: ‘‘*intense feelings of self presence during virtual experience … might create some types of identity or reality confusion*’’ (Lee and Nass 2005).

Self-Location Measurements:

Qualitative (questionnaires) and quantitative (motor and cognitive tasks performance, physiological responses) methods are used in measurements.

Agency Measurements:

Measurements of agency have not been addressed on the same level as self-location, due to concentration of interest on the body parts and VBO. RHI agency was measured only qualitatively.

Qualitative method involved questionnaire).

Quantitative methods used the following: measurements of proprioceptive drift of body part, estimation performance, reactions to a virtual body threat, physiological measurements during and without threat, measurements of the brain activity using the electrophysiological method, temporary brain function disruption to the illusion of VBO.

In order to enhance the SOE one needs to enhance the following three components separately:

1. *Self-location*: is influenced by visual, vestibular and tactile information, why a 1PP is also demanded. Synchronous visuotactile information is needed, where tactile events are seen visually from the 1PP. In general, varied multimodal feedback should be applied.

2. *Sense of agency*: sensitivity to any temporal discrepancies between self-generated movement and visual feedback that is why it should be avoided. Users' motion should be mapped to a virtual body in real-time. This can be done by either by tracking a rigid body with the help of markers attached to the body´s limbs and computing the avatar´s movements by inverse kinematics, or by tracking the full body movements with a real-time motion capture system and applying the resulting motion to the avatar.
3. *Sense of BO*: can be enhanced by increasing synchronous sensory correlation (visuotactile, or visuoproprioceptive) between the physical stimulation of the biological body and the seen stimulation on the avatar´s body. The avatar body should have a humanoid form, and it should resemble the user´s biological body, since this will also promote body resemblance and self-recognition (Kilteni, Groten, et al. 2012).

4.7.11 QUESTIONNAIRES USED BY RESEARCHERS IN THE VR EXPERIMENTS

Suggested questions to measure the sense of embodiment (see Figure 13):

One experiences SoE toward a body B,	if one feels *self-located* inside B at least in a minimal intensity (P1)
	if one feels to be an *agent* of B at least in a minimal intensity (P2)
	if one feels B as one's *own* body at least in a minimal intensity (P3)
	if and only if one experiences at least one of the three senses at least in a minimal intensity (P4)
One experiences full SoE toward a body B,	if one experiences all of the three senses at the maximum intensity (P5)

FIGURE 13 PROPOSITION FOR MEASURING SOE TOWARDS A BODY B **(KILTENI, GROTEN, ET AL. 2012)**

The following questions has been used to specify different parts of embodiment and VBO (see Figure 14):

Sense of self-location	• Questionnaire items; for example, "I experienced that I was located at some distance behind the visual image of myself, almost as if I was looking at someone else" (Ehrsson, 2007, p. 6) [supplemental material]. • Estimation of body position: ". . .passively displacing the blind-folded participants immediately after the stroking and asking them to return to their initial position. . ." (Lenggenhager et al., 2007, p. 1097) or ". . .imagine dropping the ball that they were holding in their hand (mental ball dropping task, MBD)." The participants ". . .were instructed to indicate with a first button press when they imagined releasing the ball from their hand and with a second button press when the ball would hit the ground. . ." (Lenggenhager et al., 2009, p. 112). • Physiological response in view of a threat toward the perceived self-location; for example, Skin Conductance Response (SCR; Ehrsson, 2007).
Sense of agency	• Questionnaire items; for example, "it seemed like I was in control of the rubber hand" (Longo et al., 2008, p. 984), "I felt as if I was controlling the movements of the rubber hand" (Kalckert & Ehrsson, 2012, p. 4).
Sense of body ownership	• Questionnaire items; for example, "I felt as if the rubber hand were my hand." (Botvinick & Cohen, 1998, p. 756), "I felt as if the virtual body was my body" (Aspell, Lenggenhager, & Blanke, 2009, p. 4), "How much did you feel that the seated girl's body was your body?" (Slater, Spanlang, Sanchez-Vives, et al., 2010, p. 4), "It seemed like the rubber hand belonged to me" (Longo et al., 2008, p. 983). • Proprioceptive estimations: through intermanual movements; for example, "both before and after the viewing period (. . .) with eyes closed, the right index finger was drawn along a straight edge below the table until it was judged to be in alignment with the index finger of the left hand" (Botvinick & Cohen, 1998, p. 756; IJsselsteijn et al., 2006), or verbal estimation, "Participants saw a ruler reflected on the mirror. (. . .) they verbally reported a number on the ruler" (Tsakiris & Haggard, 2005, p. 81). • Estimation of body parts' size; for example, participants "were told to adjust the virtual belly size until they perceived it to be the size of their own real belly" (Normand et al., 2011, p. 3). • Physiological responses to threat; for example, SCR (Armel & Ramachandran, 2003; Honma, Koyama, & Osada, 2009; Petkova & Ehrsson, 2008; Petkova et al., 2011; Yuan & Steed, 2010), Heart Rate Deceleration (Slater, Spanlang, Sanchez-Vives, et al., 2010). • Changes in physiological signals; for example, temperature (Hohwy & Paton, 2010; Moseley et al., 2008).

FIGURE 14 SOE MEASUREMENTS ON TERMS OF SUBCOMPONENTS **(KILTENI, GROTEN, ET AL. 2012)**

Questionnaire used in a virtual arm experiment (see Figure 15 and Figure 16):

1. Sometimes I had the feeling that I was receiving the hits in the location of the virtual arm.
2. During the experiment there were moments in which it seemed as if what I was feeling was caused by the yellow ball that I was seeing on the screen.
3. During the experiment there were moments in which I felt as if the virtual arm was my own arm.

Each question was rated by the participants using a 7-point Likert scale, with 1 meaning 'totally disagree' and 7 'totally agree'.

FIGURE 15 INDICATION TOWARDS THE VIRTUAL ARM ILLUSION **(SLATER ET AL. 2009)**

1. I sometimes felt as if my hand was located where I saw the virtual hand to be.
2. Sometimes I felt that the virtual arm was my own arm.

FIGURE 16 ANOTHER INDICATION TOWARDS THE VIRTUAL ARM ILLUSION **(SLATER ET AL. 2009)**

Questions to measure the strength of VBO illusion (see Figure 17):

Variable name	Item	Statement category
Mybody	I felt that the body I saw was my body	Ownership
Clothing	I felt that I was wearing different clothing to my real clothing	Ownership
Stress	I was stressed when I saw the legs coming apart	Psychophysical reaction
Discomfort	I felt physical discomfort when the legs were coming apart	Psychophysical reaction
Catch	I wanted to try to catch the yellow ball	Interaction in VR
Touch	It seemed as though the touch I felt was caused by the yellow ball touching my body	Implementation
Twobodies	I felt that I had two bodies	Control

FIGURE 17 7-POINT LIKERT SCALE FOR ACCESSING THE LEVEL OF QUALITY OF THE ILLUSION **(MASELLI AND SLATER 2013)**

Questionnaire used in RHI experiment (see Figure 18):

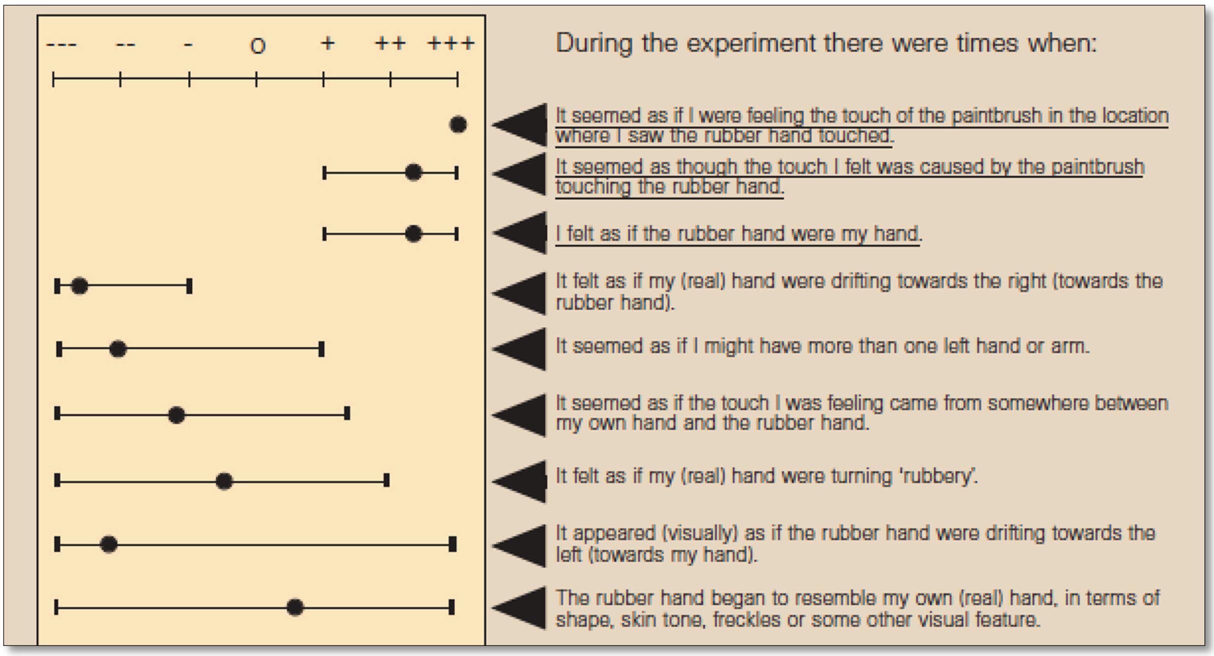

FIGURE 18 RHI EXPERIMENT - QUESTIONNAIRE AND RESULTS **(BOTVINICK AND COHEN 1998)**

4.8 PHYSICS OF FLIGHT

When bats fly they have a full controlled movement or agency over the body. They can precisely navigate in the environment, as was discussed in section 4.1. Since bat´s flight is a biological locomotion, it is very important to understand the main aerodynamic laws (also from the future development point of view), before coming onto the biological locomotion of flight, since it has its own specifics, which will be also described at the end of this section. There are 3 main aerodynamic principals that are used, when constructing a realistic flying algorithm: Newton´s laws, Bernoulli gas equation and Kutta – Joukowski theorem, which will be described without any specific details in this section.

Since the principles of aerodynamic are the same for all flying objects it is essential to understand the main principles of carrying capacity – the weight wings support. The forces influencing on the body and its wings (depending on its geometrical and material characteristics) are keeping it in the air.

Flying capacity takes into consideration the following variables:

- Wing size,
- Airspeed,
- Air density,
- The angle of the attack[15], depending on the flight direction.

According to the physical laws these variables (shown in the Figure 19), combined together as unified force acting on a flying body are:

1. **Gravity** (weight) is the force of gravity. It acts toward the center of the Earth.
2. **Lift** is the force that acts at a right angle to the direction of motion through the air. Lift is created by differences in air pressure.
3. **Thrust** is the force that propels a flying machine in the direction of motion. Engines produce thrust, if airplanes are considered.
4. **Drag** is the force that acts opposite to the direction of motion. Drag is caused by friction and differences in air pressure (NASA Official 2015).

[15] The angle between the oncoming air and the reference line on the wing (Boeing.com n.d.)

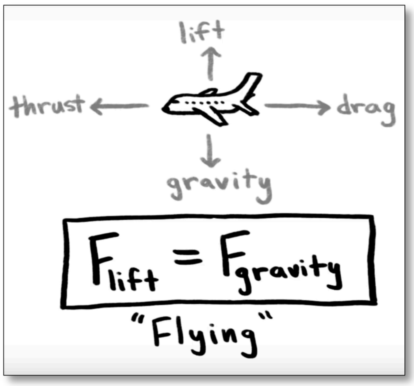

FIGURE 19 PHYSICAL FORCES ON A FLYING BODY (MINUTEPHYSICS 2015)

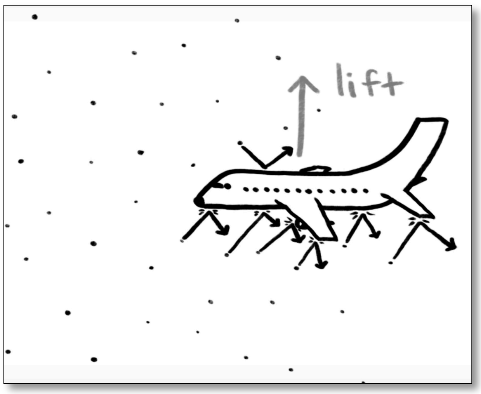

FIGURE 20 AIRSPEED AROUND A FLYING BODY

As shown in the Figure 20, the airspeed over the top wing has to be faster than below the wing, and respectfully the air pressure on top will be lower than at the bottom. Air molecules moving chaotically in the environment "support" and "direct" the flying object depending on its position.

Newton´s Second and Third Laws of physics explain the main principals of aerodynamics. When applied to wings they explain that a wing produces the amount of lift that is equal to the downward impulse given to the surrounded air (Third Law (Fitzpatrick 2011)[16]), while force equals rate of change of momentum, which is computed as mass flow times speed change (Second Law of Motion (Fitzpatrick 2011)[17]).

Aerodynamics includes general laws of motion of the gas (mostly air) as well as interaction between gas and moving bodies in this medium. Therefore the main parameters, characterizing air is:

- Temperature,
- Density,
- Pressure.

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[16] Newton´s Third Law: ***"For every action, there is an equal and opposite reaction."*** **F=-F**

[17] Newton´s Second Law: "*The acceleration of an object as produced by a net force (an unbalanced force, or* the vector sum of all forces acting on an object*) is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object*." $a = F_{net} / m$ →

$F_{net} = m \bullet a$, **or** $F = dp/dt = d(mv)/dt$, meaning that **F** = the rate of change (that is, the *derivative*) of its linear momentum **p** in an inertial reference frame.

A unity of force is measured in **1 Newton = 1 kg • m/s²**

The standard or normal atmosphere for a 0 level is considered to be a mean of a sea level. If Gravity is neglected it could be assumed that air movement occurs in a horizontal plane, which means that potential energy of air mass does not change (Atmosphere 2000). The factors that might be necessary for flight calculations are presented in Figure 21.

Height in m	Air Pressure	Temperature in C°	Weight Density	Mass Density
—1000	854,6	+21,50	1,3476	0,1374
— 500	806,2	18,25	1,2854	0,1311
0	760,0	15,00	1,2250	0,1250
500	715,9	11,75	1,1677	0,1191
1000	674,1	8,50	1,1110	0,1134
1500	634,2	5,25	1,0580	0,1079
2000	596,1	2,00	1,0060	0,1027
2500	560,0	— 1,25	0,9567	0,0976
3000	525,7	— 4,50	0,9093	0,0927
3500	493,1	— 7,75	0,8630	0,0881
4000	462,2	—11,00	0,8193	0,0836
4500	432,8	—14,25	0.7766	0,0792
5000	405,0	—17,50	0,7362	0,0751

FIGURE 21 AIR FACTS (ATMOSPHERE 2000).

Bats can only fly at the lowest layer of atmosphere[18] - in troposphere[19], since a flying-fox for example (the largest bat), can fly up to 3.048 km high (Parsons et al. 2008).

Air Pressure - is the force per unit area perpendicular to it. The fact of atmospheric pressure could be explained due to the air, like all the other substances, has a weight and is attracted to the ground by gravitation. It is measured in $P = N/m^2$ (Atmosphere 2000).

Air Density – is the ammount of air contained in the volume of $1m^3$. It is decided that at the standard atmospheric conditions 1 m^3 = 1.225 $\frac{kg*sec}{m^3}$ (air weight), but density = 0.1250 $\frac{kg*cm^2}{m^{43}}$ (Atmosphere 2000).

The mechanical effect of the upcoming airflow is distributed over the surface of the body. Aerodynamic force $\underset{R_A}{\rightarrow}$ and Moment $\underset{M}{\rightarrow}$ are applied to the Center of Mass (COM) of the flying body, as shown in the Figure 22, under the pressure of incoing airflow (Atmosphere 2000).

All the forces and Moments are vector units, since they represent changes of the position of the body in space under the applied forces. Momentum is applied as soon as the body changes its position in the space.

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[18] The layer of gases surrounding the Earth

[19] It varies between 16.18 km at the equator and 7-8 km at the poles. The temperature at the troposphere falls each 1000 m with 6.5° (Atmosphere 2000).

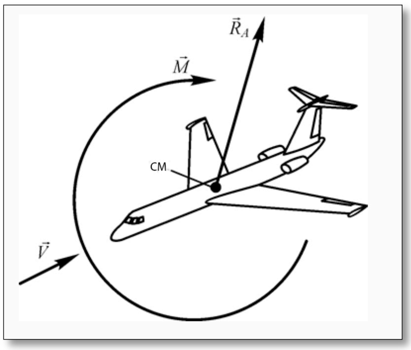

FIGURE 22 AERODYNAMIC FORCE AND TORQUE, RETRIEVED FROM: HTTP://LEKTSII.ORG/1-15929.HTML

The main **Aerodynamic force equation** is the following:

$$R_A = C_R \frac{pV^2}{2} S$$

C_R - is coefficient of proportionality and is called the coefficient of aerodynamic forces.

$\frac{pV^2}{2}$ - is the oncoming air flow velocity, where p - is air density (depends on the height of the air in the atmosphere).

S - is the surface area of the body (Atmosphere 2000).

Bats alter their kinematics and wing morphology across flight speeds in order to generate enough weight support and thrust (Von Busse et al. 2012). As was described in 4.8 larger animals should fly faster than smaller ones in order to generate lift required to fly.

Since wings generate lift due to the flow of air over the wing surface, larger wings with low wingload would have more lift at any given speed (Von Busse et al. 2012).

This means that the airflow around the wing is the following: the mass flow is proportional to the air density ρ *(kg/m^3)*, the wing area *S (plan surface from above in m^2)* and the airspeed *V (speed m/s)*. This means that mass flow is *ρVS* = kg/s, which comes directly from Bernoulli gas equation[20]: where $\frac{pV^2}{2}$ is **dynamic pressure** or *thrust*.

Airspeed leaving the bottom of the wing is proportional to the flight speed *V* and the angle of attack of the wing α (Tennekes 2011).

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[20] https://www.princeton.edu/~asmits/Bicycle_web/Bernoulli.html

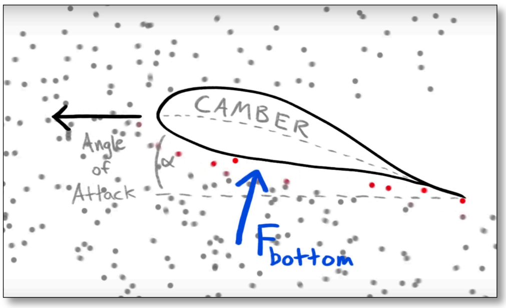

FIGURE 23 ANGLE OF THE ATTACK (MINUTEPHYSICS 2015)

The feeling of the angle attack, presented in the Figure 23, can be experienced, when driving a car and sticking the hand out of the window. If the wrist is not involved one might feel only air resistance, but as soon as you turn your wrist it is where aerodynamic lift is generated, since the hand might want to move up or down in regards to the angle of the wrist. Increasing the angle of the hand generates more resistance though loses lift.

The same principle can be applied to a flying object – as soon as the critical angle of the attack of the wings reaches 15°, as shown in Figure 24, the airflow on the top surface is disrupted, which means that the lift decreases and is not proportional anymore to the angle of the attack. At the same time drag increases and the bird can go down like a brick (Tennekes 2011).

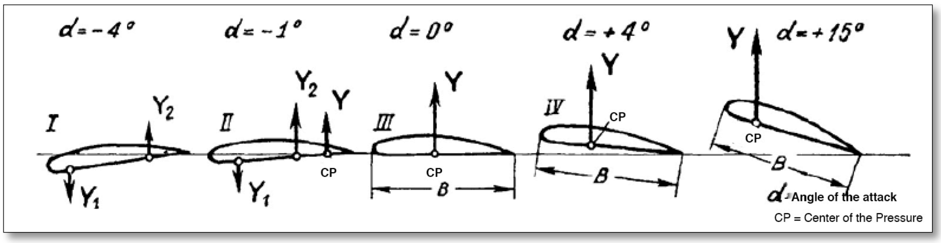

FIGURE 24 THE ANGLE OF THE ATTACK AND THE CENTER OF THE AIR PRESSURE (ATMOSPHERE 2000)

The Lift on a wing is proportional to $\alpha\rho V^2 S$, where V^2 is the square of the airspeed. This means that the airspeed influences lift.

For example, in order to obtain lift a bird needs to fly faster with the same angle of the attack, but it will reduce the angle of the attack if it needs to support its weight, since lift L should be equal to weight W, since the wings have to support the weight against Gravitation[21]. When birds need to fly slowly or make a sharp turn they fly with the high angle of the attack, and

[21] Gravitational force is proportional only to the mass of an object, not weight, which is a downward force, while mass is an amount only. Though here weight is considered, not mass (Tennekes 2011).

with low angle of the attack when they speed or dive. For a fly long distances they use the same angle of the attack, which is 6° in average (Tennekes 2011).

Drag and lift can be presented through the following **equations**, where ρ (air density) could be replaced with sea-level value = 1.25 kg/m^3, which is true to most of the bats that fly close to the ground, ***V*** = forward Velocity of the wing, ***S*** = wing area, $\boldsymbol{C_d}$ and $\boldsymbol{C_l}$ are the coefficients of drag and lift (that are between 1 and 3), that indicate a capacity of the wing at a given angle of incidence to generate drag and lift. Lift is the sum of weight/Gravity and Thrust in order to overcome Drag. That is why at high speeds Thrust increases a lot, while Drag increases at low speeds. In general with speed increase Thrust and Drag increase exponentially. (Swartz et al. 2012; Tennekes 2011):

$$\text{Drag: } \boldsymbol{D = 0.5pV^2SC_d}$$

$$\text{Lift: } \boldsymbol{L = 0.5pV^2SC_l}$$

Lift ($\boldsymbol{C_l}$) and ($\boldsymbol{C_d}$) coefficients can be calculated both theoretically and experimentally (Tennekes 2011). Thus according to Kutta – Joukowski theorem[22], for a plane-parallel flow of the wing at small angles of the attack, **Lift Coefficient** ($\boldsymbol{C_l}$) could be calculated through the following equation:

$$\boldsymbol{C_l = 2m(a - a_0)}$$

From this equation on could see that $\boldsymbol{a}$ - is an attack angle (the angle between the flow velocity and the chord of the wing), $\boldsymbol{a_0}$ - the angle of zero lift, $\boldsymbol{m}$ - is the coefficient, depending on the shape of the wing profile, such as a slight thin curved plate $m = p$ (Atmosphere 2000).

[22] *Kutta – Joukowski theorem* is the fundamental theorem in aerodynamics and could also be used for calculating the lift force of an airfoil, where lift generated by airfoil, relates to the speed (V) of the airfoil through fluid, the airdensity (p) of this fluid and the circulation (Γ)[22]. Γ is the Lift (L) per unit span of airfoil.

Lift Equation (from *Kutta – Joukowski theorem*[22]):

$$\boldsymbol{L = -pV\Gamma}$$

p - is the fluid density, V - is the fluid velocity and Γ - is the anticlockwise positive circulation defined by line integral the following way:

$$\boldsymbol{\Gamma = \int c\,V\,ds = \int c\ V\,cos\phi\,ds}$$

$\int c$ - is the line integral (the integral, where the integrated function is evaluated along the curve), c there – is a closed contour, $V\ cos\phi$ - local fluid velocity into the direction of tangent to the curve c, while ds - is length of the curve.

Thrust Force (T) is another mechanical force, generated through the reaction of accelerating gas mass to the rear, which allows the engine and the aircraft to accelerate to the opposite direction, as described by Newton´s third law of motion. In other words thrust is the amount needed to accelerate 1 kg of mass at the rate of 1 $\frac{m}{s^2}$.

$$\boldsymbol{T = V\frac{dm}{dt}}$$

Where $\frac{dm}{dt}$ - is a rate of change of mass with respect to time, V - is speed of the gasses. Thrust depends only on the velocity change across the engine[23](Atmosphere 2000).

Thrust is produced only when bat starts flapping the wings (Swartz et al. 2012).

4.9 BAT´S FLYING LOCOMOTION

As was described in section 4.8, body size and shape influences locomotion. The same should be applied for locomotor kinematics[24]. It had been assumed that bats use similar mechanisms as aerodynamic force production of flight regardless of their size, even though their mass size varies between 0.002 kg to 1.2 kg (Riskin et al. 2010), although that is not the case.

Bat has a wing shape, which is an ideal airfoil, as shown in the Figure 7. Due to the specifics of airfoil's convex upper surface it creates the area of a low pressure above the wing and high pressure below, basically a net aerodynamic force (NAF, shown in Figure 29) that raises the wing. When a bat is flying forward NAF has two components – a vertical lift (to overcome gravity) and thrust component to overcome drag (as wings and body resist forward movement), which is around 20-30 % of the lift. Wings move forwards and downwards relative to the airflow, due to lift acting at right angles to the movement of the wings (Altringham 2011).

Vortex wake theory explains bat´s flight technique: The camber (shown in Figure 25) of the wing increases the velocity of airflow over it, also pushes the air downwards and induces rotational flow around the wing and behind it (bound and trailing vortexes). At the start of the down stroke the wing motion sets up the starting vortex at the edge, which induces air rotation around the wing. This is called a bound vortex or circulation. At the down stroke a trailing vortex is formed at each wind tip, due to rotated air.

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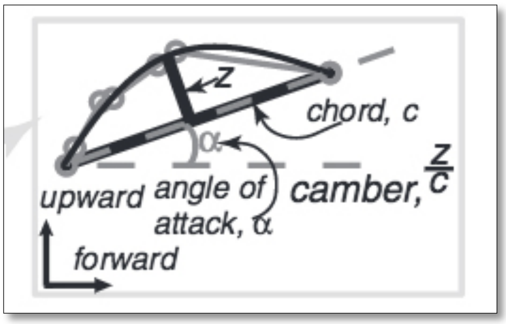
[23] http://lektsii.org/1-15936.html

[24] *Kinematics* (the branch of mechanics) describes motion of points, bodies and system of bodies as groups of objects. It does not take into consideration forces influencing on these bodies. It is used in biomechanics, robotics, etc. to describe rigid transformations through mathematical functions. *Kinetics,* on the other hand, describes motion of bodies and the cause of that motion, such as forces and torques.



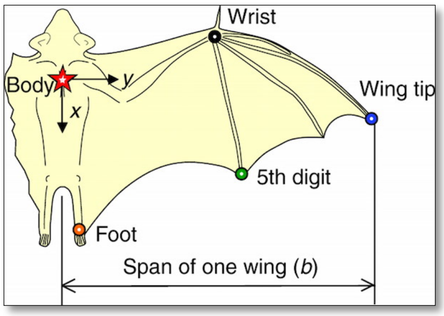


FIGURE 25 ANGLE OF THE ATTACK **(SWARTZ ET AL. 2012)** FIGURE 26 WINGSPAN **(HUBEL ET AL. 2010)**

Lift acts at right angles to the direction of wing movements. It is proportional to the wingspan[25] (shown in Figure 26), movement speed and to the circulation of the bound vortex, which is determined by the angle of the attack. A down stroke will provide weight support and forward thrust, can be seen in the Figure 8. Drag has an impact on kinematics, since it depends on the flying speed and wing (Altringham 2011).

Lift (C_l) and **Drag** (C_d) **Coefficients** are non-dimensional constants with the range of values between 0.1 and 3.0. The exact value is determined by the shape and motion of the wing. A highly streamlined wing would have a high lift coefficient, which could be calculated through the Joukowski equation, described in section 38**,** and low drag coefficient. But less streamlined wing would have a lower lift coefficient and higher drag coefficient (Swartz et al. 2012).

If bat wants to increase lift coefficient (C_l) it increases the angle of the attack, creates a larger edge vortices as it also creates high camber of the wing (Von Busse et al. 2012).

The angle of the attack at low speed is 50° (without loosing lift) and at high speed is 10° during downstroke. This decreases during upstroke until midstroke, such as for low speeds -70° and for high speeds -10°. For hovering flight (V=0) the highest value of the angle of the attack reaches 80° to -60° (Von Busse et al. 2012).

By stalling[26] their wings they achieve a great momentary lift increase, which gives them a possibility of making sharp turns during the flight (Von Busse et al. 2012).

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[25] If the wingspan (distance between 2 wingtips of the fully outstretched wings, as shown in the Figure 26) is b, the wing area is proportional to b^2 and the weight is proportional to b^3(Tennekes 2011).

[26] Stall - reduction of the Lift coefficient generated by foil, when increasing angle of the attack due to decrease of speed, for example.

There has been published several findings about bat´s ability to fly. These facts should be considered, when creating a virtual flight, as well as some important facts for calculations of bats´ morphometrics, presented in Figure 27 and Figure 28:

With *increase of flight velocity* there was also

- Decrease of maximum wingspan,
- Increased wingbeat period (the time to complete wingbeat cycle),
- Decrease angle of the attack (the angle of the wing chord relative to the incoming air flow)
- Decrease lift coefficient (Riskin et al. 2010).

Vertical and horizontal Acceleration ($A_{vert/hor}$) was presented as the change in forward velocity between a beginning of the wing beat cycle and the end of the wingbeat cycle, divided by the duration of the wingbeat cycle.

$$\boldsymbol{A} = \frac{\Delta \boldsymbol{V}}{\Delta \boldsymbol{T}}$$

Where $\boldsymbol{A}$ is acceleration, $\Delta \boldsymbol{V}$ is the difference between final velocity and the start velocity ($V_{final} - V_{start}$); $\Delta \boldsymbol{T}$ is the time duration of wingbeat cycle (Riskin et al. 2010). Net (see Figure 29) horizontal acceleration depends on Thrust, Acceleration and Drag all together (Swartz et al. 2012).

Measure	Symbol	Units	Bat M (male)	Bat F (female)
Mean body mass	m	g	21.6	23.0
Forearm length		cm	5.03	5.10
Span	$2b$	cm	33.5	32.3
Wing area	S	cm^2	157.6	152.9
Mean chord	c	cm	4.7	4.7
Aspect ratio	AR		7.1	6.8
Wing loading	Q	N/m^2	13.4	14.7

FIGURE 27 FRUIT-NECTAR BATS´ MORPHOMETRIC DATA **(VON BUSSE ET AL. 2012)**

Species	M (g)	B (cm)	S (cm^2)	ar	M_g/S (N/m^2)	TI
Pteropus vampyrus	**1180**	**130**	**2000**	8.4	**57.8**	1.30
Rousettus aegyptiacus	140	57	558	5.9	24.6	1.08
Cynopterus sphinx	41	41	258	6.7	15.6	1.50
Rhinopoma hardwickei	16	28	114	6.9	14.0	**0.89**
Saccopteryx bilineata	7	27	125	6.1	5.9	1.29
Taphozous kachhensis	50	46	219	9.5	22.4	1.41
Craseonycteris thongl.	**2**	**16**	**36**	7.1	5.2	1.07
Nycteris thebaica	1	31	171	5.5	6.3	1.57
Megaderma lyra	38	44	312	6.2	11.8	1.70
Rhinolophus ferrumequinum	23	33	182	6.1	12.2	1.22
Hipposideros bicolor	6	25	100	6.2	6.1	1.00
Hipposideros speoris	11	28	121	6.5	8.9	0.97
Noctilio leporinus	59	58	380	9.0	15.2	1.55
Pteronotus suapurensis	8	30	110	8.0	7.3	1.06
Phyllostomus hastatus	107	56	417	7.6	25.2	1.63
Phyllostomus discolor	42	42	262	6.6	15.8	1.33

FIGURE 28 BATS´ MORPHOMETRIC DATA, RETRIEVED FROM: (NEUWEILER 2000)

The leading edge vortex is a primary mechanism for generating force, as was mentioned before, and it is presented in all flapping flights among insects, birds, bats, etc. Usually, it forms on the downstroke and due to the angle of the wing it produces lift vertically and thrust in the direction of flight. The same way as thrust - drag is presented throughout the wingbeat cycle and zero acceleration of the center of mass in the direction of flight indicate that thrust equals drag (Iriarte-Diaz et al. 2011). During a forward and steady flight the average lift over the course of wingbeat must be equal the body weight and average thrust must be equal drag. Drag and Thrust are both parallel to the flight direction, while Lift is perpendicular, as shown in the Figure 29.

Since we are considering bat and not an airplane it is possible to compute thrust the following way (also taking Newton´s third law of motion into consideration):

$$\boldsymbol{Thrust} = -\boldsymbol{Drag}$$

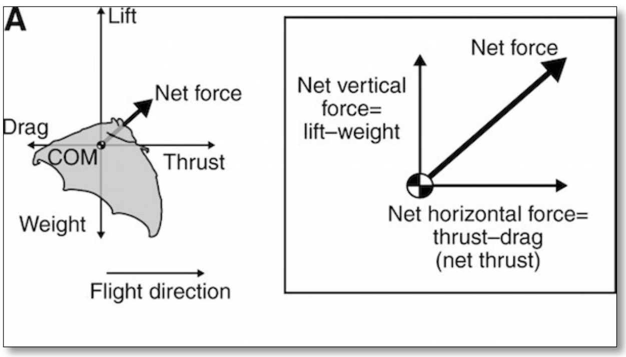

FIGURE 29 FORCES INFLUENCING BAT´S FLIGHT **(IRIARTE-DIAZ ET AL. 2011)**

When summing all forces of the wingbeat cycle up, it is possible to say that horizontally directed net force is the sum of thrust and drag, while vertically it is lift (Iriarte-Diaz et al. 2011).

4.9.1.1 CONCLUSION ON PHYSICS OF FLIGHT

Since agency should be understood as movement of the body it was important to investigate both motion and forces influencing the body during locomotion of flight.

The main flight goal is to minimize Gravitational force during the upstroke and maximize air-displacement during the downstroke.

If all 4 forces (Gravity, Thrust, Drag, Lift) are balanced than the object stays in the air, which could be characterized through temperature, density and pressure.

Furthermore the angle of the attack controls the Lift[27].

Bats wingbeat cycle could be roughly divided into:

- *Downstroke*, when the wing goes down it opens in the joint similar to an umbrella principle and creates the following:
  1. Surface of the wing (S) becomes bigger
  2. It resists the forward movement, meaning that Drag increases, but Thrust decreases
  3. A highly streamlined wing would have a high lift coefficient and low drag coefficient
  4. - Angle of the attack at low speed is 50° (without loosing lift)
     - Angle of the attack at high speed is 10° (without loosing lift)
- *Upstroke*, when the wing goes up, it bents at the joint.
  All bats produce an inversed vortex, indicative of thrust and the production of negative lift, at the end of the upstroke
  1. Surface of the wing (S) becomes smaller
  2. Lift increases
  3. Thrust increases, but Drag decreases
  4. A less streamlined wing would have a lower lift coefficient and higher drag coefficient
  5. - Angle of the attack at low speed is -70° (without loosing lift)
     - Angle of the attack at high speed is -10° (without loosing lift)

[27] It can also and influence stall (reduction of the Lift coefficient generated by foil, when increasing angle of the attack due to decrease of speed, for example).

For hovering flight the highest value of the angle of the attack reaches 80° to -60°.

In general, during the flight, wings produce thrust while the whole body produces drag.

Furthermore during linear horizontal movement Thrust almost equals Drag Force (with slight difference in coefficients).

With *increase of flight velocity*:

- Maximum wingspan decreases,
- Wingbeat period increases (the time to complete wingbeat cycle),
- Angle of the attack decreases (the angle of the wing chord relative to the incoming air flow)
- Lift Coefficient decreases

Bat do accelerate their flight by a change in forward velocity between the beginning of the wing beat cycle and the end of the wingbeat cycle, divided by the duration of the wingbeat cycle.

With the help of stalling (reducing C_l by increasing attack angle due to speed reduction) their wings bats achieve a great momentary lift increase, which gives them a possibility of making sharp turns during the flight.

4.10 INTERACTIVE GESTURAL INPUTS

The biggest advantage of using gestural input for generating flying experience is to involve multisensoral integration of visual, proprioceptive, (visuo) vestibular and audio inputs from the body. These inputs would help users to orient themselves in the virtual environment. At the same time applying biologically correct flying algorithm, bats are using in nature, might provide more realism. Due to the fact that there has been no known research done on the input gestures for controlling the bat´s flight in IVE, I will come up with my own suggestions underneath.

There is a possibility that vestibular system might react to visual input and cause cybersickness during the virtual flight due to both the system´s to latency, described in section 4.4, and multisensory integration conflict between human visual and vestibular systems. This discrepancy might cause spatial disorientation and imbalance, since visual cortex (together with audio) is responding to vestibular inputs. Body motion perception comes from vestibular system and vision, which means that the brain uses visual motion information to estimate a better self-motion (Wolfe et al. 2008). When generating virtual flight speed (the speed of optic flow) at a certain height relative to the objects in IVE, it is unknown how physical body of a non-trained participant might react to flying experience. When, for example, astronauts are trained for a special spaceflight programs, they have a trained vestibular system due to specifics of such programs.

If we take into consideration “Birdly”, developed by Somniaco.co, described at the end of chapter 3 users would still have a stable platform to lay on, even though it is slightly going up and down, depending on the flight direction, which would produce some sensation of security and connection to the real physical world. In my case the participants would need to stand on their feet vertically, but navigate with virtual bat, which would fly horizontally. This might influence their balance system and cause positional changes in physical world. However, for full understanding of this problem, tests should be conducted.

In order to keep participants safety in order in physical world, only hand gestures should be involved into mapping for this project. There feet would work as an anchor to the physical world.

4.10.1 SUGGESTED POSITIONS FOR TESTING VBO

In order to test only the perception of the virtual body in IVE controlled movements, belonging to agency should be excluded, meaning that test participants should not be able to move at all, therefore no gestural inputs are proposed. However correlated visual and tactile inputs still induce body ownership over another object (RHI), when movements are absent (Tsakiris et al. 2006), if this object has the same morphology as the human body or its limb, which is not the case here. Therefor at least it might be useful to match both body positions and locations – physical and virtual.

Since in nature bats can be in vertical position when they hang upside down this is unacceptable for the experiment and therefore horizontal position should be considered. Sitting on the chair for example might also cause visual discrepancies, if virtual bat would be placed horizontally. If virtual bat would not be flying and neither would take vertical position (as it might be perceived unnaturally) participants should be placed also horizontally, for example on the floor, as the virtual bat would be. Finally placing participants on the floor might give them more stability and restrict body movements, if they would be asked to place their arms on a specific spot and not move.

4.10.2 SUGGESTED GESTURES FOR TESTING AGENCY (LIMB MOVEMENT)

According to the described theory in section 4.6.2.2 the sense of body ownership could be generated by active movements. Based on this theory and taking into consideration that controlled movements might be spitted into the movements of the body limbs and the movements of the whole body through the environment using limbs suggested gestures should also be different, depending on the virtual limb control, staying in place, or virtual movement control by flying through the virtual environment.

In order to test if participants might obtain VBO illusion over a virtual bat´s body it is suggested to apply one of the two simple movements, with possibility to involve visuotactile feedback and a body threat, as was described in 4.7.1:

- Moving the arm up and down could activate the whole wing movement, as shown in Figure 30.

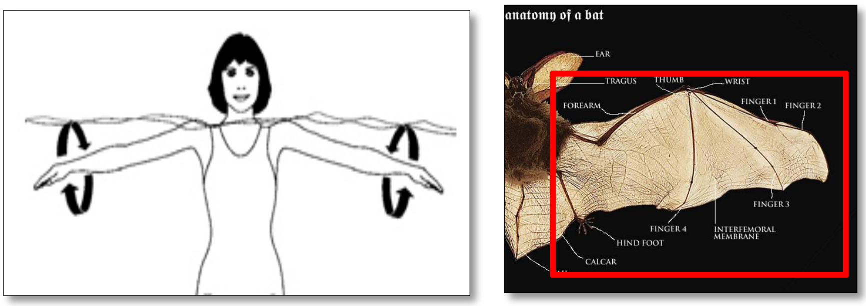

FIGURE 30 ARM MOVEMENT

- Moving the wrist up and down could activate only bones with membrane attached to it - only bat´s "wrist", as shown in Figure 31

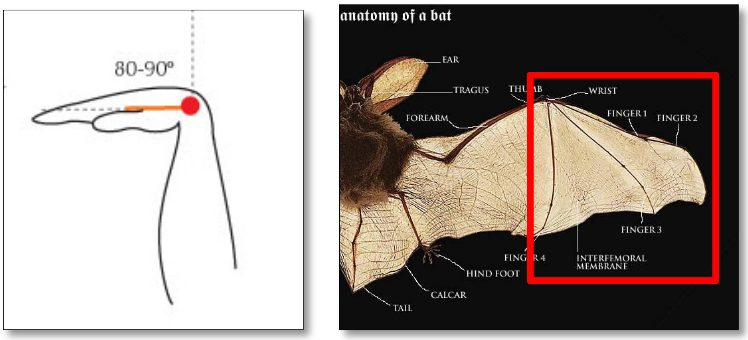

FIGURE 31 WRIST MOVEMENT

In this case scenario visuomotor correlation would play another important role in causing body awareness, as described before. If visual feedback on the display would be fully correlated with the movements of the biological body (arms and wrists) and the virtual wings, virtual wings might be accepted as belonging to them.

Taking into consideration that gestural control of the whole virtual body would be the best for producing agency, but also delimiting controlled movements to only virtual wings would allow to use the two described gestures in order to see if control of the virtual wings might trigger the sense of body awareness even using a different anatomy for the virtual avatar.

4.10.3 SUGGESTED GESTURES FOR TESTING AGENCY (NAVIGATION THROUGH THE ENVIRONMENT)

Controlling body movement through the environment includes several things. First of all it might be difficult to visually control the limbs during the flight as attention might be consecrated on navigation and environment. Second of all it should be taken into consideration that asynchronicity of active movements might consequentially lead to cheating perceptual system and perceiving them as more synchronous than they really are, as described in section 4.6.2.2. This might give us a possibility to adapt some gestural similarity to the bats´ flying locomotion and control the flight through the environment almost as bats would do.

When discussing gestural inputs that might help navigating through the environment, it is necessary to take into consideration the most natural movements people are doing when replicating the bird´s or bat´s flying in nature.

1. The first suggested movement is moving hands up and down, replicating bird´s wingbeat cycle (section 4.9), as shown in the Figure 32.

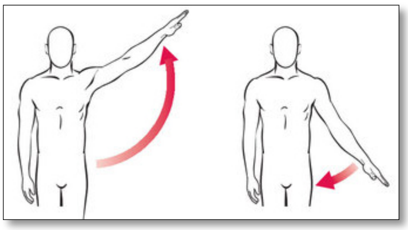

FIGURE 32 HAND MOVEMENTS UP AND DOWN (HTTP://UK.ASKMEN.COM/ U.D.)

2. The second suggested movement reminds swimming, which would be closest to bat´s wingbeat cycle described in section 4.2, as shown in Figure 33. Hands should be on the sides (as a starting position), and then moving them to the front of body´s egocentric coordinates and from this position to continue up above the head.

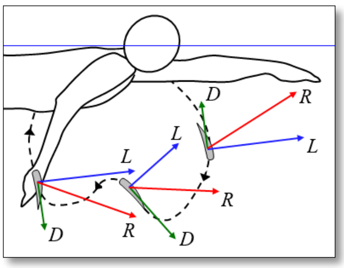

FIGURE 33 HAND MOVEMENT WHEN SWIMMING (BLAHA 2009)

3. The third suggestion is the movements of the wrists only up and down in front or on the sides, as shown in the Figure 34. This movement would save participants´ energy,

which is not the case for the first two described movements and thereby users might be able to do this movement for a longer period of time.

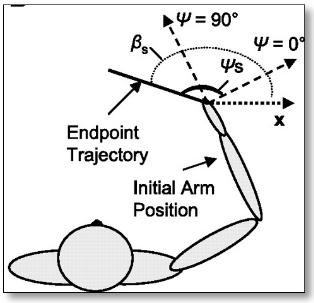

FIGURE 34 WRIST ROTATION **(DOUNSKAIA, GOBLE, AND WANG 2011)**

4. And the last one is to control the flight with the body, using waist for direction and flight altitude.

In order to give participants more proprioceptive feedback and taking into consideration that the most common gesture replicating bats would be suggestion 1 – moving hands up and down, even though it is energetic costly this gesture would be used for navigation through the virtual environment.

4.11 CONCLUSION ON THE ANALYSIS

The main purpose of VR is to create realistic experience in the virtual world, despite the users´ knowledge of its artificial origin, where it is possible to act, react and even have impact on it by changes or alterations of the virtual world. Interaction with this world foresees a number of certain rules when building the VR system. It is equipment consideration, integration of multisensory information, level of realism, users´ point of view, spatial and temporal synchronicity of visuotactile stimulations and visuomotor correlations.

All these points described in this chapter were applied for a humanoid avatar, since the researchers mean that it is the best suitable way to get representation of oneself in IVE. It has been argued to what extent it is possible to alter morphological shape and look of physical body representation in VR.

According to the literature reviewed in this chapter under the section 4.7.9 the main building blocks for VBO are the following and should be taken into consideration when working with humanly-shaped avatar and it´s movements:

- 1st person perspective illusion.
- Synchronicity (both temporal and spatial) should be preserved. Although spatial

synchronicity might be altered, but not too obvious for the users. Asynchronous visuotactile cues might be perceived as correct if the 1PP is applied with realistic looking body (this was tested only on a humanoid avatar).

- Level of realism strengthens the illusion, including realistic skin texture.
- Multisensory and/or sensorimotor contingencies might influence the level of VBO.

Unfortunately there are differences in terminology concerning agency and body ownership. In psychology and psychophysics body awareness or embodiment consists of BO and Agency. However in VR field the concept of embodiment is rarely used, but is replaced by the concept of VBO (illusion) and therefore agency has not been paid deserved attention to, but rather has been substituted by visuomotor correlation term instead, while VBO is characterized by visuotactile information and visuomotor correlation.

Agency is accompanying body ownership and as discussed in section 4.6.2.2 it might shape BO, which might mean that in VR agency might be the main contributing factor for creating VBO illusion, though it is still unknown, as in real reality agency and BO work together.

It is also questionable if agency might be enhanced. If free will should be taken into consideration then restricted movements might not be considered as full agency. Therefore the 1st order system, mention in section 4.3, might be the best possible solution full interaction with IVE.

Nonetheless realistic bat movements and physics of flight were explored. This was done with the purpose of providing participants interactive experience and IVE and researching which senses should be primary incorporated into the system. Albeit bats´ flying gate was investigated, there are still some questions even among the researchers how high do some bat species fly or what are the exact amounts of coefficients used by bats at a specific height during a specific speed, etc. However these coefficients might be found through repetitive tastings in VR application.

4.12 FINAL PROBLEM STATEMENT

It has been postulated that VBO obeys structural and morphological constrains, like similarity, and might be susceptible to individual differences. But would it be possible to reach VBO illusion only with the help of visuotactile input and only slightly similar anatomy that bats have (with humans) and if the illusion would be strong enough to get the feeling of ownership over the virtual bat´s body?

However, involving proprioceptive and visual senses might make it possible to obtain VBO illusion over a virtual bat´s body, as was discussed in section 4.6.2. Though would a controlled but slightly asynchronous mapping of the correct bat´s locomotion movement to participant flying gesture give the illusion of correct synchronicity and allow achieving a strong illusion of VBO or it would be perceived still as asynchronous and break the sense of presence in IVE? An if we go further, there also might be interesting to see if agency of limb movements might be perceived the same as agency of the flying locomotion through virtual environment.

It might also be worth testing if agency might structure VBO or if agency might even enhance VBO illusion in Immersive Virtual Reality. Even if theoretically it is possible to split BO from agency, in real reality it is a compound concept and is treated as such.

Based on these considerations the main research questions is:

What are the main factors of creating a believable illusion of owning virtual bat´s body in IVE?

And finally, based on the Analysis chapter two research questions that will be treated in separate experiments, should be considered as the Final Problem Statement.

1) *Is it possible to achieve a virtual body ownership illusion over bat´s avatar with the help of visuotactile stimulation in IVE?*

2) *Would voluntary controlled movement of bat´s avatar through the environment enhance the sense of embodiment in IVE?*

5 EXPERIMENT I – EXPERIMENTAL DESIGN

This chapter will describe the design of Experiment I. After establishing research hypothesis conditions that are going to be tested are specified. The design of the experiment is discussing methods and biases followed by the design questionnaire that is based on previous research. Finally the general course of the experiment will be elaborated on. The design and description of the environment and virtual avatar follows after these topics. Everything is rounded up by implementation. This chapter also includes the results, discussion and findings.

5.1 RESEARCH HYPOTHESIS

Before designing the experiment the research hypothesis should be clarified. Based on null hypothesis it would be possible to identify the number of independent and dependent variables. The main goal of the experiment is to find statistical evidence for proving the null hypothesis and except or fail an alternative hypothesis (Lazar, Feng, and Hochheiser 2010). Both hypotheses are presented down below after the main research question.

The first research question that is going to be treated in this chapter is as following:

> *Is it possible to achieve a virtual body ownership illusion over bat´s avatar with the help of visuotactile stimulation in IVE?*

Null Hypothesis:

> *There is no significant difference between the self-reported VBO resulting in exposure to three visual scaling factors (no scaling, 50% scaling, 70% scaling) applied to a virtual bat´s avatar in IVE, when interacted with physical human body through visuotactile feedback.*

Hypothesis 1:

> *There is a difference between the self-reported VBO resulting in exposure to three visual scaling factors applied to a virtual bat´s avatar in IVE, when interacted with physical human body through visuotactile feedback.*

Independent variable shows what I am measuring, while dependent variable shows what causes the result and therefore determine how many conditions there will be to measure the independent variable with (Lazar et al. 2010). These variables are presented in Table 1.

Independent Variables	Dependent Variables	Conditions **for scaling mapping/tapping position (in percentage)**
Scaling	VBO over bat´s avatar	1:1 (direct)
- **No scaling**		1:50 (middle)
- **50% scaling**		
- **70% scaling**		1:70 (extreme)

TABLE 1 RESEARCH VARIABLES AND CONDITIONS, EXPERIMENT I

5.1.1 CONDITIONS

Since the main goal was to measure if VBO could be gained only through visuotactile sense and excluding proprioception it was decided to change visuotactile conditions, but accompany it with the same audio feedback through all the conditions. Audio feedback should contain sonic atmosphere of the environment – soundscape and sounds of touch and threat.

Visually touch input should be changed, depending on condition 1, 2 or 3. Since bat wings are different in shape from the human hands it was decided to visually change the place of the hit. The conductor would be touching each participant with a wand, which would be virtual presented to the test subjects as a yellow ball, as shown in Figure 35.

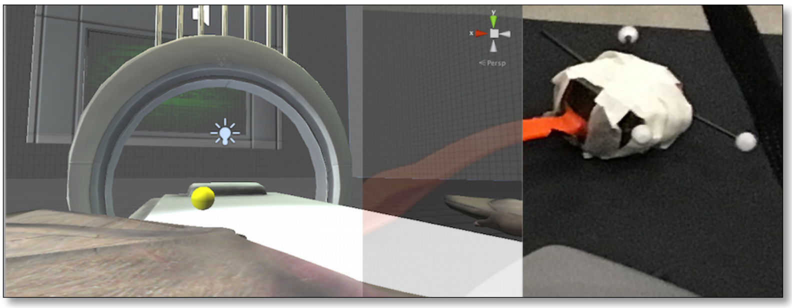

FIGURE 35 WAND WITH TRACKABLE AND YELLOW VIRTUAL BALL

- *Condition 1*
  Touch should be felt the same place it is seen on the screen. There would be no deviations, 100 % “direct” 1:1 mapping would be used.
- *Condition 2*
  Touch would be 50% displaced too the end of the virtual wing. Test subjects would feel touch on the hand (same as condition 1), but visually they would see that the yellow ball would be hitting them somewhere in the middle of the virtual wing. Condition is called “middle” with 1:50 mapping.

- *Condition 3*
  Touch would be 70% displaced to the end of the virtual wing. Test subjects would feel touch on the hand (same as condition 1), but visually they would see that the yellow ball would be hitting them somewhere at the end of their virtual wing. Condition is called “extreme” with 1:70 mapping.

5.2 DESIGN OF THE EXPERIMENT

When conducting the experiment several issues have to be taken into consideration.

- Assignment Method

Within subject design approach will be applied to this group, as it requires smaller amount of population sampling and saves time for the researcher, since the same test subjects will attend all 3 conditions (Lazar et al. 2010). Although this approach saves time and resources, several issues are discussed underneath.

- Learnability

Due to the fact that test takes into consideration only the feeling of VBO, which is purely perceptual capability, no bias could be influencing tests subjects. Tests subjects would be exposed only to one independent variable at a time therefore test subjects would not be able to learn anything from the previous task conditions. Based on that this structure allows to learning effect and limits biases. Test conditions will be applied in a random order in order to limit learning effect potential and individual differences. For a particular test subject another test subject would offset these issues (Lazar et al. 2010).

- Fatigue

The experimental time is set up to 5 minutes per condition, including filling out a questionnaire after each condition test. In this case no issues of fatigue or frustration should take place.

- Randomization

In order to avoid individual differences and to find out causal relations between the variables random assignments of tasks should be applied, which would help to get a clean comparison between 3 groups.

In order to avoid unnecessary influence from the conductor as well as mentioned above issues, test subjects would be randomly assigned for each group digitally (Lazar et al. 2010). This was done in Matlab with randperm(N) function, which returns a vector containing a random permutation of the integers 1:N [28].

5.2.1 POPULATION SAMPLING

Convenience method sampling would be used, although it is not optimal, as the majority of Medialogy students are acquainted with VR experiments conducted in multi-sensory lab, which might create bias. However, since they do not know the main aim of the experiment and are not acquainted with this particular virtual environment and conditions and their perceptions are different, this method sampling might eliminate the major biases. Besides, convenience sampling is not that much time and resource consuming (Sharp, Rogers, and Preece 2011). Taking into consideration the "medialogy-student" problem, I would try to find some independent test subjects that are not familiar with the technology and theory behind.

5.2.2 TARGET GROUP

There were no specific requests for the target group apart from having a reasonable eyesight in order to perceive visual feedback and no tactile sensitivity disorders in order to feel touch on the body at the right place. Target groups did not have to have a specific knowledge of computers nor VR technology. No age or gender preferences were required, since the main goal of this test did not include finding out the differences between age or gender groups.

5.2.3 DATA ACQUISITION METHODS

In order to measure perceptive experience qualitative and quantitative research methods for data acquisition will be involved.

Quantitative method involves questionnaire of quantitative nature using rating scales and would help to sample data in a very quick way, which would allow comparing data between the conditions or groups. Test subject should be answering to which degree of agreement or disagreement they measure their feelings during each test. Questions will be formulated in the way that they gradually increase the level of perceived feelings towards the virtual body ownership illusion, including touch and threat. Likert scale would be used (from 1 – totally disagree to 7 – fully agree), which would help to sample data score from the questions and later use it in data analysis.

Qualitative data would allow collecting test subjects´ subjectively perceptive opinion about the feelings they experienced during the test, as well as it would allow collecting their comments.

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[28] http://se.mathworks.com/help/matlab/

The methods for data acquisition are the following:

a) Questionnaire using Likert scale;

b) Observation notes;

c) Personal Interview after the test;

5.2.4 DESIGN OF THE QUESTIONNAIRE

In order measure the differences between the groups same questions will be used for each group.

Semantic analysis[29] - might be helpful in analyzing other researchers questions construction. Based on this analysis and the questions they used I will construct my own questionnaire that would be suitable for this research.

Each question or sentence that is pronounced and addressed to the receiver tunes him or her to a particular psychological state. For example, affirmative statement constructions are different from ordinary constructions: "*You have read this book, haven't´ you*? " or "*Have you read this book*?" In the first case scenario sender has a hope and might assume that the book has been read; in the last one the sender wants to know generally if the receiver has read the book.

Of course intonation places also an important role in speech as well. Though, since the questionnaire that will be constructed belongs to quantitative data and will be provided digitally to test subjects, intonation will not play any role. In order to avoid double meaning of the sentences it is important to construct them clearly. Words and phrases in the text might be used to construct associated psychological links with feelings, emotions, or even other objects. Down below I will try to analyze the questions on lexical and compositional sematic level.

5.2.4.1 SEMANTIC ANALYSIS OF SLATER´S QUESTIONS

Since M. Slater researched VBO for many years, as examples for the questions I will try to use his and similar other approaches to questions construction.

Analyzing Slater´s approach to questionnaire formulation, some particular details are visible and noteworthy. He helps test subject to reveal a special cognitive association link between perceptions of the actions in virtual environment and their subjects´ feelings. He measures these associations with the help of a 7-point Likert scale.

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[29] Semantic analysis is construction of meaning of representations on lexical level (meaning of the words) and compositional level (combination of the words and their structure) that form a larger meaning. (Schroeter 2012)

Slater uses phrases like: “*During the experiment there were moments when I felt…*” in stead of a direct statement like “*I felt that the virtual body belonged to me*”, which might give worse results in comparison to his construct, where he uses “*there were moments*” , indirectly saying that the feeling might have been broken at some points, but still the test subject felt it sometimes. The same structure has another phrase – “I felt as if…might belong to…”, where “*might*” indicates a possibility of getting a feeling at some point and is very subjective. However, one may argue that these constructs are uncertain and might not show the true objective measurements as the topic of the discussion is very subjective due to personal reflectivity (González-franco et al. n.d.; Kilteni, Normand, et al. 2012; Maselli and Slater 2014; Normand et al. 2011; Osimo et al. 2015).

By mentioning that there were some “*moments*”, when test subject might have felt some similar feelings gives a possibility to collect more or less correct results. “More or less” is again due to the results subjectivity (the feelings and relativity to the virtual body) and perceptual individual differences, concerning visuotactile feedback. That is why the main question - if a test subject felt that the virtual body belonged to him, should be rephrased the following way: “*There were moments during the experiment when I felt as if the virtual body belongs to me*”.

Another very distinctive feature of Slater´s questionnaire is that he makes associations and therefore connections and links to the virtual objects from the physical world. For example: “*During the experiment there were moments in which it seemed as if what I was feeling was caused by the yellow ball that I was seeing on the screen.”* (Slater et al. 2008). Based on this technique I came up with the following question: “*There were moments during the experiment when I felt that the touches on my arm were caused by the yellow ball I saw on the screen*”, which leads to association between the hits on the physical body and the yellow digital ball, test subjects see on the screen, and therefor helps to link physical body to the virtual body, as this construction helps to create a perceptual cognitive link in the test subject´s brain and therefore an hopefully a VBO illusion.

5.2.4.2 DESIGNED QUESTIONNAIRE

All these thoughts and analysis of the questionnaires gave inspiration to the following questions that were used in all 3 conditions, constructed as 7-point scale from totally disagree to totally agree:

- *General Information about the participants*

1. Gender (m/f)
2. Age
3. Occupancy

4. Computer knowledge (none, poor, average user, very good user, advanced user, expert)
5. I use Computer the most (at home, at work, for my education, for gaming)

All the questions belonging to VBO, Touch, Threat and Agency were based on questionnaire from different researches and could be seen in section 4.7.11.

- VBO

1. During the experiment there were moments where I felt as if the virtual wings belonged to me, despite the differences in physical shape between the wing and the hand.
2. During the experiment I felt that my physical hand was located at the same spot where the virtual wing was.
3. During the experiment there were moments when I felt as if the virtual wing was my own hand.
4. During the experiment there moments when I felt as if I was located inside the bat´s body.
5. Even though the virtual body I saw in the environment might not have had the same physical shape that I have, I felt as if the virtual body belonged to me.

- Touch

6. There were moments during the experiment when I felt that the touches on my arm were caused by the yellow ball I saw on the screen.
7. I felt that the touch of the yellow ball on the wing corresponded to the same place as the touched I felt on my arm.
8. There were moments during the experiment when I felt hits on my physical body, when the virtual wing was hit with the yellow ball.

- Threat – Hammer/knives

9. When I saw a hammer there were moments during which I felt as if the hammer was hitting my own physical hand.
10. I felt suffocated, when my body moved closer to the knives.
11. I wanted to move away from the knives when they started cutting the virtual wings.

- Agency

12. I wanted to control the wings of the bat inside the environment.
13. I felt that I was in control of the virtual body inside the environment.

- Additional Information

14. Please describe if you needed to move (or may be not) inside the environment and why.
15. If you have any comments, please add them here. You can also describe your feelings when being inside the environment.

5.3 THE COURSE OF THE EXPERIMENT

The focus within this section is how the test subjects will experience the test procedure.

Test conductors will explain to each test subject what the experiment is about and what will happen during the test, followed by the assurance that the test subject can at all times stop the experiment, if there is a need for that. He or she will also be given a letter of consent, included in Appendix, under the section 12.2 with a short description of the experiment.

5.3.1 TEST SUBJECTS

There were overall 22 participants that were involved into the experiment – 13 males and 9 females, with age between 15-54. Four of the test subjects were Medialogy students; the rest had no relations to the technology used in the experiment. The majority of the test subjects has never had any experience with VR and were average computer users.

5.3.2 TEST SETUP AND PROCEDURE

Test subjects were asked to put on a head-mounted display, which allowed experiencing virtual reality environment. Headphones were provided for the further immersion into the virtual environment, through which participants heard surrounding soundscape and the touch of a wand.

During the test participants were asked to lay down on the floor with their hands stretched in front of them. The conductor was touching the left hand of the participant with the wand. The wand did no harm to the participant´s body.

There was no recording of this procedure. Instead the conductor was taking notes and interviewing test subjects at the end of the whole test.

At the end of each session test subjects were given digital questionnaire to fill in. Finally at the end of the test each test subject could provide personal comments about the sessions to the conductor.

Test subject were also reassured that all information collected through the study would be kept strictly confidential. None of the information would be distributed to public or private use, neither would be posted on any website.

5.3.3 PILOT TEST

In order to find out all system's inconsistencies, it was decided to conduct a pilot test on two participants. The primary meaning was with to test system´s stability and behavior.

Comments were collected and changes were made in the system accordingly.

5.3.4 TEST PERFORMANCE

Each test took only a couple of minutes, including filling in the digital questionnaire after each condition.

There were no cases of nausea registered and the test was not interrupted by any of the test subjects. However test subject 12 experienced technical problems with the hammer, which accidently hit the virtual body and the last started flying in the environment, which for couple of seconds gave him the feeling of control over the body movements, as he characterized it. This error was fixed immediately and the test was continued.

In case of the test subject 22 the whole system needed to be rebooted, since it produced a bigger latency including disappearance of audio, which none of the previous test subjects experienced. However the results were decided to keep in the test, since it did not give a bigger difference. Besides this test subject was also bias, since he conducts similar experiments in VR.

5.4 DESIGN OF THE EXPERIMENTAL STIMULI

In this section the design of the environment and body would be explained. Under the design of the environment there will be discussed the design of the threat to the body and the design of touch, since the three conditions are based on the last stimuli. Furthermore the design of the body followed by rigging and animation would be described. Finally technical design of the system would be presented.

5.4.1 ENVIRONMENT

For the environment of the experiment Unity sci-fi pack´s prefabs were used. The sci-fi pack is called "*SciFi Laboratory Environment Pack 1.0*" and was downloaded from Unity asset store[30]. In general the main idea was to design an environment, which test participants would find similar to the lab environment, or at least it should be clear to them that an experiment would also be conducted in the virtual lab.
Virtual avatar was placed on a scanner prefab from sci-fi pack, as shown in Figure 36. In the physical reality test subjects were supposed to lay down on the floor, which would be similar to the condition in the virtual environment.
Since the highest priority was to show the participants virtual wings, virtual body mesh was beheaded and replaced by virtual camera containing a prefab for bio-vision usable by Head Mounted Display. Test subjects were getting the 1PP view, as shown in Figure 37.

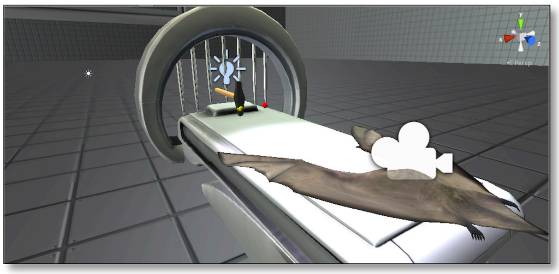

FIGURE 36 OBJECTS ON THE MAIN SCENE

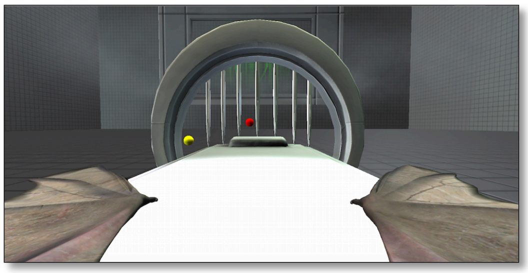

FIGURE 37 MAIN SCENE, SHOWN FROM THE 1PP

5.4.1.1 TOUCH AND THREAT

Two types of body threats were designed – Touch as a Threat (presented as hammer hitting the body on the screen) also made by the wand as ordinary Touch of the body to test conditions and the falling knives grid.

Touch will be done by the wand with a trackable attached to it, as shown in Figure 35. Visually test subjects will only be seeing "Falling Object", also from the same image. This object would be representing an object (yellow ball) touching the surface of the virtual body, while the real wand with trackable attached to it would be touching the physical body. Since it will be possible to change the position in Unity 3D of the "Falling object" (further away or closer to trackable with the wand) it would be possible to test how much the test participants accept or feel their virtual bat´s body in terms of accepting a different anatomy. Each touch is also provided with the appropriate sound, in accordance with the surface of the virtual body. Sounds on the body would sound more hushfully than on the scanner in order to preserve realism.

[30] https://www.assetstore.unity3d.com/en/#!/content/29258

After the touch procedure is done, signaling by the wand being taken up to a certain position in the air on Y-axis, the virtual body would be moved forward to the knives threat on Z-axis and would be stopped on the other end of the scanner. Body itself would not be able to make any movements. Knives, as shown in Figure 37 being attached to the scanner, will start moving up and down. When moving they produce also a synchronous with the movement specific heavy metal sound.

After the body would be stopped at the end of the scanner, the virtual hammer would appear on the exact position as the wand would be on X and Y-axis, but moved forward on Z-axis, so that it could be seen on HMD, as shown in Figure 36. Virtual hammer, imitating a heavy blow, accompanied by a hash sound, would be the last touch/hit (touch by the wand again in physical world) in the experimental condition.

All sound samples were obtained from sample sound webpage[31] and modified in Audacity [32] opened source for recording and editing sounds.

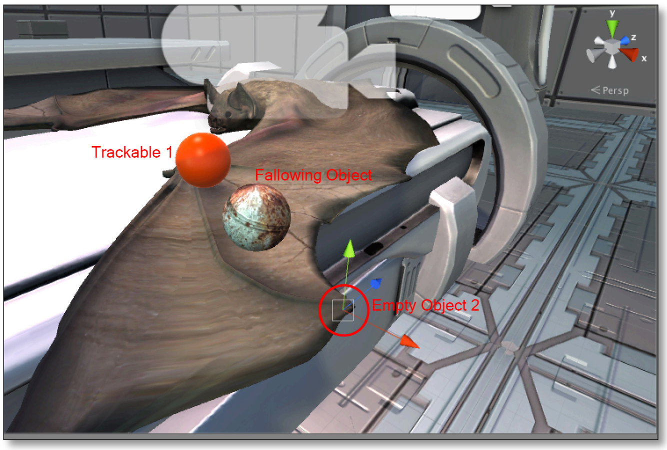

FIGURE 38 OBJECTS FOR THE TOUCH SESSION

5.4.2 VIRTUAL BODY

Bat 3D character was obtained from Turbosquid[33]. However, it was found out that the model was not low polygon model, as was described on the page, which created some problems later in the process. Since the model did not contain bone structure or animation, I had to make it

[31] https://www.freesound.org/

[32] http://www.audacityteam.org/

[33] http://www.turbosquid.com/3d-models/3d-model-vampire-bat/384046

myself with the help of Autodesk Maya 3D[34]. This model is called the vampire bat. The preference to this model was because it has longer wings than any other models and very precise similarities to the bat´s morphological body structure, as described in section 4.1. Since this model was supposed to be used for animation and IK I had to rig the model myself, which will be described briefly in the following section. Rigging and animation was made in Autodesk Maya 3D. Rigging process could be split into: bone system, painting weights, creating controls.

5.4.3 RIGGING

I have modified bat model (for later use in Unity 3D), and made two models - one with the head and another one without a head. These models have different bone systems. The one with the head was used for animation and movie purposes another one (without the head) used IK system for direct bone access in order to directly animate the limbs. Both of them will be used in the second experiment.

- *Bat with the head*

The whole skeleton and control system was made using Autodesk Maya 3D, seen in Figure 39. After the anatomy was analyzed (could be seen on Figure 5) and the skeleton was built, I attached it to the skin and painted weights in order for the mesh to be smooth, when animation would be performed. One of the drawbacks of not using built-in Human IK system was that the bones needed the correction of the direction they were facing in X, Y, Z plane, as also shown in Figure 40, which had to be done manually.

Another possibility for smoother animations might have been using cloth for the wings – skin. However, since the users would be seeing the virtual body from the 1PP I decided that it would not be necessary, since it is also time and computing consuming process, especially because the model was a high polygon one. Finally I manually attached IK handles in Maya and created controls for the future animation.

[34] http://www.autodesk.com/products/maya/overview

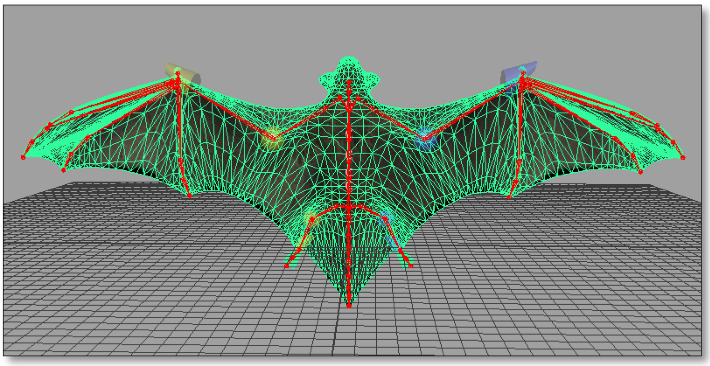

FIGURE 39 SKELETON AND CONTROLS FOR BAT MODEL WITH THE HEAD

- *Bat without the head*

First of all I deleted the head and merged edges. I also decided to shorten the process and used Human IK system for creating skeleton this time. Further in the process I attached the skeleton to the skin. For the exact reason, as before, I also needed to paint weights, as also could be seen from Figure 40. Since I did not need controls for this skeleton (I used controls and manual IK only for animation and movie) I finally could export the model to Unity.

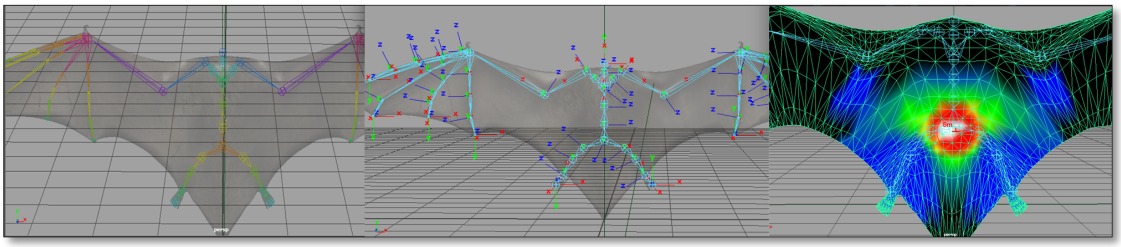

FIGURE 40 RIGGING WITH HUMAN IK

5.4.4 ANIMATION TECHNIQUES

Animation was used for movie and for Unity 3D animation of the flight.

I used rotoscoping[35] animation technique in order to trace animation frame by frame from video footage, which gave the most close to natural results for animating bat´s flying locomotion.

Video footage (UNC Lab 2012) used for rotoscoping was shot with a high-speed video camera by researchers from the University of Northern Colorado, Bat Research Lab.

35 https://www.rocketstock.com/blog/rotoscoping-from-early-animation-to-blockbuster-vfx/

Firstly I needed to import video footage to a plane in Maya, which could be done only by importing image files that was why I used MPEG Streamclip[36] to cut the entire video into images and only afterwards I could import images into Maya 3D and use them on plane attached in front of the main camera.

Albeit animation contained forward movement I deliberately excluded it from animation that was exported to Unity.

For the movie I also used Fcheck application that comes along with Autodesk Maya 3D, which allowed me to set all rendered images together. With the help of OneTube[37] free video converter I could reduce movie size.

Another technique I used was ordinary animation of the limbs – of the wings and of the wrists separately. Both cases contain backwards and forward animations. These animations would be used as voluntary controlled movements of the virtual limbs. This was done using IK handles and simply moving the limbs backwards and forward keying the movements in a timeline in Maya 3D.

All the files that were exported to Unity 3D using general application preferences were set up to centimeters working units, also marked as "animation" (when contained animation also checked as "bake animation") in order to export file as fbx file format[38], suitable for programming animations in Unity 3D, together with mesh and skeleton (and in the first case – bat with the head - case with already baked animations).

5.4.5 VIRTUAL BODY POSITION IN PHYSICAL WORLD

Touch on the physical and virtual body should have matched. Therefore in order to avoid mistakes I needed to know where the virtual body was placed in the physical world. Marking the wing area helped to get a better understanding where the wings were, as shown in Figure 41. Markers on the floor were set during one of the pilot test sessions for a better visualization purposes. The marked territory to the right from the wing was also marked. This was a place for test subjects´ hands. Crosses to the right marked some essential areas – a down one for the thumb and the upper one for the elbow.

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[36] http://mpeg-streamclip.en.softonic.com/mac

[37] http://wontube_free_video_converter_for_mac.en.softonic.com/mac

[38] http://www.autodesk.com/products/fbx/overview

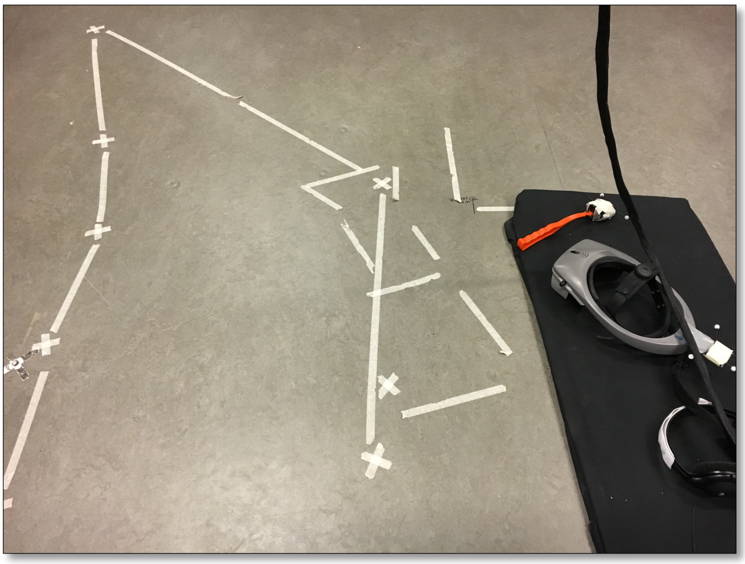


FIGURE 41 POSITION OF THE VIRTUAL BODY ON THE FLOOR IN MULTISENSORY LAB

5.5 IMPLEMENTATION OF THE VIRTUAL STIMULI

In this section system set up and Development of the prototype will be explained, based on the theory and design.

5.5.1 HARDWARE AND TECHNICAL CHARACTERISTICS OF THE SYSTEM

The used system consists of an HMD and 13 cameras, capturing the user's movements with the help of three trackables; one attached to the HMD and one to each of the user's knees. The system can be seen in Figure 42.

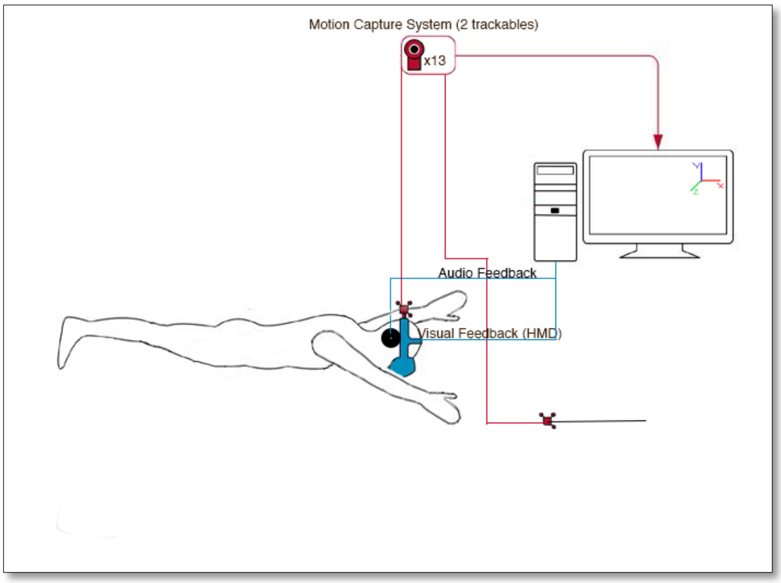


FIGURE 42 SET UP WITH MOTION CAPTURE SYSTEM

The used HMD is the nVisor SX60 model, used for virtual reality applications. The HMD has a resolution of 1280x1024 pixels, with field of view of 60 diagonal and a refresh rate of 60Hz. It supports most of the trackers. It weighs 1 kg (Display 2010). In comparison to Oculus Rift, which has a lower resolution 960x1080 and a higher refresh rate 75Hz, nVisor SX60 has several described advantages (Oculus n.d.). The Oculus Rift has a wider viewing optics: 100 degrees field of view and an update rate of 60 Hz for positional tracking. Since the main goal of the system is immersion, Oculus Rift might be the better choice regarding the field of view. Albeit quite reasonable characteristics of both displays, we had to consider that it was only a prototype version we are creating, in order to test, why the best option was nVisor SX60.

The OptiTrack motion capture system – Motive - was used to capture movements of the users (OptiTrack n.d.). The Motive optical motion capture software (OptiTrack n.d.) allowed seeing the three used trackables on a computer screen and assigning them to the chosen trackables via Unity scripts. Cameras used for the test had 100 fps with resolution of 640x480. All reflective materials were eliminated during the tests by either covering visible or removing from the stage, as it might have influenced the tracking process.

Sennheiser HD570 stereo headphones were used for audio feedback.

5.5.2 DEVELOPMENT

The main challenge behind programming this experiment was to implement 3 different touch mappings – 1:1; 1:50 and 1:70 scaling of the distance between the wand and the virtual visual yellow ball on the screen, while the wand touch point is hidden from the test subject.

The second challenge was to use the reference position of the wand trackable and move the hammer further more into a 3D space, to a point where the virtual body was moved to so that it would be visual on the screen for the test subject and at the same time using the wand hit test subjects with the virtual knife representing a body threat.

There were two trackables on the scene – Trackable 1 belonged to HMD and Trackable 2 belonged to the wand, which render was set to false through the whole programming session in the Start() Function so that it would be invisible to the test subjects, is shown in Figure 43.

```
//Gets Renderer component of the TRackable2
rend = GetComponent<Renderer>();
rend.enabled = false;
```

FIGURE 43 RENDER TRACKABLE 2 IN THE SCENE

5.5.2.1 THREAT

The virtual yellow ball, which is called "*Controlled Ball*" in the program is rendered to the scene with the SetActive() Function set to true through the whole session, until the hammer appears on the scene at the end, after the virtual body has been moved.

```
if (reactionStarted)
{
    //moves position of the body till the knives
    Vector3 temp = new Vector3(0.0f,0.0f,0.005f);
        body.transform.position -= temp;

    //hammer gets the same ImagePosition as Trackable 2 so that it can be used for harming the body
        temp = Trackable2.transform.position;
        temp.z = 41.0f;
        hammer.transform.position = temp;
```

FIGURE 44 MOVEMENT OF THE VIRTUAL BODY

"*Temp*" variable is used as a reference variable to the position of the Trackable 2 in the scene, shown in Figure 44. Reference type of variables do not contain data, but stores the reference to the actual data and it contains its address [39]. Trackable 2 stores the actual data, it is a value type variable. That is why it was possible to manipulate with the hammer object on the scene and use the wand/Trackable 2 position in the 3D space to touch test subjects even though their virtual body has been moved further on Z-axis by moving the hammer also on Z-axis.

Virtual knives were animated and were triggered as soon as the Trackable 2 was up to a certain position on Y-axis in 3D space. Knives were animated directly in Unity 3D with the event added as a Function to play the sound animSound(), which would be played only once per animation. This is shown in Figure 45.

[39] https://msdn.microsoft.com/en-us/library/490f96s2.aspx

```
IEnumerator AnimTimer()
{
    yield return new WaitForSeconds (0);
    GetComponent<Animation>().Play();

    // GetComponent<AudioSource>().PlayOneShot(CloseAudio);
}
void animSound()
{
    GetComponent<AudioSource>().PlayOneShot(knives);
    GetComponent<AudioSource>().volume = 0.1f;
}
```

FIGURE 45 ANIMATION AND AUDIO SOURCE

5.5.2.2 TOUCH AND SCALING FACTOR

The method to scale touch position on the body with the virtual yellow ball presented visually on the screen to the test subjects was based on linear interpolation. The main point of using that method was that I could not predict where I would hit test subjects during the test. If hitting position and direction would be possible to predict I could simply use the position and the direction and add, for example, half of the distance to the hitting position of the Trackable 2.

Linear interpolation is based on filling in the data (in computer graphics by drawing a line between two known variables) with the help of linear polynomials[40].

I used an Array of empty objects that were placed on the scene at the end of the left wing, going around its shape, shown in Figure 46.

```
void MinDist()
{
    //Creating array of distances between empty objects
    float[] Distances = new float[]{dist1/*, dist2*/, dist3, dist4, dist5};
    //Finding a minimum distance between three empty objects that are in the array
    minDist = Mathf.Min(Distances);
    return;
}

void CalcMinDist()
{
    //Calculates min Distance between an Empty_object and Trackable1
    dist1 = Vector3.Distance(Trackable3.transform.position, Trackable2.transform.position);
    //dist2 = Vector3.Distance(Trackable4.transform.position, Trackable2.transform.position);
    dist3 = Vector3.Distance(Trackable5.transform.position, Trackable2.transform.position);
    dist4 = Vector3.Distance(Trackable6.transform.position, Trackable2.transform.position);
    dist5 = Vector3.Distance(Trackable7.transform.position, Trackable2.transform.position);
}
```

FIGURE 46 CALCULATING MINIMUM DISTANCE TO AN EMPTY OBJECT

Next I needed to compare all the distanced and find out which one was the minimum one and lay close to the Trackable 2 hitting spot. If that distance was the minimum distance I used interpolation function of Vector 3, since the position in space is a Vector 3 with X, Y and Z coordinates in space. The process is shown in Figure 47

40 http://www.eng.fsu.edu/~dommelen/courses/eml3100/aids/intpol/

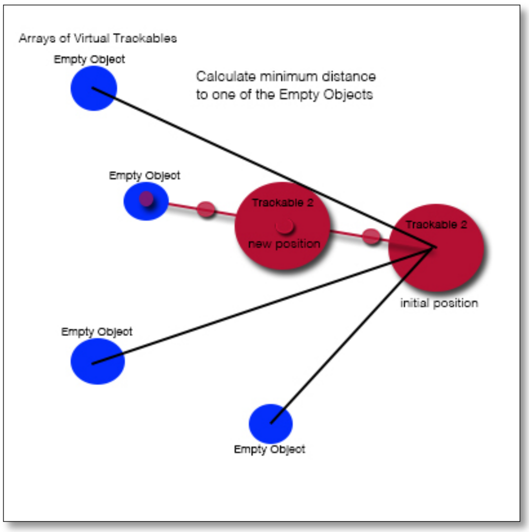


FIGURE 47 VIRTUAL YELLOW BALL - NEXT POSITION CALCULATIONS

Lerp() function has the following parameters – “from”, “to” and a “scaling variable/factor”[41], shown in Figure 48. If scaling factor were 1.0 - the position of the yellow ball would have the same coordinates as the wand with Trackable 2. If scaling factor would be 0.5 - yellow ball would change its position moving to in-between the empty object and Trackable 2. If scaling factor were 0.3 – it would move its position in 3D space to 70% to the left from Trackable 2.

```
void Compare()
{
    if(dist1 == minDist)
    {
        // Moves the target to an empty object's position
        transform.position = Vector3.Lerp(Trackable3.transform.position, Trackable2.transform.position, scaling);
        //print(minDist);
    }
```

FIGURE 48 LERP FUNCTION

The whole interpolation process is shown in Figure 47 in details, where the interpolation factor is presented as 50%, which would give the next position being in the middle on the line between an empty object and the initial position of Trackable 2.

[41] https://unity3d.com/learn/tutorials/modules/beginner/scripting/linear-interpolation

6 EXPERIMENT I - RESULTS

This chapter would present the results from the first experiment on achieving VBO illusion of the of the bat´s avatar using visuotactile input. It would be split into quantitative and qualitative presentation of the results as well as my interpretation and discussions of results usability.

Since the results include statistical analysis of quantitative data, they would be presented first, divided into subgroups, as visualization, data distribution and correlation test.

Since test subjects were rating questions on Likert scale I decided to take the ratings and use them as ordinal data. Normality of data would also be checked. Since I was working with numbers, data could be described as discrete and ordinal, which indicates that non-parametric test approach should be used, since data got a relevant order from the rank responses (Mathworks 1994-2016).

Discussion of the results and bias would be done at the end of this chapter.

6.1 PRESENTATION OF THE RESULTS

The test was done in the following way. First I decided to see how data behaves in different situations, if groups are correlated or not, how test subjects reacted on touch and threat in different conditions that is why I made data visualization.

Then I split the samples into several groups, described in the next section and then tested data score for linear relationship - correlation. After that I applied Friedman´s test, which will be described later in this chapter. There are other possibilities to analyze data and even perform more tests, for example, if touch might be perceived differently from male to female, which might even influence VBO, etc. but this information would not be taken into consideration in the present analysis and these speculations would be left for discussion.

To star with I decided to present the means per each question for all 3 conditions, presented in Table 2. The higher the rating is the more VBO test subjects got in regards to Likert scale.

Condition 1 Question 1 "*During the experiment there were moments where I felt as if the virtual wings belonged to me, despite the differences in physical shape between the wing and the hand*" and Question 3 "*During the experiment there were moments when I felt as if the virtual wing was my own hand*" scored the highest results.

Condition 2, though got the highest results for Question 2 that described the location of the hand and the wing. Question 6 for condition 2 was also rated higher than for the rest of the groups "*There were moments during the experiment when I felt that the touches on my arm* *were caused by the yellow ball I saw on the screen*". Question 9 was rated higher in condition 2 "*When I saw a hammer there were moments during which I felt as if the hammer was hitting my own physical hand*". Question 10 also "*I felt suffocated, when my body moved closer to the knives*" together with Question 11 "*I wanted to move away from the knives when they started cutting the virtual wings*".

Since Condition 2 was the most repetitive one at the end of each session, test subjects had a possibility to adjust more to the environmental settings and bat´s virtual wings than the rest of the groups, as shown in Table 3.

Questions	Condition 1	Condition 2	Condition3
Question 1	3.7273	3.3182	3.3636
Question 2	4.5909	4.7273	4.4545
Question 3	3.9091	3.2727	3.1364
Question 4	3.1818	2.8636	3.0000
Question 5	3.6818	2.9545	3.0455
Question 6	4.2727	4.5909	4.0909
Question 7	4.7727	3.9091	3.2273
Question 8	4.6364	4.9091	5.0909
Question 9	3.8182	4.1818	3.8636
Question 10	3.5455	3.6364	3.1364
Question 11	3.5455	3.5909	3.0000
Question 12	4.8182	4.7727	5.0455
Question 13	3.0000	2.6818	2.2273

TABLE 2 MEANS PER EACH QUESTION FOR CONDITION SEPARATELY, EXPERIMENT I

Condition 1 scored the highest rating for Question 13 "*I felt that I was in control of the virtual body inside the environment*", while condition 3 got the lowest rating for this question. On the contrary condition 3 got the highest rating for Question 12 "*I wanted to control the wings of the bat inside the environment*".

Condition	Times

3, 2, 1	6
1, 3, 2	6
2, 1, 3	1
2, 3, 1	4
1, 3, 2	3
3, 1, 2	2

TABLE 3 NUMBER OF CONDITION FOR THE AMOUNT OF TIME

General means per conditions are presented in the following table Table 4.

Conditions	Mean	Median
Condition **(1:1)**	3.96	4
Condition **(1:50)**	3.8	3.5
Condition **(1:70)**	3.59	3

TABLE 4 THREE CONDITIONS PRESENTING OVERALL MEAN AND MEDIAN FOR ALL QUESTIONS WITHIN EACH GROUP

The overall mean, median, std and var per each question in each condition separately could be found in Appendix under the section 12.5.

6.1.1.1 GROUP DIVISION

Since there were 3 conditions participants were divided into Group1 (1:1 mapping), Group2 (1:50 mapping) and Group3 (1:70 mapping).

Group3 was assumed as a primary low-VBO group, while the highest-VBO group was assumed to be Group1.

Another important factor was that the 2 last test subjects (number 21 and 22) were biased. Though I decided to leave in the groups, since results visualization did not show any noteworthy differences in mean (see attached PDF of Experiment I Results).

Furthermore, for different comparisons I decided to split data according to the subgroups from the questionnaire – as VBO, Touch, Threat and Agency subgroup, according to the questions asked. This division gave a possibility to test samples for correlation, which results would be also presented later in the same chapter.

6.1.2 NORMALITY AND DATA DISTRIBUTION

Before conducting any other tests I performed normality test using Kolmogorov-Smirnov test. There was null hypothesis and alternative hypothesis stated:

H_0 =

Data from the group comes from a standard normal distribution.

H_1 =

Data from the group does not come from a standard normal distribution.

Results are shown in Table 5. Null hypotheses was rejected at 5% significance level therefor it is clear that data is not normally distributed. Histograms, presented further below would show each data distribution per group.

Condition 1	Condition 2	Condition 3
H = 1	H = 1	H = 1
P = 1.9791e-178	P = 1.9791e-178	P = 1.9791e-178

TABLE 5 KOLMOGOROV-SMIRNOV TEST EXPERIMENT I

When looking at distribution we are interested in mean of the sample, which is basically the extent the information about population that could be inferred (Mathworks 1994-2016).

Normal distribution shows that samples came from normally distributed population observations. The more deviation is from the mean, which is measured in standard deviation the less normality data has (Lazar et al. 2010).

I built 3 histograms for each group in order to see how these samples are distributed and if data fits, shown in Figure 49, Figure 50 and Figure 51. There are no big differences in standard deviation between the participants from the first group. In the second groups standard deviation is a little bit higher. In the third group deviation is much bigger in comparison to the first two groups, as could also be read from Table 4.

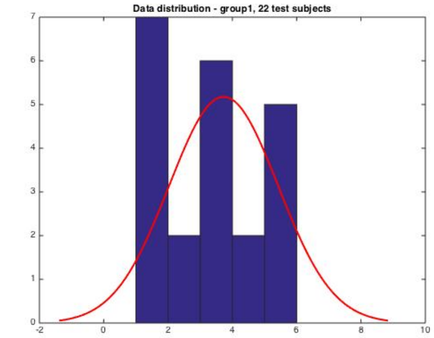


FIGURE 49 SAMPLE DISTRIBUTION, CONDITION 1, EXPERIMENT I

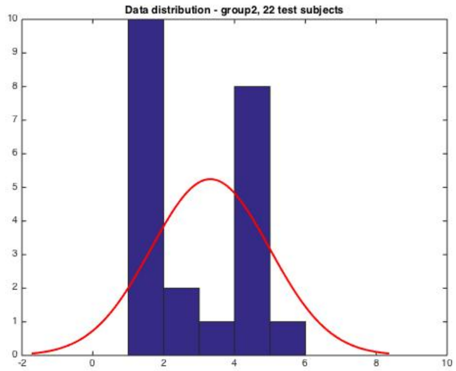


FIGURE 50 SAMPLE DISTRIBUTION, CONDITION 2, EXPERIMENT I

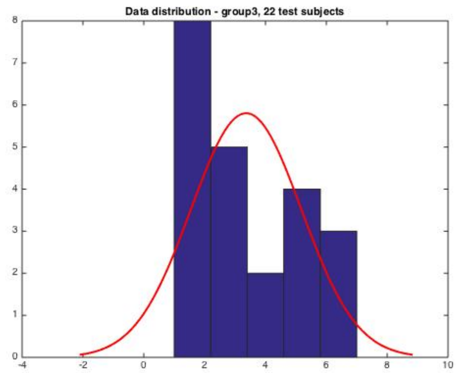


FIGURE 51 SAMPLE DISTRIBUTION, CONDITION 3, EXPERIMENT I

In the following Table 6 one could see means for different subgroups of questions and two different Agency questions.

Subgroups	VBO	Touch	Threat	Wish for controlled movement (Agency, question 12)	I was in control over the body (Agency, question 13)
Condition1	3.82	4.56	3.64	4.81	3
Condition2	3.43	4.47	3.80	4.77	2.68
Condition3	3.4	4.14	3.33	5.05	2.23

TABLE 6 MEANS FOR ALL THREE CONDITIONS FOR SPECIFIC SUBGROUPS OF QUESTIONS

The lower Condition3 rated VBO, the higher wish for Agency test subjects had and the lower control over bat´s body they felt. However, The higher Group1 rated VBO, the higher feeling of control test subjects reported. Furthermore it might also mean that the more anatomically correct touch test subjects experienced, the higher control over the virtual body they got, or so they perceived. Albeit they felt more control over the virtual body, that did not mean that they were able to control the movements, as controlled movements were totally absent. The only movement they experienced was uncontrolled movement. Most probable explanation, as I see it, is that the test subjects misunderstood the feeling of the virtual body ownership for control over the virtual body, which in VR most likely might be obtained only through movement. All these probable explanations might also be tested, as they are general guesses after observations that would be discussed later in the same chapter. All this means that VBO and agency might be correlated, which will be known only after Experiment II. Nonetheless theoretically they are constituent parts of body awareness and should work together.

Since Condition2 had only 50% touch deviation (from condition 1), it is most probable that test subjects were not that uncomfortable seeing touch a little bit further away from the hit place, and that was probably why they paid more attention to the threat factor than to touch. Besides test subjects were randomized, but according to randomization condition 2 was more present as the last condition therefore a reason might be that test subjects got more used to the environment and threat. However that is another guess that should also be tested further.

Means, medians, std and variance per questions for each group could be seen in Appendix section 12.5.

6.1.3 LINEAR CORRELATION

In this section I aimed to see if there would be any correlation between pairs of variables. At the same time I wanted to see how VBO and Touch, VBO and Threat, VBO and Agency subgroups behaved.

Correlation expresses linear relationship between two variables - an average degree of corresponding change between them (Mathworks 1994-2016). R is a correlation coefficient, while P is the probability value (to see if null hypothesis is true) (Mathworks 1994-2016).

Since the data is ordinal, not normally distributed Spearman correlation is calculated for each group. Correlation was calculated between VBO, Touch, and Agency in order to see if there are any tendencies between these subgroups.

Calculations for VBO and Touch could be seen in Figure 52. They show only one pare of significant correlation - in condition 1. Mostly significant correlation is presented in Condition 3. Touch was performed by the wand gently hitting test subjects´ bodies, which visually was represented by the yellow ball on the screen.

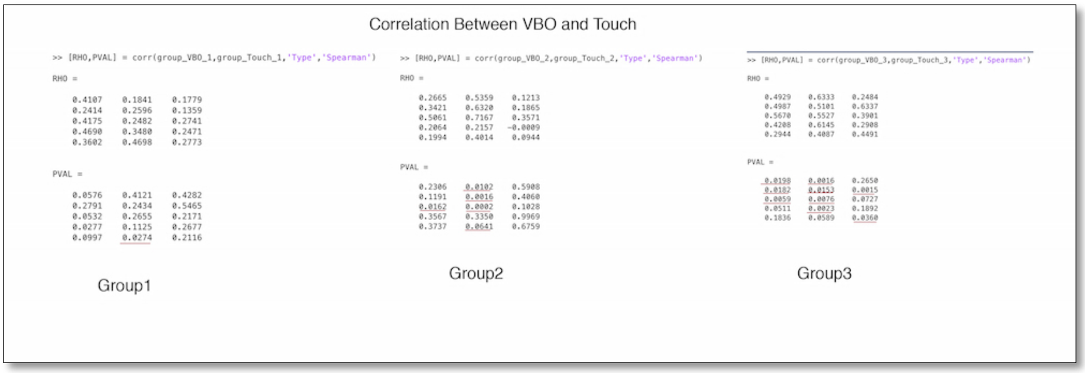


FIGURE 52 CORRELATION VBO - TOUCH, EXPERIMENT I

Correlation calculations between VBO and Threat presented in Figure 53 show more correlations condition 1 and less correlation pairs in condition 2.

In general, during personal interview the majority of the test subjects said that both Threats (knives and hammer) caused them to think that they wanted to move away from the Threats. In general, personal interview showed males preferred hammer, while females preferred the yellow ball as the last threat experience. In case of the Knives, test subjects wanted to move their head away. In case of the Hammer, they wanted to move their hand.

However Group1, where the touch on the virtual wing corresponded to the place on the physical hand, especially when the participants were touched around the thumb area, reported that they wanted to move their thumb away very strongly. It should be noted that visually, thumb area was 100% covered in comparison to the further away area - up the hand, which test subjects could see with difficulty, due to they had to move their head more to the side, while they were laying down during the experiment. Taking into consideration that participants had HMD, which weight was heavy and FOV was not large, it was difficult for them to fallow touch around the whole wing.

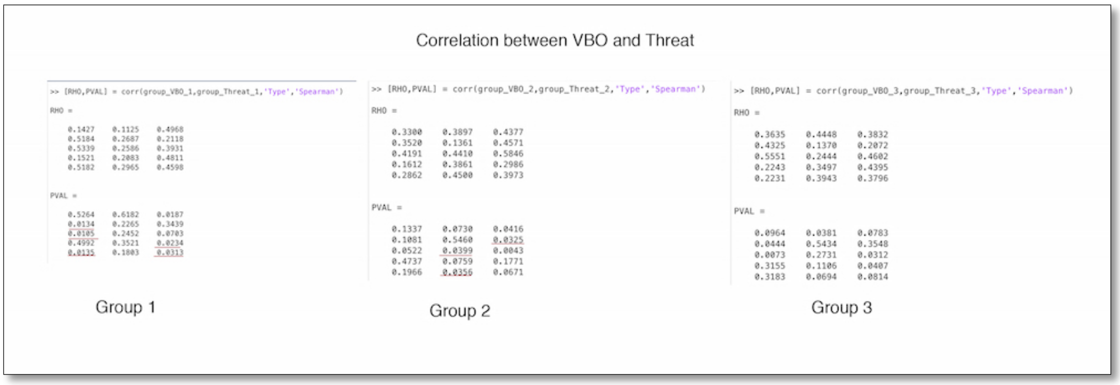


FIGURE 53 CORRELATION VBO - THREAT, EXPERIMENT I

In personal interview all test subjects admitted that they wanted to move away from the threat. On the other hand test subjects were given clear instructions not to move during the test and probably their wish to move was connected to the feeling of the body, which they felt through the touch of the yellow ball. Question 13 indicated that test subjects felt the movement but again connected it rather with controlled movement than unintentional movement belonging to VBO. However all of the test subjects related this movement to presence than to VBO or agency, some of them even mentioned that they felt as observers in IVE. For the argument sake the majority of the participants also rated this question very low - on the left hand side as “disagree”.

Correlation between VBO and Agency, presented in Figure 54, shows equal amount of significant values in each condition followed by different coefficients, though significance was observed in different questions.

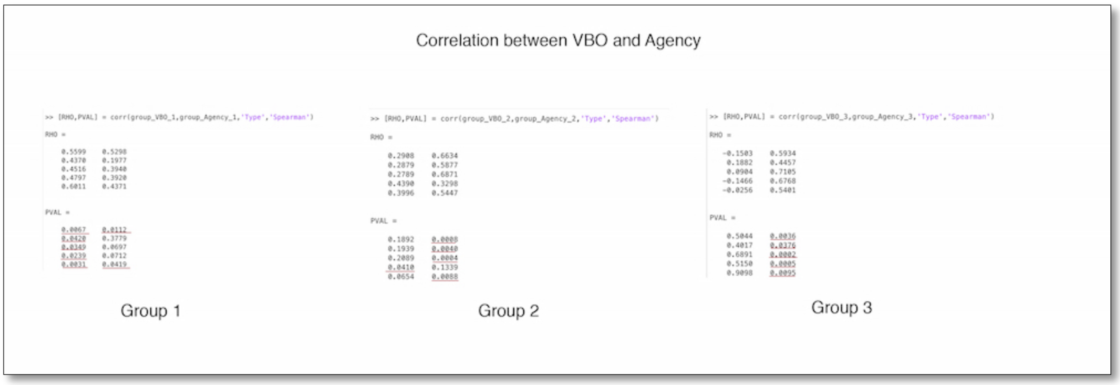
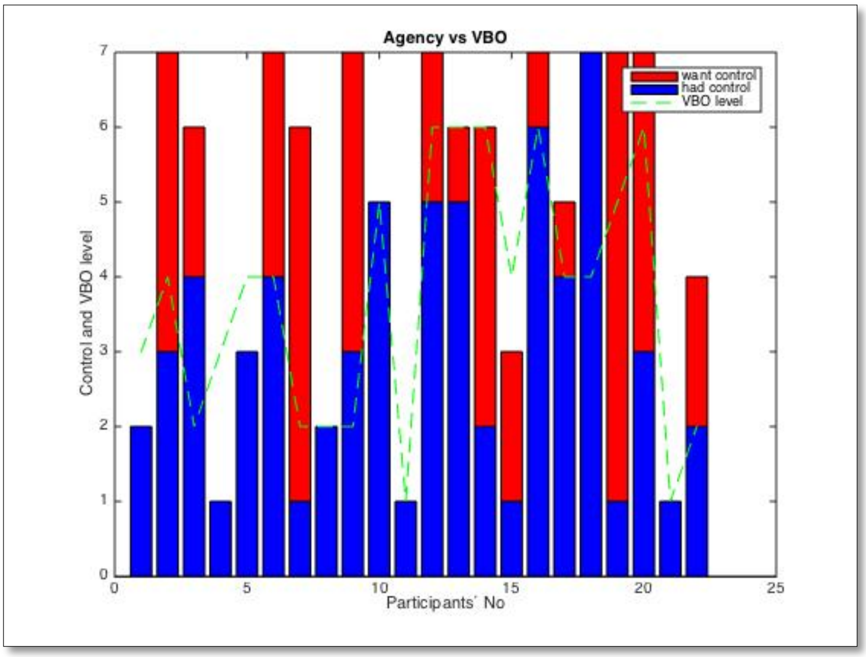


FIGURE 54 CORRELATION VBO - AGENCY, EXPERIMENT I

In Figure 55 one could see Question 12 and 13 combined with VBO level. There were cases when VBO level matches participants anticipation about the wish for control and sometimes it matches the feeling of control, but it would be difficult to see uncontrolled movement as belonging to VBO.



6.1.3.1

FIGURE 55 VBO LEVEL AND CONTROL

On the following images below one could see correlation plot for each condition, showing correlation among the pairs of variables on X-axis. On the diagonal there is a histogram of the variables. Scatter plots of variable pairs could be seen off diagonal. Red values indicate that correlation is significant presenting the coefficient.

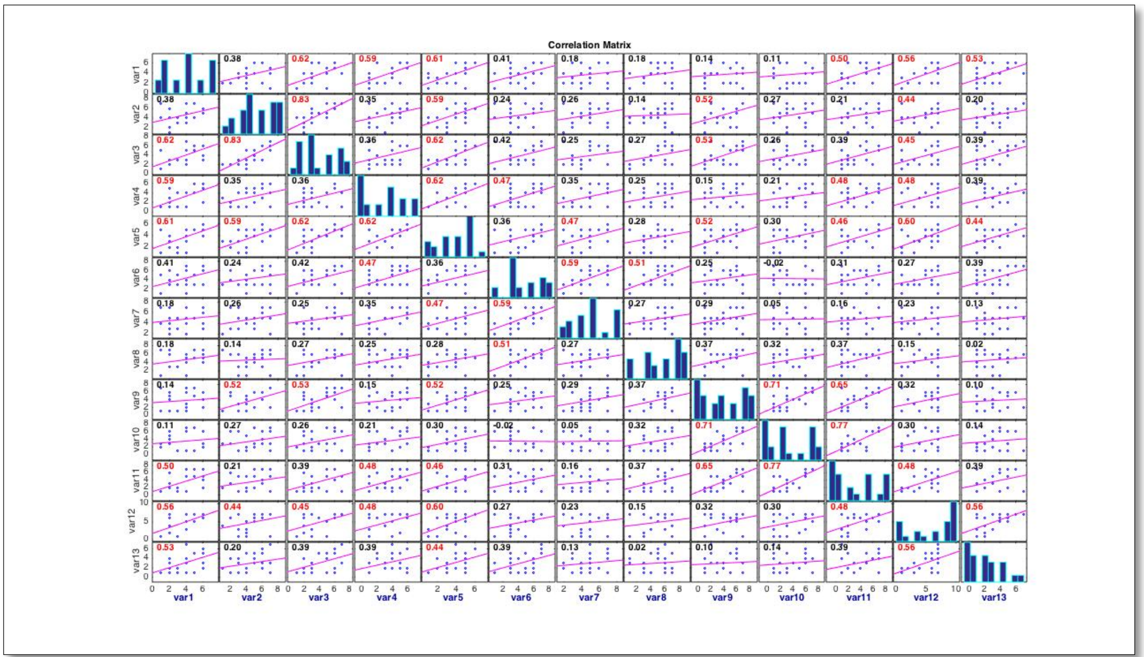


FIGURE 56 CORRELATION MATRIX CONDITION 1, EXPERIMENT I

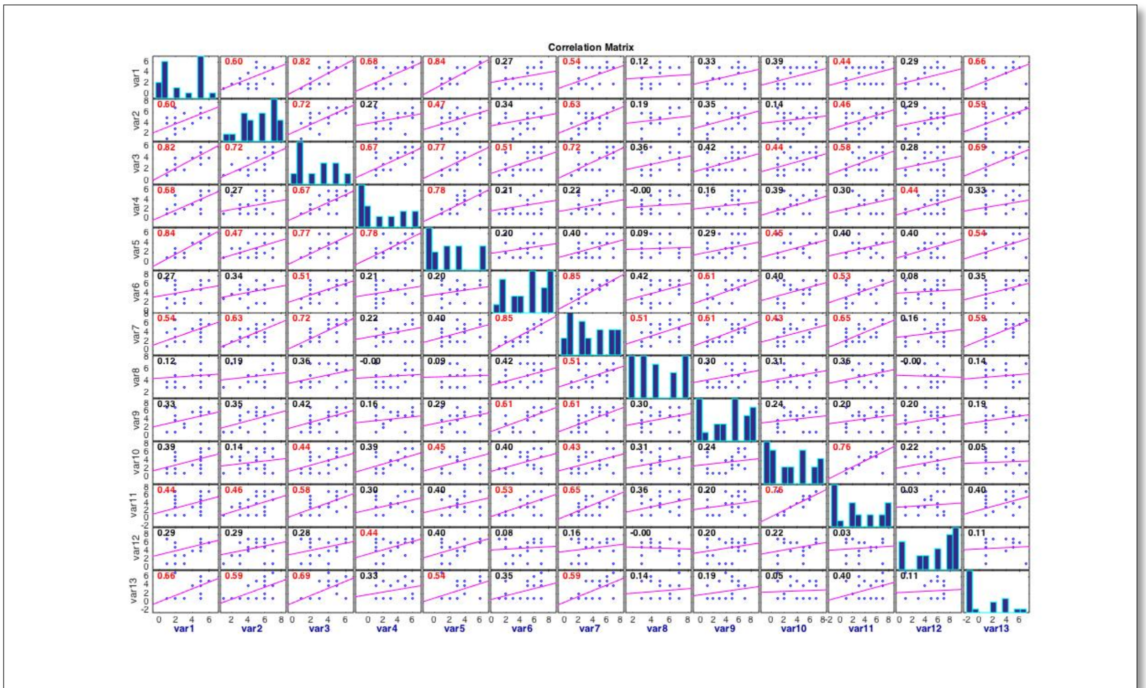


FIGURE 57 CORRELATION MATRIX, CONDITION 2, EXPERIMENT I

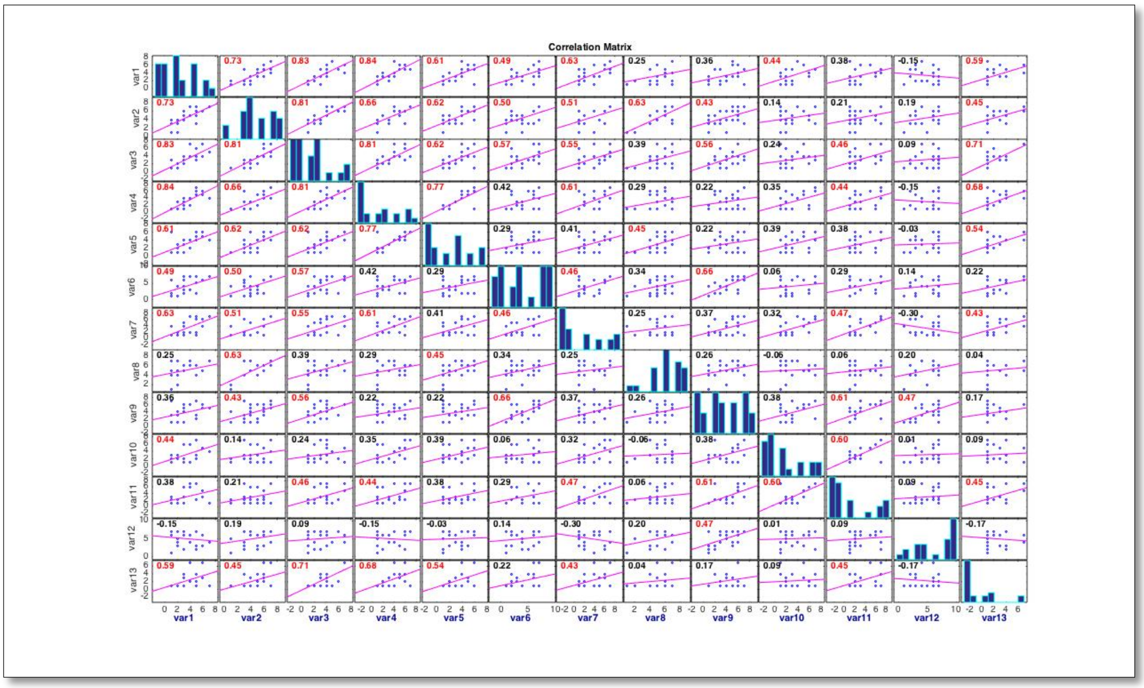


FIGURE 58 CORRELATION MATRIX, CONDITION 3, EXPERIMENT I

Based on presented visualization it helped to identify some preliminary trends in the data and to draw some preliminary conclusions and potentially decide the course of further analysis.

Normal parameter estimates visually showed that Group1 differed from Group3. Normality test showed that data is not normally distributed.

There is some amount of significant correlation between the pairs in the groups, though there are also a lot of pares that are not correlated. In condition 1, questions 1 and 5 (VBO group) showed significant correlation to agency question (wish for controlled movement), though the rest 2 conditions showed they no wish for control, but perceived it as controlled movement. Condition 1 and 2 showed correlation between VBO and Touch only in a few questions, while condition 3 had more significant correlations between these two subgroups.

6.1.4 FRIEDMAN´S TEST

In general non-parametric tests are less reliable unless there is a big test subjects sampling and are more difficult to interpret. Taking into consideration that non-parametric test analysis should be applied with ordinal data, Friedman's´ test will be used (Mathworks 1994-2016).

Since data is ordinal, coming from a Likert scale and is not normally distributed a non-parametric test should be applied, which will test groups´ medians. Before I will do this test I will present visually how the medians look like for each groups (Kruskal-Wallis test is used only for visualization purposes, but I will not perform this test).

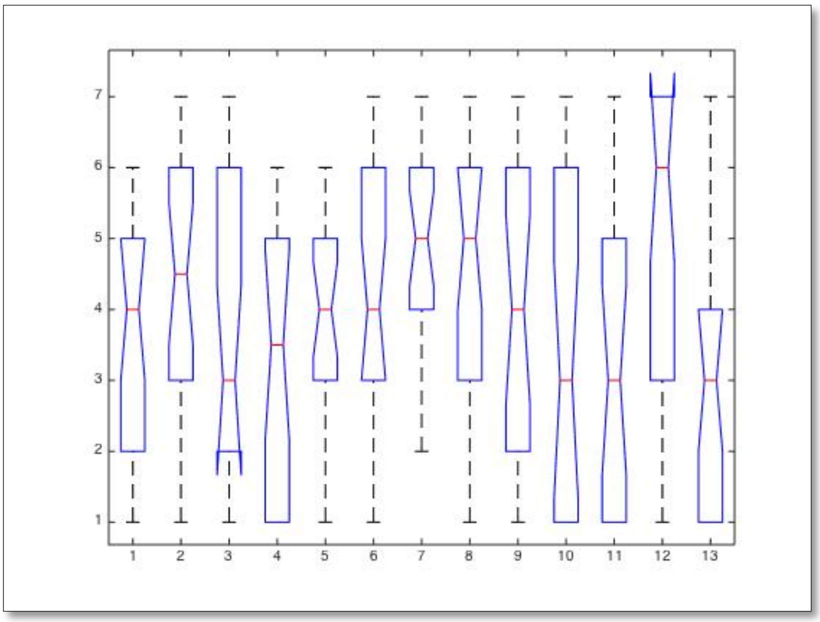


FIGURE 59 MEDIAN - GROUP 1

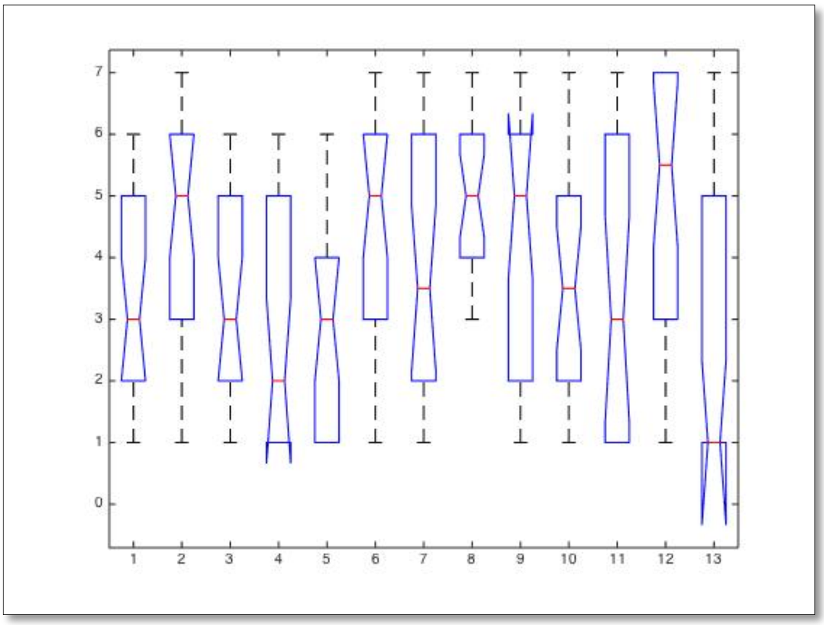


FIGURE 60 MEDIAN - GROUP 2

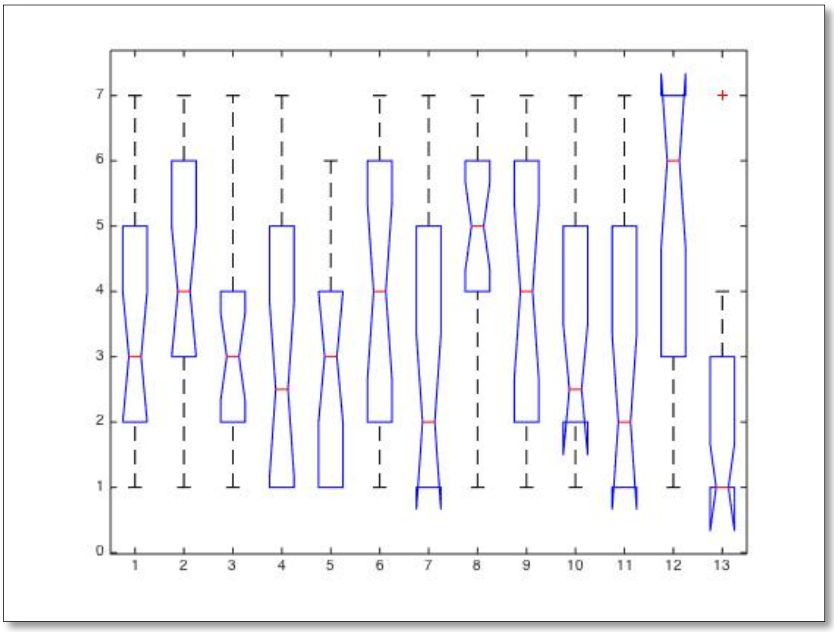


FIGURE 61 MEDIAN - GROUP 3

Friedman´s test assumes that population variances are equal and it checks the variability of medians between and within groups of data samples. In other word it tests if there is any difference of medians between the groups (Mathworks 1994-2016).

The following hypotheses were defined:

Ho = There is no differences in medians between the groups.

H1 = There is at least 1 median that is significantly different in the groups.

Friedman´s test was conducted, which compared the effect of different scaling factor of visuotactile input on the amount of VBO, using 3 conditions – no scaling, 50% scaling and 70 % scaling.

A significant difference of scaling factor on VBO at $p< .05$ level for 3 conditions [$F(38, 798) = 161.53$, $p = 3.59408e-17$] was found.

Mann-Whitney-Wilcoxon rank sum test suggested that there was a significant difference between condition 1 and condition 3. Null hypothesis was rejected with confidence level of $p< .05$. There were not found any significant differences between the other groups.

Bonferroni test using LCD[42] with tolerance of $\alpha = .05$, analyzed further the significant

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[42] LSD - Least Significant Difference, follows 1-way anova, compares means between each group. It is like a set of individual t-test. http://www.graphpad.com/guides/prism/6/statistics/index.htm?stat_fishers_lsd.htm

differences between the groups.

Statistical comparison within this test shows that Group3 differed from any other groups in Question 13 - 10 groups have mean significantly different from Question 13 Group3. There were other differences as well, but mainly regarding Question 13 (" I felt that I was in control of the virtual body inside the environment").

Each group mean is represented by a symbol, and a line extending out from the symbol represents the interval. Two group means are significantly different if their intervals are disjoint. And two group means are not significantly different if their intervals overlap (Mathworks 1994-2016).

Other significant differences in means are presented below in Table 7:

Conditions	*Q 2-Q13*	*Q6 – Q13*	*Q7-Q13*	*Q8-Q13*	*Q12-Q13*	*Q13*
Group1	+		+	+	+	+
Group2	+	+		+ +	+	
Group3	+	+	+	+ +	+	+

TABLE 7 OTHER DIFFERENCES BETWEEN RESULTS (AFTER QUESTIONS MULTICOMPARE)

6.2 OBSERVATIONS

The conductor noticed that test subjects in general felt more and more present in the environment with each next experiment. One of the test subjects that works with VR on daily bases suggested that the conductor should have given some sensible time for the participants to adjust to the environment, which would have weaken subjectivity ratings reasonably down and provide more reliable results.

Comparing Touch by Hammer and the Yellow ball gave overall different subjective results. In accordance to some of the comments from the participants - males in general preferred hammer, while females preferred the yellow ball.

Comparing Threat: Hammer (Question9) and Knives (Question11) gave also different subjective results. But in general the majority of the participants said that both threats caused them to think that they wanted to move away from the threats. In case of the knives, participants wanted to move their head away. In case of the hammer, participants wanted to move their hand away. However, Group1, where the touch on the virtual wing corresponded to the physical hand, especially when the participants were touched around the thumb area, reported a wish to move their thumb away very strongly. It should be noted that visually virtual thumb area was 100% covered in comparison to further area up the virtual wing, which the participants could see with difficulty, due to the fact that they had to move their head more to the side, while they were laying down. Taking into consideration that participants had HMD, which weight was heavy, it was difficult for them.

6.2.1 PERSONAL INTERVIEW WITH TEST SUBJECTS

There is a difference in results between Questionnaire and a Personal Interview (PI) with the test subjects. According to the questionnaire test subjects experienced VBO at least to some extant during the tests. When analyzing interview and if relying on their answers, test subjects neither got any sufficient VBO illusion, in order to identify and attribute themselves to the virtual body of the bat, nor they could attribute their hands to the virtual wings. However, some of them admit, which also reflects through the questionnaire that the position of the hands were more or less on the same spot and as the position of their virtual wings.

According to PI, VBO illusion was created for several seconds and then was broken as soon as the test subjects did not feel touch of the virtual ball on their physical hands. This might lead to a conclusion that VBO might be created only when there is a physical connection between the physical and the virtual body.

There were also differences in the perception of the motion of the virtual body and virtual knives. A couple of test subjects reported that their virtual body did not move, but the virtual knives moved towards them instead.

Down below I would like to describe the main questions and answers from the PI, presented as Table 8. The full answers could be found in Appendix under section 1.

Answers marked with “ + ” are positive answers marked with “ - ” are negative answers.

Questions at the interview:

1. Did you feel presence in the environment?

2. Did you feel VBO illusion over the bat´s body?

3. To which of the following categories would you place movement that you experienced in virtual environment[43]?

a. VBO as a feeling that virtual body is "my own" and it had been moved;

b. Presence as being present in the environment and observe the movement;

c. Agency as controlling movement of "my own" virtual body;

No	1. Presence	2. VBO	3. Unintentional Movement		
			a. VBO	b. Presence	c. Agency
1	+	-		+	
2	+	-		+	
3	+	-		+	
4	+	-		+	
5	+	-		+	
6	+	-		+	
7	+	-		+	
8	+	-		+	
9	+	-		+	
10	+	-		+	
11	+	-		+ (knives moved, not me)	
12	+	+ (little – when body was flying at		+	

[43] This question was constructed based on Pilot test where the test subjects had to describe their feelings – what they felt when their body moved unintentionally through the environment. Almost all test subjects said they felt as observers of the virtual bat moving forward.

		some point)	
13	+	+ and – (it was lost again; knives moved, not me)	+
14	+	-	+
15	+	-	+
16	+	-	+
17	+	-	+
18	+	+ (very little, when knives moved, not me)	+
19	+	+ and – (no, if ball did not touch me)	+
20	+	+ and – (no, if ball did not touch me)	+
21	+ (some)	-	+
22	+ (some)	-	+

TABLE 8 PARTICIPANTS´ ANSWERS FROM THE PERSONAL INTERVIEW

The majority of the test subjects did not get the feeling of VBO illusion, although 18 % (4 test subjects, since the 5th - test subject experienced question 12 as a system error that was fixed straight away) got the VBO illusion a little bit. For those that got it to a certain extent it was either important to feel the touch all the time or illusion disappeared, or they felt as knives were moving towards them instead of the body was moving to the knives, or some of them were saying that the physical position on the floor was very comfortable and they knew that nothing happened towards them, so they felt control over the physical body and therefore over the virtual body.

All 100 % of the test subjects categorized unintentional movement as belonging to presence, as they watched that the body was moving. Many of them explained it as the feeling of being like observers in the virtual environment, when camera started moving towards the threat.

Almost all of them mentioned that without movements it might be impossible to feel the virtual body, even when they felt touch on the virtual body.

There were only few Medialogy students, who were familiar with the equipment and testing methods and almost none of them (only 1) were familiar with the VBO theory. In this content possible subjective bias should be excluded and the results from the PI should not be considered as containing noise.

6.3 DISCUSSION OF THE RESULTS

In this section several observations and results from the questionnaire will be discussed and some explanations given to the tendencies that test showed. Furthermore bias would be analyzed. Based on that reliability would be looked upon, where I would try to see how usable results are.

Results usability would be the final topic for this discussion, where I will try to predict, how these results might be used for further experiments and research.

6.3.1 UNINTENTIONAL MOVEMENT

Since it was described in section 4.6.2.2 agency is a controlled movement or its intention, while unintentional movement belongs to body ownership. However in the physical world unintentional movement, which the body undergoes is applied with the force influencing on the body and involves proprioceptive sense. That might be not the case in VR, which is going to be explained underneath.

A very important finding of this test was that the type of unintentional movement, used in the test and experienced by test participants, might not belong to VBO. The majority of the test subjects rated unintentional movement as controlled movement (question 13).

The most important factor is that this unintentional movement was not connected to proprioceptive sense (proprioceptive stimuli was missing in the test, since test subjects were asked not to move), but rather to optic flow[44] of the virtual environment, when virtual body

[44] *Optic flow* is a pattern of apparent motion of objects, surfaces etc. in VR caused by the relative motion between a user and a scene. In the VR users rely on optic flow, as it gives them clues about the direction and the speed of the environment (Warren et al. 2001).

started moving forward. A couple of the participants even reported that it was not their virtual body that was moving to the knives in the scene, but knives were moving towards them instead. This might of course be a difference in subjective perception of relative motion in the virtual environment.

It should also be considered that test subjects did not feel any force influencing on their physical body and therefore did not feel the unintentional movement. This might conclude that there might be different types of unintentional movements:

1. Force-caused;
2. Created visually with the help of optic flow;

As the test showed the second type of unintentional movement did not influence test subjects feeling of VBO.

Based on that assumption another experiment should be conducted, where the force should be applied on test subjects´ physical body and it should be visually (on the screen) synchronous with their virtual body unintentional movements.

The question is if Agency structure or overrides VBO still remains unanswered, meaning that Agency might be the main and essential component on getting a full VBO illusion (Embodiment) in VR.

Another question that arises after the PI with the test subjects is if this type of unintentional movement that test subjects experienced (optic flow) might belong to Presence in VR and not to VBO, as could be seen from Table 8. All of the test subjects placed unintentional movement to Presence category, claiming (the majority) that they felt as if they were observers and not the participants, when the camera was moved to Threat area during the test in IVE.

As a result from this experiment a higher presence is possible to achieve by adaptation period to the environment as a starting point. Another possibility is emotional involvement, which might be done through the virtual body, which is possible to control and therefore relate to. If control is missing test subjects feel only as observers in the virtual environment, when camera was moving and optic flow created.

6.3.2 POTENTIAL BIASES

Here I would like to discuss bias that might have had an influence on the experiment. These biases would be taken into consideration in the further tests.

6.3.2.1 LIKERT SCALE BIAS

The questionnaire was based on Likert scale, ratings from 1 to 7 (strongly disagree to strongly agree). At the same time, after the whole test was performed test subjects were giving Personal Interview (PI) to the conductor. Some deviations were strongly noticeable in the PI and were very different from answers to the questionnaire. The problem is situated in the 2nd question in the PI, if participants got VBO over virtual avatar´s body/wings. 82 % of the interviewers answered that they did not get VBO at all. However in the questionnaire they were rating their answers about owning the virtual body/wings (in the first 5 questions of the Likert scale in all 3 conditions).

Traditionally Likert scale allows test subjects to choose from totally negative on the left hand side of the scale to totally positive on the right hand side of this scale. Albeit it is a good measuring tool, it might be biased and lead to order effects (Friedman 2015). Unfortunately order effects might result in error. For example, if we take a look at mesomorph and endomorph body type constructions in connection to 7-point Likert scale, presented in Figure 62, order effects would be more understandable.

Depending on which order each of the body types are presented might come to different average ratings on 7-point Likert scale, as it is very subjective. As an example, if mesomorph is presented first, it might lead to average of rating 5, as human tendency is not to rate towards the extremes of our ratings, we are less likely to rate 7 or 1, but in stead of that in between on Likert scale. If endomorph body type would be shown after mesomorph body type the average of rating would be 2 in stead. If it would be shown first, it would most likely get 3 and visa versa in case of mesomorph body type, as human´s natural inclination is to compare the first image to the previous one (Robb Bubb 2014). In order to avoid order effects randomization is necessary.

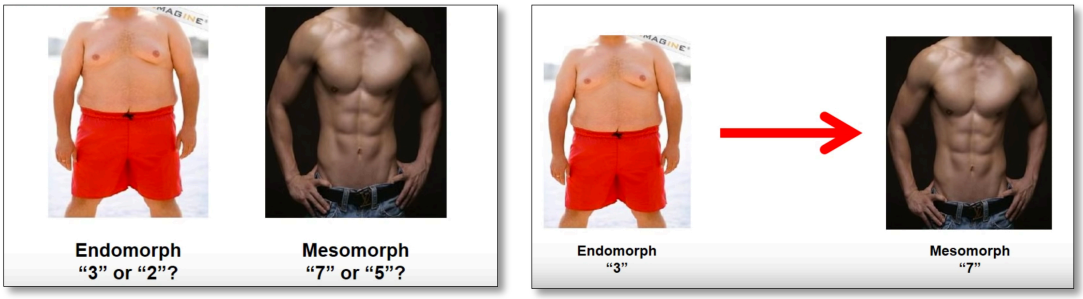

FIGURE 62 ORDER EFFECT ERROR (ROBB BUBB 2014)

Researchers started noticing bias effect on scale checking styles on response to a Likert scale since the end of 60-s. Modern researchers came also to a conclusion that Likert scales are bias. Bias exists on the left hand side of the scale – a negative side (Friedman 2015). In order to avoid it Friedman suggests that the right side should be presented first followed by the left side.

Problem here might be in bias of the questionnaire method, which means that the order of the scale might matter. In my case, the majority of the test subjects never tried VR technology before, which might have influenced their judgment, though not into a negative direction, but into more positive and higher ratings on the negative side of the scale. However, since the majority of the test subjects according to PI did not feel VBO at all, they could not rate a positive scale very high and I think that they even might have rated it less in comparison to the negative side of the scale which they rated higher. In other words the tendency here was to overestimate the negative side and underestimate the positive side of the scale.

6.3.2.2 ADAPTATION TO THE ENVIRONMENT AND VIRTUAL BODY

Another suggestion to such difference might be that participants did not get used to the environment, since they did not get any adaptation time. This might have resulted in that they rated next experiment higher than the previous one, however these differences are compensated by random task assignment and should have reduced the bias effect.

And my final suggestion to these deviations is that in general – being in the environment and by the end of the 3d condition, test subjects adapted to the environment and got used to see their virtual body. Memory factor also might have played a role– test subjects were told what VBO meant at the beginning of the test, but most likely forgot. When the conductor clarified to them what VBO meant during PI, they might have rated it more objectively, taking into consideration their feelings and memories straight after the tests.

6.3.2.3 SUBJECTIVITY OF MEASUREMENTS

Since questionnaire had some bias due to scale subjectivity, and personal interview due to total subjectivity of the perceptual feelings and interpretations, physiological measurement might have been used as collection of the quantitative results. However, studies done by the researchers, described in 4.7, did not give any useful results, especially concerning VBO threat measurements, as they could only measure that test subjects´ level of stress was a little bit higher. In this research test subjects´ wish to move the body might have been physiologically measured as well, which might be done through muscle registration in case of some movements intentions. These physiological measurements might have been involved together with questionnaire or personal interview. On the other hand, I tried to measure only VBO and not movements, which is very subjective on the first place.

Another idea is to make threat more realistic, as test subjects suggested in the personal interview – to show them the real physical hammer and start virtual hits with the hammer instead of the yellow ball, or try to hit their virtual wings with the knife in different places and measure the level of stress with galvanic skin response, for example, since virtual body threat and touch might be the main factors that influence the VBO. And the last point is to make threat more realistic by using better graphical and software opportunities.

6.3.3 RELIABILITY

Even though subjectivity factor played a big role in the quantitative method (questionnaire) of collecting the results, they should be still reliable.

Randomization helped to eliminate individual differences between the groups.

Even though test subjects did not have enough time to get used to the environment, using within group and randomizing the conditions gave test subjects more time to be in the environment.

Although test subjects claimed that they did not feel VBO at all in their personal interview, showed that anatomically correct touch condition (1:1 mapping) gave a higher VBO feeling, especially when Agency questions were cut out of the test analysis (during the second attempt in anova testing).

6.3.4 RESULTS USABILITY

First of all these results might be used for further research: which part of embodiment plays the major role in VR – if it is VBO or agency. These results might be used in the further comparison of VBO and agency.

Second of all the results might be helpful in finding out how each part of the embodiment influences the sense of presence – if it is actions that have the biggest impact on the sense of presence in VR or it is the look with tactile input that is more essential. And also if tactile input should be more repetitive (as having permanent would be almost impossible) in order to keep the VBO illusion going.

Third of all, what the researchers tried already to do is, if it is possible to split VBO from agency in VR. However, the test results should be more objective and more controlled – they should be measured with physiological measurement method in stead and not with a subjective one as Likert scale.

Finally, these results might be used in the further experiment of non-human avatar body representations in VR. This experiment used a flying mammal, which wings reminded of human hands anatomically. We still don´t know how much VBO test subjects might get, if they will get another avatar, which has nothing in common with human´s anatomy, for example, reptiles, like snakes. To which extant the virtual body could be modified in order to achieve the full feeling of VBO illusion. Of, course, here, agency might play more significant role, when controlling the avatar with gestural input. Nonetheless, it is still interesting to see, if and how the feeling of VBO might be created and what would be the differences between different VBOs depending on the physiological differences between the amount of likeness towards the human anatomy.

The last but not least is that VBO illusion might have been created only when there was a physical touch connection between the physical and the virtual body. This raises also some questions for further research – how reliable tactile feedback is without agency. Is VBO illusion is broken without touch input. As this test showed, VBO might be incomplete without agency.

Another possibility for continuation of the test is that 50% deviations from anatomically accurate touch showed that test subjects did not perceive it as drastic as in condition 3. This means that this gap between 100% touch accuracy and 50% deviation should be explored more in order to reveal what is the threshold for deviation.

One more possibility is to find out if females perceive touch differently from the males, or if gender plays any role in VBO perception. Or if gamers are quicker to get attached to their virtual body than non-gamers and under which conditions that might be true.

6.4 CONCLUSION ON THE RESULTS FOR EXPERIMENT I

Friedman´s test showed a significant difference between the groups. Post hoc test showed a significant difference between the 1st and the 3d condition. The major difference between the groups was given by Question 13 "I felt I was in control of my virtual body movement" from Group3.

Test subjects from Group1 (100% accuracy) felt mostly accurate anatomically placed Touch on the area of the wrist, since this was the area they could best see, taking into consideration difficulty due to the position on the floor and rather heavy HMD with a narrow POV. This might draw a conclusion that anatomically accurate Touch (1:1 condition) might provide the best illusion of VBO over a non-human virtual body. At the same time most all test subjects rejected achieving VBO in their Personal Interview.

Test showed that anatomically correct tactile feedback is one of the factors of creating VBO illusion over a non-human avatar body.

This test opened several more possibilities for further testing, as well as showed a possibility of existence of bias of the Likert scale, which should be eliminated in the future testing.

Furthermore it presented a possibility that unintentional movement in IVE might include 2 categories – movement caused by optic flow and force-caused movement, which might not produce the same results concerning VBO illusion.

To round it all up, in order to get the actual “VBO illusion” as defined by Slater I would suggest that in case of anatomical differences between the test subjects and the virtual avatars, physical and emotional connection should be adapted, as VR users might need the purpose for the virtual body (what to use it for) and possibility (full control over the movements) to use either virtual body.

Although if touch is studied further and if it will indicate that VBO illusion is created only at the exact moments when touch is perceived on the body or only through controlled movements that might lead to further studies of agency body awareness in VR.

7 EXPERIMENT II - EXPERIMENTAL DESIGN

This chapter would be devoted to the second experiment, involving agency. The basis for the methods were described in chapter 5 and therefore will be used here as a reference.

7.1 RESEARCH HYPOTHESIS AND CONDITIONS

The second research question that I would like to get answer to is the following:

> *Would voluntary controlled movements of a non-human avatar through the environment enhance the sense of embodiment in IVE?*

Based on the research question null hypothesis is defined down below. Synchronized audio feedback is included but not tested. Audio source should contain environmental soundscape and the sounds of wings´ beat, when movement taken. Supporting audio would be constant through all the conditions.

H_0 :

There is no significant difference between:

a) Fully controlled voluntary movements through the environment with the virtual body,

b) Fully controlled voluntary movements through the environment without the virtual body present,

c) Only fully controlled voluntary movements of the virtual body, where the body cannot move through the environment,

d) Involuntary movement through the environment without the virtual body present.

H_1 :

There is a difference between:

a) Fully controlled voluntary movements through the environment with the virtual body,

b) Fully controlled voluntary movements through the environment without the virtual body present,

c) Only fully controlled voluntary movements of the virtual body, where the body cannot move through the environment,

d) Involuntary movement through the environment without the virtual body present.

Conditions should include visual and proprioceptive feedbacks, which should be synchronous through all the experiments.

These conditions contain the following variables:

Condition 1

With the help of specified gestural inputs test subjects would be able to control virtual body movement through the environment, being able to see bat´s virtual wings.

Summarized Structure:

- Wings movement (controlled)
- Environment movement (controlled)
- Body present

Condition 2

With the help of specified gestural inputs test subjects would be able to control virtual body movement through the environment, without being able to see bat´s virtual wings.

Summarized Structure:

- Wings movement (controlled)
- Environment movement (controlled)
- No Body

Condition 3

With the help of specified gestural inputs test subjects would be able to control virtual body movements being able to see bat´s virtual wings in the same position where their hands are. There would be two possible ways to control the wings – being able to move hands up and down would allow them to control virtual wings going up and down; being able to move wrists up and down would give them a possibility to move virtual wrists of the bat up and down.

Summarized Structure:

- Wings movement (controlled)
- No Environment movement

- Body present

Condition 4

This condition would not allow the test subjects to control their virtual body movement through virtual environment and neither gives them a possibility to see their virtual body. Test subjects are suppose get a feeling of “watching a film” through HMD, where it would be impossible to interact with the environment in any way.

Summarized Structure:

- No wings movement
- Environment movement (not controlled)
- No Body (camera animation)

Based on this structure the following independent and dependent variables could be seen in Table 9.

Independent variables: cases of voluntary movement through the environment when body is present and when body is absent, voluntary movement of the limbs with body being present but no movement through the environment; finally as a controlled condition involuntary movement through the environment when body is absent.

Dependent variables: virtual embodiment, which includes test subject´s virtual representation as non-human avatar and controlled by test subjects movements as agency.

Independent Variables	Dependent Variables
- Voluntary movement through the environment using voluntary movement of the limbs; - Voluntary movement of the limbs.	Agency
- Presence of Virtual Body; - Absence of Virtual Body; - Involuntary movement (movement of the camera through a predefined path as a controlled condition).	Virtual Body Ownership

TABLE 9 INDEPENDENT AND DEPENDENT VARIABLES

7.2 DESIGN OF THE EXPERIMENT

- Assignment Method

Crossover study as within subject design (repeated measured design) will be applied to the groups, as this approach would save the time and resources, as described in section 5.2.

- Learnability

No learnability effect should be influencing the test subjects due to different perceptive experiences through all 4 conditions, which would also help to eliminate bias effect, as random order appliance would be useful in limiting individual differences. Next in line test subject should offset the difference produced by the first test subject, as described in section 5.2.

- Fatigue

The experimental time is set up to 2 minutes per condition, which might help to eliminate fatigue and at the same time would limit cybersickness, as flying in itself might provoke it together with the flying sinusoid pattern (wings up will produce lift and thrust, while wings down will produce drag and more gravity).

- Randomization

This would be applied to eliminate individual differences, as described in before in section 5.2.

7.2.1 POPULATION SAMPLING

Convenience method sampling would be used. Test subjects would be searched through Facebook groups. In order to avoid bias, Medialogy students would not be invited to this experiment.

7.2.2 TARGET GROUP

No specific requirements are required to the target group apart from having reasonable eyesight in order to perceive visual feedback and no proprioceptive disorders in order to make proper hand movements. Target groups should not have to have a specific knowledge of VR technology. No age limitation is specified to the target group.

7.2.3 DATA ACQUISITION METHODS

Both quantitative and qualitative methods will be used in this study. Both methods are described in section 5.2.3.

Since previous study showed that there might be some bias concerning data acquisition as described in section 6.3.2.1, this time Likert scale would be presented differently to the test subjects, as 1 – from fully agree to 7 – as totally disagree.

Methods for data acquisition are the following:

a) Questionnaire using Likert scale;

b) Observations;

7.2.4 DESIGN OF THE QUESTIONNAIRE

Questions 1-5 that will be used concerning virtual body are the same questions as used in the previous experiment, as described in section 5.2.4.

Questions 6-18 are questions about agency that are built using the same principals as described in section 5.2.4.1.

Question 6 is used to get a general impression of the test subjects about their impression if they could achieve the control and feeling of the flight, even though physically they were aware that they were not flying. The same principal was used in question 10, which was based on the questionnaire used in the study described in section 4.7.4.

Question 7 comes directly out of the definition of agency, since agency is the knowledge of the movement being produced by the body, meaning that the body has to have control over the movement. Though the form of the question is still based on the semantic analysis made in section 5.2.4.

Question 8 is based on the research of the embodiment in VR, particularly studying perceptual changes of the virtual body and self-representation. The body moved from 1 PP either synchronous or asynchronous, depending on the condition. One of the questions asked was: "*I feel that the movement of the virtual body are caused by my own movements*". Based on the analysis, described in section 5.2.4.1 I altered this question to "I felt as if it was me who caused the movement of the virtual body."

Question 9 and 16 are based on the concept that the interaction with the environment should be natural and realistic, in order to achieve a continuous sense of presence. This question was inspired by the study of interaction of the virtual hand with IVE, where test subjects were asked the following: "*I felt like I was able to interact with the environment the way I wanted to*." "*I felt that the interaction with the environment was realistic*."

Question 12 is also inspired by the same article as above, where the following question was asked: "*I felt like I controlled the virtual representation of the hand as if it was part of my own* *body*".

Since test subjects will not get the a specific instructions to avoid obstacles (as there will be no obstacles in the environment) but will told that it will be in their best to avoid collision with the rocks, question 13 was based on the question asked in the same study of interaction of the virtual hand with IVE: "*Did you try to avoid the virtual obstacle (barbed wire) while performing the task?*"

Question 15 is based on the concept that agency is not only actions but also intentions of these actions, which means that it is a internal process generated or "*at least linked to motor commands*", just before the commands are sent to the muscles (Kilteni, Groten, et al. 2012; Tsakiris et al. 2007), therefor it will be interesting to see if this small part of the theory would be supported by the experiment and test subjects will be thinking first of the direction and only then will fly there, since this will show their control of the virtual body actions.

- *VBO*

1. During the experiment there were moments where I felt as if the virtual wings belonged to me, despite the differences in physical shape between the wing and the hand.
2. During the experiment I felt that my physical hand was located at the same spot where the virtual wing was.
3. During the experiment there were moments when I felt as if the virtual wing was my own hand.
4. During the experiment there moments when I felt as if I was located inside the bat´s body.
5. Even though the virtual body I saw in the environment might not have had the same physical shape that I have, I felt as if the virtual body belonged to me.

- *Agency*

6. Sometimes during the experiment I got a feeling that I myself could fly.
7. I felt as if I was in control of the virtual body inside the environment.
8. I felt as if it was me who caused the movement.
9. I felt that the interaction with the environment was natural and realistic.
10. My virtual body moved in the environment as I wished it to move.
11. I felt that it was hard to control the virtual body in the environment due to the difference in shapes between my body and the virtual body.
12. I felt that I could control the wings as if they were part of my body.
13. I intentionally tried to avoid collisions inside the environment.
14. I did not feel a need to see my virtual representation (body) in the environment.

15. I was thinking about the direction first and then I moved to that direction when I was flying.
16. I could fully interact with the virtual environment just as bats would in nature.
17. It was difficult for me to move in the air.
18. The sound of the flapping wings helped me to feel my movement through the environment.

- *Comments*

19. If you have any comments, please add them here. You can also describe your feelings when being inside the environment.

- *General Information about the participants*

20. Gender (m/f)
21. Age
22. Occupancy
23. Computer knowledge (none, poor, average user, very good user, advanced user, expert).
24. I use Computer the most (at home, at work, for my education, for gaming).

7.3 THE COURSE OF THE EXPERIMENT

Before the test the letter of consent will be given to each test subject, where they will find the description of the purpose of the test, test procedure and some ethics and confidentiality moments as well as a possibility to stop the test at any time and privacy statement, included in Appendix, under the section 12.4.

7.3.1 TEST SUBJECTS

There were 40 participants all in a whole taking part in the experiment. However due to system instability only 25 of them were chosen as presenting the results of the study – 15 males and 10 females, aged between 15 and 53. The majority of the participants had none previous VR experience, except for 1 Master student from Sound and Music Computing from Aalborg University (who insisted on testing himself) and a couple of test subjects, who are currently working with sensor technology. The majority of the test subjects have had although relation to IT, being either students (mostly from IT university, advanced software development program) or working within IT field, as software developers or IT engineers. Only 12 users out of 25 defined themselves as “average users”, the rest were either “advanced” or “expert users”.

7.3.2 TEST SETUP AND PROCEDURE

All test subjects, as in the last test, were provided with HMD and audio headphones.

During the test participants were asked to stay in a T-pose with their hands stretched to the sides in order to calibrate the system. Afterwards, they were asked to control the avatar´s flight with the help of specific gestural inputs, described in section 4.10.3 and 12.4.

At the end of each session the participant were given digital questionnaire to fill in. Finally at the end of the test each participant could provide personal comments about the sessions to the conductor.

7.3.3 PILOT TEST

The primary meaning of the pilot test was with to test system´s stability and behavior.

The problem of the flying locomotive model built for this experiment was that physical data acquired through different research articles did not give specifically adjusted figures for thrust and drag coefficients, apart from these coefficients are supposedly being used as a range between 0 and 3 by different types of bats in nature. Therefore there were conducted 7 pilot sessions continuously adjusting these measurements. Since the speed was controlled by thrust and drag coefficient, as will be described later in section 7.5.2, these coefficients and the sense of speed was tested and some average numbers were applied at the end in the program, depending on the way pilot test subjects were using gestural inputs.

If hands were closer to the body it was found out that the up and down hand movements were easier and faster to perform than with the arms fully stretched to the sides.

Another notification was made that during the calibration process test subjects were stretching the arms by taking them higher on Y-axis, which created some physiological difficulties for them later during the flying session when controlling lift and drag, as they had to cross the T-pose line in order to generate these forces, which also will be described in section 7.5.2.

Pilot tests also showed some other system’s inconsistencies that were corrected.

7.3.4 TEST PERFORMANCE

There were no cases of registered nausea and the test was not interrupted by any of the test subjects. However, some of the test subjects felt a little dizziness in the head, if they needed more time to adjust and learn to control bat´s flying locomotion in IVE due to a sinusoid movement form (up when lifting force with thrust was applied and down when lift was disabled, gravity enabled and thrust with drag continuously influenced the flying virtual body) in order to stay in the air.

There were some problems with OptiTrack System´s performance. The problem was in tracking the direction virtual bat was facing. The problem started from the third pilot tester. Instead of facing forward direction the digital body moved 180 degrees backwards. Moreover it created latency, but in a small amount and only at the start of the session. To start with at was assumed that this happened due to a rather big size of the digital trackable objects in Unity 3D. Afterwards during pilot testing and several recalibrations of the system it was supposed that there were communication problems and bugs between OptiTrack and Unity 3D. Restarting the system almost after each test subject helped to keep it stable during each test. As was discovered later the previous group that was using OptiTrack System in multisensory lab had experienced the same type of problems.

7.4 DESIGN OF THE EXPERIMENTAL STIMULI

Body awareness includes both agency and body ownership. Since agency is both controlled actions and intentions test subjects should be able to get a feeling of fully controlled actions. Though due to the condition that controlled actions are limited by locomotion of flight with specific gestural input design of the specifics of flight algorithm should be investigated and further implemented based in the theory of flight from section 4.8.

Environment package “Medieval Environment Pack” was bought from Unity asset store[45].

7.4.1 FLIGHT MODEL

In order to create a realistic flight experience physical formulas, described in section 4.8 should be taken into consideration

Since there are a lot of variables/scenarios that will be taken into consideration I decided to make a user case diagram first

However there are known variables that might be used in the code already. They come from morphometric data, when considering vampire bat specie. Its data will be described below and used in the program.

7.4.1.1 MORPHOMETRIC DATA AND ATMOSPHERIC CONDITIONS

The vampire bat has the following biometrics, which could be seen from the table in Figure 28:

[45] https://www.assetstore.unity3d.com/en/#!/content/6859

Mass – 1180 g;

Wingspan – 130 cm;

Wing Area – 2000 cm^2;

Wing Load (Q) – 57.8 N/m^2;

Flying speed – 50 km/h

Hovering Flight: velocity = 0;

Bats flap wings per second = 10 times in general (Neuweiler 2000).

Since the vampire bat´s altitude is unknown it is possible to consider Mexican free-tailed bat that can fly up to 3.048 m high and obtain speed up to 97 km/h [46].

As an example in one of the lab experiments the researchers used the following parameters in the wind tunnel (Carpenter 1985):

Max horizontal airspeed 8-6 m/s

Air pressure – 0.15m/s

Temperature – 25°

7.4.1.2 CONDITIONS FOR THE ALGORITHM

Wingbeat Cycle:

As it was described in section 4.9, bat´s wingbeat cycle consists of 1 upstroke and 1 downstroke.

Angle of the attack (α):

Since angle of the attack controls Lift, Drag and Thrust forces it should be used as a dependent variable in accordance with upstroke or downstroke.

The horizontal position of the hands (stretched to the sides) should be taken as a 0 angle of the attack therefore calibration is needed, since people have different heights and body morphology.

- *Positive α* (0+180°) – hands are going up in upstroke

[46] http://facts.randomhistory.com/bat-facts.html

- *Negative* α (0-180°) – hands are going down in downstroke

Speed or Velocity

The speed of the moving body should take into consideration the position in space, such as a distance between the new and the previous position divided by time.

Hovering Flight

When the flying body starts hovering it does not have velocity, which means that the moving speed = 0. However the air speed would move it forward instead.

Stalling

The sharp turn could be made by reducing the Lift coefficient when increasing angle of the attack due to decrease of speed (this allows to achieve momentary Lift increase).

Physics in Unity 3D

Another very important consideration is, since I will be working with physics of the rigidbody in Unity I would have to work with a FixedUpdate function, as it makes calculations in a fixed frame rate rather than a non-fixed one that is used by Update function, as forces influencing the body should not differ depending on the frame rate.

Forces influencing the body

For the sake of simplicity it would be better to calculate only 1 aerodynamic force and then use it in accordance with different coefficients (Thrust, Drag, Lift). Since Gravity force is not changeable it might be as well be calculated by itself and applied as a permanent force.

Calibration

Calibration should be a staring point of the whole program, since it is there, where the zero angle of the attack would be calculated. Since the users might have different heights and body morphology it would be better to calculate the initial positions of the trackables on their body.

7.4.2 OVERALL SUMMERY OF THE FLIGHT

Test subjects will be controlling the flight with their hands. Hands up movement, which is called Upstroke, will generate Lift and Drag force. Drag will be stronger then Lift, while hands will be up, which will allow the forward movement through the environment. Hands down, which will be called Downstroke, will generate Drag and Thrust. Thrust have higher coefficient than Lift. This will allow test subjects to stop their flight. On top of that Gravity will be applied through the whole movement – during Upstroke and Downstroke. Nonetheless Lift will overcome Gravity under the Upstroke. Since during the Downstroke no Lift is applied it would allow test subjects to go down to the ground, as Gravity force would still influence them.

The second but not least important part is the period of time, when test subjects would have their hands on the sides (between Upstroke and Downstroke). I called it a "zero angle", nonetheless it could be called Middlestroke, as described in the literature. Zero angle will be calibrated, as test subjects would have different body height. After its calibration it would be used to split Upstroke from Downstroke. Based on that Upstroke angle and Downstroke angle would be calculated and the highest/lowest angle, which is the highest or lowest hand position, would be used by the system in order to process it and send information further to the forces, since without it the system would not know, which force to apply.

Furthermore, the zero angle would be used for calculating the interval, when the information would be sent to the system. Since it would be a bad practice to overload the system, only the smallest amount of data should be sent (actually the only one number out of many). For this purpose the zero "positive" angle would be treated as a ratio between 0.0f and 0.2f (I will use floats, as angles are a decimal number). The same will be done for zero "negative" angle, but numbers would be negative, between 0.0f and -0.2f.

This interval would also be used for sending the amount of time that would take to make an Upstroke or Downstroke.

Finally the forces would be applied per stroke and disables after each stroke, which would allow test subjects to accelerate, if they will make faster movements, depending on the angles.

For hovering simulation, test subjects would be able to keep their hand up at Upstroke and would be able to move forward, since Thrust and Drag would still be applied. It would not though allow them to move faster.

7.4.2.1 USER CASE DIAGRAM

User Class Diagram helps to structure the future program as an interaction representation of the users´ actions as well as it visualizes system´s requirements in the easiest way possible. It describes the sequence of actions happening as soon as the program starts, using an actor as representation of a user or an external system that interacts with the given system. As soon as the actor is interacting with the system association appears graphically presented as a line, shown in Figure 63 (Amber 2011).

For the User Case Diagram Violet UML Editor[47] was used, since it is very easy in use and is free of charge.

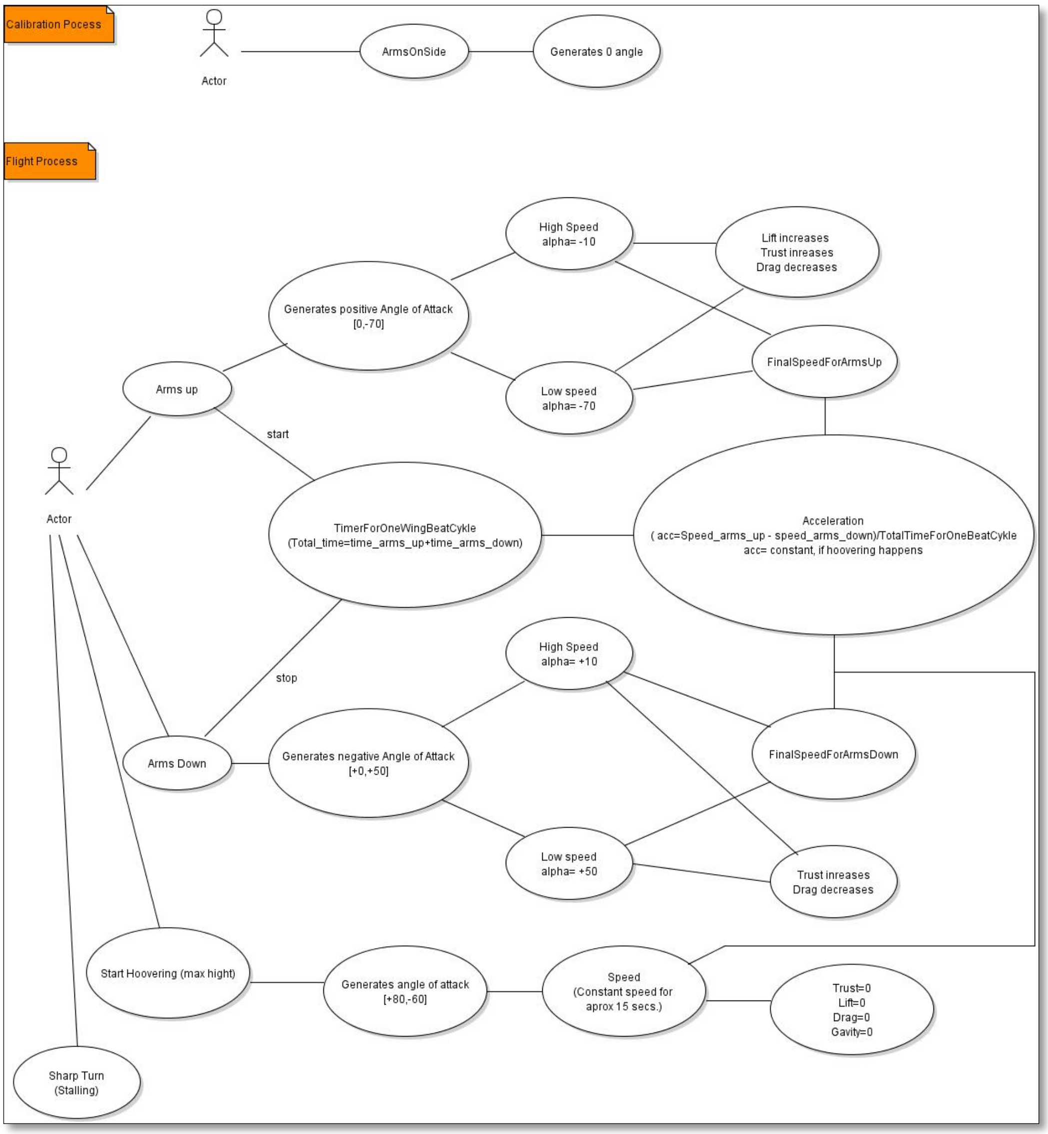

FIGURE 63 USER CASE DIAGRAM OVER A BAT´S FLIGHT

7.4.3 PSEUDO CODE AND CALCULATIONS

The following calculations of forces are necessary in order to simulate the physics of flight – Lift, Gravity, Thrust and Drag, which are the consistent parts of the main aerodynamic force that will be applied on the virtual bat, controlled by gestural input. Implementing physical

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[47] http://alexdp.free.fr/violetumleditor/page.php

forces and using trackables of the mocap system would give the feeling of the control over the virtual bat´s body.

7.4.3.1 AERODYNAMIC FORCES AND THEIR COEFFICIENTS

All forces will be distributed along the axis in 3D space, as shown in Figure 64. This should be done because Gravity depending on the mass of the object, if represented in the coordinate system, goes into the negative direction of the Y-axis; Lift goes into the positive direction of the Y-axis, since it is suppose to lift the object into the air. Drag is basically the air resistance or friction that is why it should be placed onto negative Z-axis; Thrust is the forward linear movement. Since Thrust is a forward movement it could also be considered as forward velocity from the programming point of view, or acceleration, depending of course on several other factors that will be explained later.

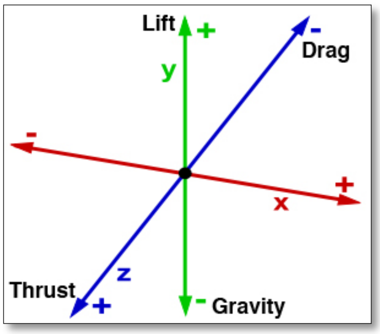

FIGURE 64 FORCES IN 3D SPACE

For simplicity solution I decided to emit details involving the center of mass of the object, and momentum that influence a flying object. I would calculate the main aerodynamic force, using formula and the rest of the forces, using the same main aerodynamic formula, would be multiplied by their own coefficients. This would be the easiest solution. However if the forces would have to use a negative direction they would also be multiplied by -1.

The Main Aerodynamic Force and Dynamic Pressure

The first variable that should be considered before main Aeroforce calculation is Dynamic pressure explained in Bernoulli equation. Since the whole pressure *p* consists of static and dynamic pressure together they should have been calculated together. However due to the fact that static pressure means that the fluid (air) is not moving, which from the programming point of view would give us 0, I would only take into consideration dynamic pressure, which is the following:

$$dunamicPressure = \frac{airDensity * \ airVelosity^2}{2}$$

From this equation it would be easy to calculate air velocity/ velocity of the flow:

$$airVeosity = \sqrt{\frac{2 * dynamicPressure}{airDensity}}$$ [48]

airSpeed could be calculated as*: Ground Speed – Wind Speed.*

However the higher into the air the bat will fly the more different air density variable there would be, therefore a table from Figure 21 could be used for this case scenario.

As these variables are known, it would be easy to calculate the main aerodynamic force, which is:

$$aerodynamicForce = \frac{dynamicPressure}{2} * wingArea$$

Lift Coefficient and Lift Force

There are 2 possibilities to calculate lift coefficient.

1) The first one is the following: since the wing is a perfect airfoil (it´s naturally curved) I will use p rather than any other coefficients. a_0 - would be a zeroAngleOfTheAttack, and a - would be angleOfTheAttack that might be captured by the trackables, when the test subjects would make a move (this angle is the angle between the flow velocity and the chord of the wing).

$$C_l = 2p(a - a_0)$$

$$C_L = 2 * 3.1415 * angleOf\ The\ Attack$$ [49]

(angleOfTheAttack in radians: pi radians = 180°).

2) And the second possibility is to use the following equation, also described in section 4.8 or rather to calculate Lift first and from the generated Lift calculate the lift coefficient:

$$theLift = aerodynamicForce * cLift$$

[48] https://www.grc.nasa.gov/www/K-12/airplane/dynpress.html

[49] https://www.grc.nasa.gov/www/K-12/airplane/incline.html

$$cLift = \frac{theLift}{dynamicPressure * wingArea}$$ [50]

Drag Coefficient and Drag Force

The same could be calculated for Drag force:

$$theDrag = \ aerodynamicForce * cDrag$$

It could also be determined experimentally - through the code testing, though the following formula could be useful:

$$cDrag = \frac{theDrag}{dynamicPressure * wingArea}$$ [51]

Angle of the attack

For the angle of the attack a starting point (zero attack angle) will be on X-axis, when the arms are stretched to the sides, therefor

- Positive angle of the attack:

  0 + 180° → arms are above 0 angle
- Negative angle of the attack:

  0 – 180° → arms are below 0 angle

In order to calculate the angle between 2 points (initial arm position and rotated arm position) I would need to calculate the angle between two vectors (I will be working with vectors in Unity 3D). Their common vertex would be the beginning of the hand and would be considered as (0,0,0), as shown in Figure 65.

---

[50] https://www.grc.nasa.gov/www/K-12/airplane/dragco.html

[51] https://www.grc.nasa.gov/www/K-12/airplane/dragco.html

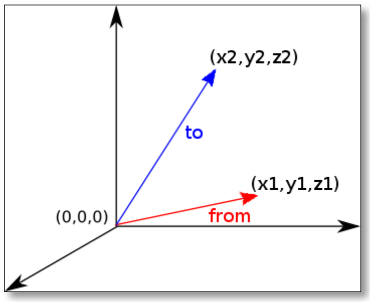

FIGURE 65 TWO VECTORS REPRESENTING A HAND POSITION IN THE SPACE

$$\cos a = \frac{A \cdot B}{|A| \cdot |B|}$$

where magnitude |A| = $\sqrt{x^2 + y^2 + z^2}$ (The same calculation is for magnitude |B|);

A·B is a dot product, which could be found as $|A| \cdot |B| \cdot \cos a$

In Unity 3D there is a special function for this Dot(), which is optimized and therefor does not use much of the calculation power.

In order to calculate the angle Unity 3D has another built in function for this purpose (Euler angles), which is calculated in degrees. But this function shows only positive angles, negative should be calculated further finding $\sin a$.

The Final Sum of the Forces

Net Force (Vector) = NetVericalForce (Vector) + NetHorizontalForce(Vector),

could be seen in Figure 29, where:

NetVericalForce = Lift-Weight (NetLift)

NetHorizontalForce = Thrust-Drag (NetThrust)

7.4.3.2 FLYING VELOCITY/SPEED

To start with flight velocity is generated by Thrust – Drag, when the bat will use energy for overcoming the forward airflow direction.

Since I will use a mocap system, where the movement would be captured with the cameras through trackables, I would need to know how much time test subjects used for upstroke and downstroke and sum this time together.

These variables could be controlled with the help of the Timer as calculating the difference between the startup time and the end time. This information could be sent to the Thrust, which will control the speed of the wingbeat cycle.

7.4.3.3 ACCELERATION

As soon as 1 wingbeat cycle happens (and the time is also calculated, as well as the program will be sure that both upstroke and downstroke occurred) it will be possible to calculate how many times per second (will be defined later through testing, how many ups and downs of the hands it is possible to make in a specific amount of time) the users moved their hands, or in other words the counter will be programmed. Based on this counter (the more wingbeat cycles there would be the more acceleration would be provided to the user) the program would calculate the acceleration of the flight with the help of the following formula, where the ration between velocity or the amount of wingbeats and T (time) happens:

$$A = \frac{\Delta V}{\Delta T}$$

7.4.3.4 CALIBRATION

Calibration would take care the registration the initial position of the trackables at the very beginning before using the application, which would be considered as the angle of the attack at 0°.

Calculations of the zero angle of the attack

The user would take the initial position: stays straight with the hands to the sides as shown in Figure 66.

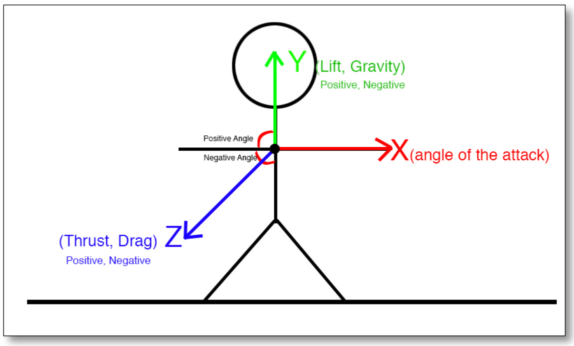

FIGURE 66 INITIAL POSITION AND FORCES

There are several possibilities how to make calibration.

1) Firstly it is possible calculate the distance between the HMD and the waist trackable. Afterwards position of the hand trackables would be captured and the distance

between the hands would be calculated. Finally with the help of the dot product (Vector3.Dot(A,B)) it is will be possible to check, if the hands-vector is totally perpendicular to the waist-head-vector and equal to 0. If it is the case, the angle of the attack with hands to the sides would get the initialization as 0 at this specific position for each test subject.

2) Find only initial positions of the trackables in the space and use these positions to calculate the zero (attack) angle per each hand.

7.4.3.5 CHANGING FLIGHT DIRECTION

Since I would like to give the users the ability to use their body in the most sufficient way, I would prefer to use waist trackable for changing the direction of the flight. Another possible way might be to use HMD. However, user would not be able to look around, as the bat might do, since with each turn of HMD the virtual bat would turn. The bats change the angle of the attack when they would need to rotate in the air. For the rotation purpose I would simply use the waist trackable and let users move around on the same spot for changing flight direction. In this case the hands would still be free for controlling attack angle.

7.4.3.6 CLASS DIAGRAM

Based on the following description and the User Case Diagram, described in section 7.4.2.1, and presented in Figure 63, I made a Class Diagram, shown in Figure 67. For the Class Diagram Nclass Free UML Class Designer[52] was used. The main advantage of this program is that when using class diagrams it has a function for code generation in C# automatically implementing necessary connections and logic behind and writing the defined attributes.

Due to a lot of variables and formulas as well as actions, programming wise it was the best to split forces, angle and wingbeat into the classes and apply them on the body from the Main class, which would be accessing the Rigidbody of a GameObject (the bat), as well as send variables from one class to another, using different programming access methods [53].

---

[52] http://nclass.sourceforge.net/

- [53] Inheritance, when the objects from the other classes can inherit and share the attributes and methods of the class they are inheriting from, where the attributes should be public. This type of relationship enables to reuse existing coding data.
- Monodirectional Associations, which are reference-based relationships, where I am setting the reference into the associated class constructor. Multiplicity indicators show the amount of connections one class has to another.

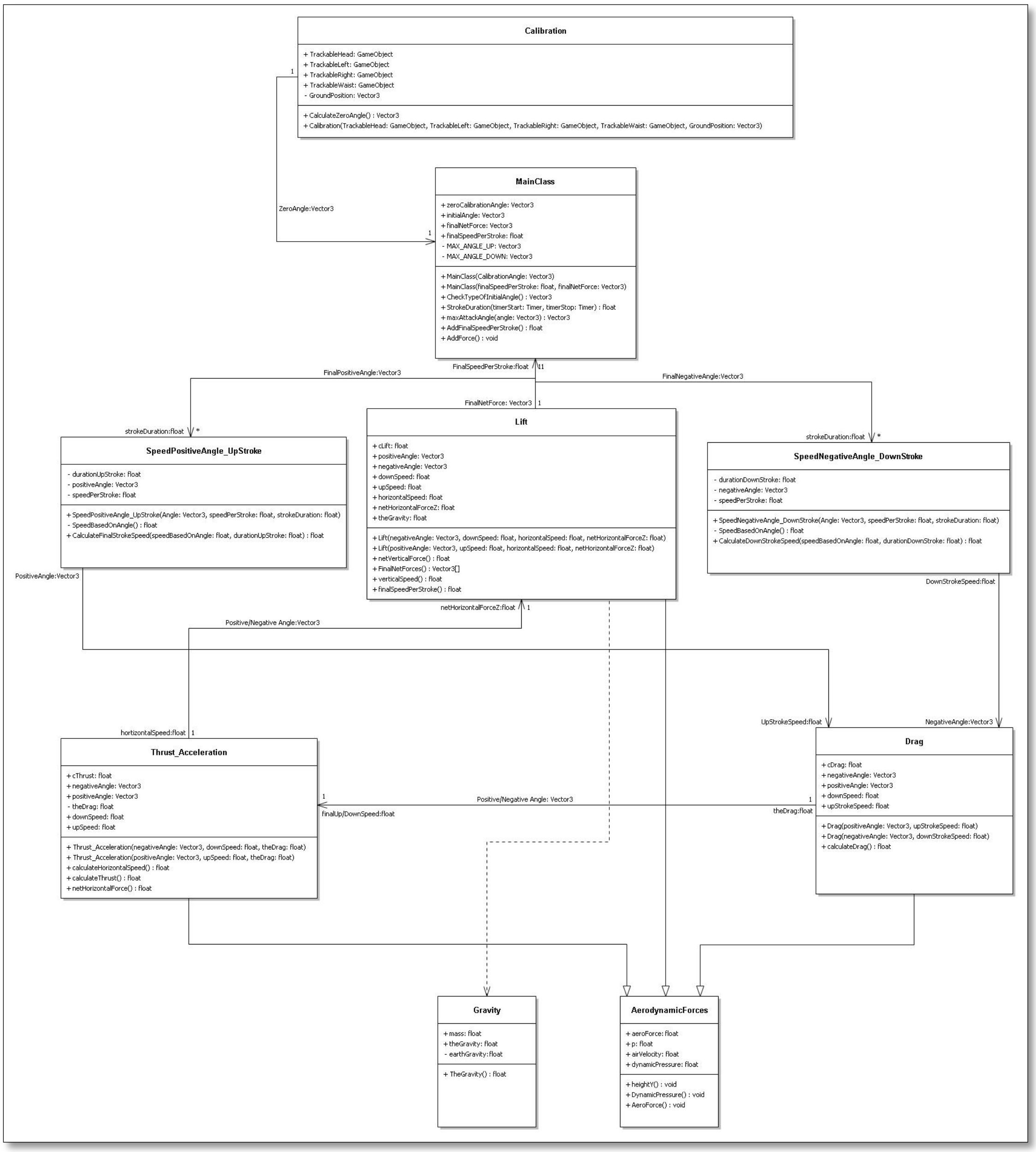

FIGURE 67 CLASS DIAGRAM

- Dependency, where I´m receiving a reference to a class as part of a method (Ambler 2003-2014), (Bhatt 2011).

7.4.4 MAPPING SYSTEMS

Mapping is the connection between test subject´s actions and the virtual environment made by the controls (using OptiTrack trackables) in natural and predictable manner (Steuer 1992). Actions between the physical and the virtual body should be matched based on synchronicity theory part, as was described in section 4.6.5. Natural mapping covers movements and intentions, corresponding to the movements in IVE, connecting actions to the virtual environment (Steuer 1992).

Mathematically speaking mapping is a transformation from A to B. It is a function. Linear mapping could include scaling or rotation, having a function $y = kx + b$, where a movement of the function is linear. Non-linear mapping include exponential transformations, as the easiest example, $y = x^2$ [54].

To simplify bat´s bio-algorithm of movement could be characterized as sinusoidal in case of linear horizontal movement and rotations (bat will be flapping with the wings up and down, going up and down in the air influenced by the forces) and therefore linear.

As was described in the section 4.6.2.2 it was found out that consequences of people´s making active movements are temporarily attracted to the action itself and therefore is leading to a paradox, where of asynchronous active movement being perceived as more synchronous than they actually are. This allows to map animated bat´s movements using rotoscoping technique, as described in section 5.4.4, to test subjects' movements and hopefully it would be perceived as correctly mapped movements (notes should be taken, if test subjects experienced it correct).

Users' movements should be mapped to virtual avatar movements in real-time, if we want to achieve a higher sense of presence in the virtual world. There are two possibilities to do so: either by attaching markers to the limbs of the biological body, tracking a rigid body, and computing the avatar´s movements by inverse kinematics, or by tracking the full body movements with a real-time motion capture system and applying the resulting motion to the avatar. Motion capture system, in general, maps users´ movements into the set of positions and/or rotations of the avatar bones. When the right body movements are captured by the optical system it is possible to use it for animation of the virtual avatar, representing oneself within a game engine (Spanlang et al. 2014).

[54] https://www.physicsforums.com/threads/how-to-find-if-eq-is-linear-or-non-linear.153714/

7.4.4.1 MAPPING TECHNIQUES

Since bats are not able to move with their fingers, but only roughly stretching their membrane and bending a little bit their fingers during the flight (section 4.1 and 4.2) it provides a possibility to directly apply several mappings to gestures, described below.

LIMB MAPPING – "ONE TO ONE" MAPPING

By linear "*one-to-one"* mapping should be understood the movements that would effect virtual wing or wrist when moving physical hand or wrist - the same effect, as looking in the mirror and watching your body move.

6 Trackables would be used for this mapping: 1 on 2 wrists, 1 on 2 arms, 1 on waist and 1 HMD, as visible in Figure 68. All trackables are presented in Figure 70.

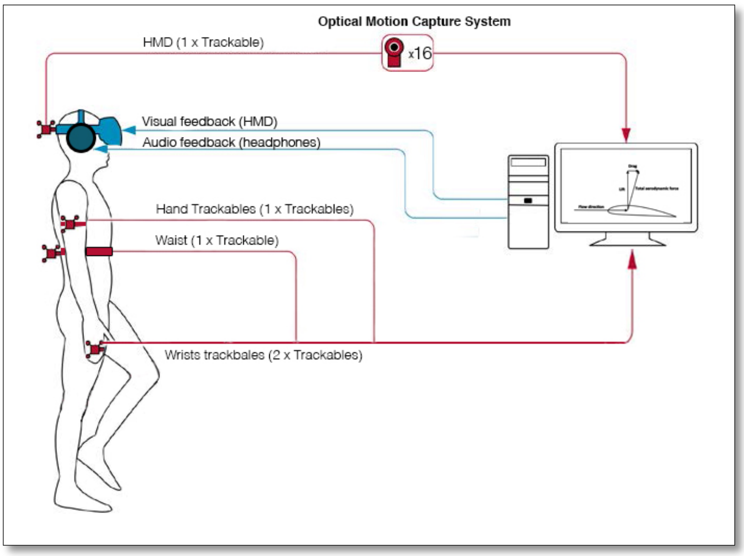

FIGURE 68 MOTION CAPTURE SYSTEM (16 CAMERAS USED) TRACKING 6 TRACKABLES, EXPERIMENT II

ANIMATION MAPPING – "ONE TO MANY" MAPPING

By linear "" *one-to-many*" mapping should be understood a linear mapping of one handbeat cycle to one wingbeat cycle of bat´s animation. For this purpose there is no need to track the exact movement of the limbs, but only track their position in space and synchronize with animation. Therefor only 4 trackables will be used, as presented in Figure 69.

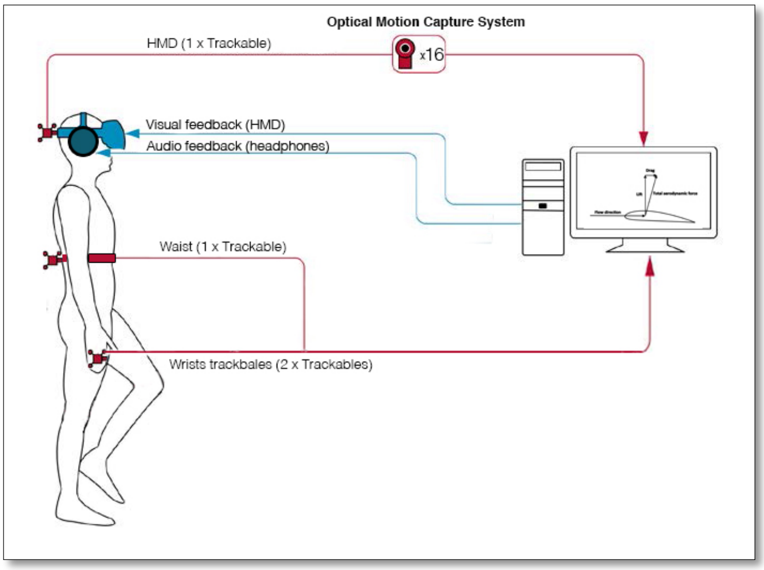

FIGURE 69 MOTION CAPTURE SYSTEM (16 CAMERAS), TRACKING 4 TRACKABLES, EXPERIMENT II

FIGURE 70 SIX TRACKABLES FOR CONDITION 3, EXPERIMENT II

7.5 IMPLEMENTATION OF THE VIRTUAL STIMULI

Based on the previous discussions and consideration, implementation was done and will be described in this section.

7.5.1.1 HARDWARE AND TECHNICAL CHARACTERISTICS OF THE SYSTEM

The same hardware and technical characteristics of the system were used for this experiment as for the previous one therefore its description could be referenced to section 5.5.1.

The only difference is in this experiment from the previous one is that through all the whole experiment 16 cameras were used to track test subjects´ movements. The whole system set up is visible in both Figure 68 and Figure 69.

The amount of trackables depended on the conditions and is described in the section 7.1.

For the limb movement (condition 3) - 6 trackables are used, as shown in Figure 68 and Figure 70. For the movement through the environment - 4 trackables are used, presented in Figure 69.

The summery of the program, what it does, and how forces, velocity and acceleration used, based on Upstroke or Downstroke and zero angle, comprising time per stroke, is described in details under the section 7.4.2

7.5.2 DEVELOPMENT

As a development environment MonoDevelop was applied, using C# language.

Since each behavior was written in a separate function, they will be described underneath, including where and why these functions were used. At the very beginning of the program I defined all necessary variables that I was using.

Ex: `public GameObject Trackable2;`

Start() function, which is called only at the beginning of the program was used to instantiated objects. Objects were found by name.

Ex: `Trackable2 = GameObject.Find("Trackable2");`

All functions, since I was working with physics, were running in the FixedUpdate()[55], where times, it is executed per frames, is fixed and synchronized with physics and rendering engines.

7.5.2.1 ANGLE CALCULATIONS

In order to calculate mean angle - Vector3.Angle (from, to) function was used, which returned an acute angle between 2 vectors. Angles could come only up to 180°. Since from the described formula (section 7.4.3) we would know how to calculate cosine of the angle, sine is very easy to find, since it is a square root of 1-cosine^2. Unity 3D has a built in function Mathf.Sign(), which would return positive and negative numbers of the angle (Figure 71).

Both angles, for right and left hand, had been calculated and mean function returned the mean float number of these two angles that would be used later (Figure 71).

```
// Calculating Left Hand ANGLE

public float CalculateAngle_LH(Vector3 fromVector, Vector3 toVector, Vector3 vectorNormal)
{
    float angle = Vector3.Angle(fromVector, toVector);
    float sign = Mathf.Sign(Vector3.Dot(vectorNormal, Vector3.Cross(toVector, fromVector)));
    finalAngle_LH = angle * sign;


    return finalAngle_LH;
}

//Calculating MEAN ANGLE

public float MeanAngle(float rightHandAngle, float leftHandAngle)
{
   float meanAngleCalculate = (rightHandAngle + leftHandAngle) / 2.0f;

    return meanAngleCalculate;
}
```

FIGURE 71 CALCULATION OF THE LEFT HAND ANGLE AND MEAN BETWEEN RIGHT AND LEFT HAND ANGLES

7.5.2.2 CALIBRATION

Calibration produced a “zero” angle between the right and the left hand. It was done so, that when “escape” key was pressed, the program loaded data from the hand positions for 5 seconds (since test subjects might have moved their hands, etc.). Afterwards the mean of these positions was calculated, which gave the “zero angle” for the right and the left hand separately, presented in Figure 72.

[55] http://answers.unity3d.com/questions/10993/whats-the-difference-between-update-and-fixedupdat.html

```
// CALIBRATION RH
public Vector3 LogDataRH () {

    if (Input.GetKey ("escape")) {
        // Time is 5 seconds
        if (Time.time <= 5.0f){

            XsRH += Trackable3.transform.position.x;
            YsRH += Trackable3.transform.position.y;
            ZsRH += Trackable3.transform.position.z;

            // THe times X positions are calculated
            timesPerPosition++;
        }
    }

    rightHandMean = new Vector3(XsRH/timesPerPosition, YsRH/timesPerPosition, ZsRH/timesPerPosition);

    return rightHandMean;
}
```

FIGURE 72 CALIBRATION

7.5.2.3 SYSTEM FOR DEFINING MAX AND MIN ANGLES

In order to make computer do less calculations I decided to give some specific number for a certain range of the meanAngle´s values. Another thought was that according to the theory of bat´s flights the max angle for the Upstroke could be 70 and min could only be 10, which is also used for the Lift. Therefore only positive numbers within the range from 10 to 70 were defined, where the Max number (the maximum position of the hand going up) was calculated with the help of built in function Mathf.Max(), presented in Figure 73.

```
public float MaxAngleUpStroke(float meanAngle)
{
    MAX_ANGLE_UP = 0.0f;

    if ((meanAngle > 0.2f) && (meanAngle < 5.0f))
    {
        val1 = 10.0f;
    }
    if((meanAngle >5.0f) && (meanAngle < 10.0f))
    {
        val2 = 20.0f;
    }
    if((meanAngle >10.0f) && (meanAngle < 15.0f))
    {
        val3 = 30.0f;
    }
    if((meanAngle >15.0f) && (meanAngle < 20.0f))
    {
        val4 = 40.0f;
    }
    if((meanAngle >20.0f) && (meanAngle < 25.0f))
    {
        val5 = 50.0f;
    }
    if((meanAngle >25.0f) && (meanAngle < 30.0f))
    {
        val6 = 60.0f;
    }
    if(meanAngle >30.0f) // && meanAngle < 22.5f)
    {
        val7 = 70.0f;
    }
    MAX_ANGLE_UP =  Mathf.Max (val1, val2, val3, val4, val5, val6, val7);

    val7 = 0.0f;
    return MAX_ANGLE_UP;
}
```

FIGURE 73 LIMITING MAX ANGLE UPSTROKE VALUES, DEPENDING ON MEAN ANGLE

Min angle was also calculated in the program, which registered the minimum down position of the hand, when test subjects were flying. Mathf.Min() Function was used for this purpose. Numbers were negatively ranged from -10 to -50 in accordance with the theory of bat´s flight.

7.5.2.4 STROKE DURATION

Several issues occurred with this function. Firstly I tried to use Time.deltaTime in order to access frames and use them as a counter. However it did not work since it kept counting for one of the hands, even when the function was reset for both of the hands. Therefore it was decided to access computer time. Before starting I needed to instantiate a new dt object, which was shortened for DateTime.

First, since this was an UpStroke duration function it was considering only meanAngle > 0. meanAngle < 0 was treated by StrokeDurationDown () function, which has the same principal. In order to send the minimum time interval (the exact seconds of the movement that took place), I needed to define the smallest interval, which was found throughout writing the time out to the console. DataTime.Now property gets an object of a DateTime that has the local data and time of the computer[56]. In order to avoid previous problems I created a variable temporaryTimeValue that counted how much time passed. This time could be removed from the Time of a stroke, each time the stroke was taken.

Secondly, there should be created some interval around meanAngle, where the values should be passed further in the program to the other functions. The smallest interval, for sending the values and time reset was found >0.12f and < 0.25f, where only 1 value passed through in order to save computational power. If there would be too many calculations done it would slow the program down, which should be avoided, since there is already some latency, described in section 4.4. Finally forces were also applied in this function.

The whole function was called in a FixedUpdate() Function, which means that it was possible to apply the forces each time the Upstroke or Downstroke were taken by the test subjects. The faster the wingbeat was the faster test subjects could fly.

[56] https://msdn.microsoft.com/en-us/library/system.datetime.now%28v=vs.110%29.aspx

```
// STROKE DURATION UP

public float StrokeDurationUP(float meanAngle, float maxAngle)
{
    DateTime dt = new DateTime();

    if (meanAngle > 0.0f)
    {
        MAX_ANGLE_DOWN = 0.0f;

        dt = DateTime.Now;
        strokeDurationUp = (float)dt.Second-temporaryTimeValue;

        bat.transform.rotation = Quaternion.LookRotation(Trackable2.transform.forward * Time.fixedDeltaTime);
        // Adding Force to rb
        rb.AddForce(0.0f, VerticalForce(), 0.0f);
        // Horizontal force is applied locally
        rb.AddRelativeForce(transform.forward * (HorizontalForce()));

        if ((meanAngle > 0.12f) && (meanAngle < 0.25f))
        {
            temporaryTimeValue = dt.Second;
            strokeDurationUp = 0.0f;
            val1=val2=val3=val4=val5=val6=val7 = 0.0f;
        }
    }

    return strokeDurationUp;
}
```

FIGURE 74 UPSTROKE DURATION AND FORCES APPLIED

7.5.2.5 STROKE SPEED

There were two functions applied – based on positive angle (hands up) and based on negative angle (hands down). SpeedBasedOnAngle(), seen in Figure 75, used positive angle. Speeds of how fast should the virtual bat move in the environment, depending on the positive or negative angle, described in section 7.5.2.3, were defined experimentally through the pilot tests. The same process was done for the negative angle.

Final stroke speed was calculated in the CalculateFinalStrokeSpeed() function, using the parameters as speedBasedOnAngleUp and durationUpStroke floats. This function background has used the basic principal of *displacement/time = velocity*.

```
private float SpeedBasedOnAngle(float positiveAngle)
{
    if (positiveAngle >= 0.25f && positiveAngle <= 10.0f)
    {
        speedUpStroke = 2.0f;
    }
    else if (positiveAngle == 20.0f)
    {
        speedUpStroke = 5.0f;
    }
    else if (positiveAngle == 30.0f)
    {
        speedUpStroke = 8.0f;
    }
    else if (positiveAngle  == 40.0f)
    {
        speedUpStroke = 11.0f;
    }
    else if (positiveAngle == 50.0f)
    {
        speedUpStroke = 16.0f;
    }
    else if (positiveAngle == 70.0f)
    {
        speedUpStroke = 21.0f;
    }
    else if (positiveAngle > 70.0f)
    {
        speedUpStroke = 27.0f;
    }
    // print ("Up Speed = " + speedUpStroke);
    return speedUpStroke;
}

// FinalStrokeSpeed depends on the UpStroke speed and Positive Angle

public float CalculateFinalStrokeSpeed(float speedBasedOnAngleUP, float durationUpStroke)
{
    finalStrokeSpeed = speedBasedOnAngleUP / durationUpStroke;
    // print ("Final UpStroke Speed = " + finalStrokeSpeed);

    return finalStrokeSpeed;
}
```

FIGURE 75 DEFINING SPEED BASED ON ANGLE

7.5.2.6 LIFT AND COEFFICIENT, GRAVITY

Lift coefficient used the formula, described in the section 7.4.3, shown in Figure 76, where p is the density and was calculated, as described also in the section 7.4.3. Since Lift was applied only on the max angle (hands up), therefore it involved only these values.

```
public float CLift()
{
    clift = (2 * p * MAX_ANGLE_UP)/10;

    return clift;
}
```

FIGURE 76 LIFT COEFFICIENT

In general Lift, Thrust and Drag were calculated similar - Aerodynamic force multiplied with different coefficients. Aerodynamic force, used the formula, described in section 7.4.3. In Figure 77 Lift force is used as an example of how I implemented the rest of the forces. -1 coefficients were used only for Drag and Gravity (private float earthGravity = 9.80665f;). Forces were applied in StrokeDurationUp/Down() functions, which were called in FixedUpdate() function.

```
// Lifting Force
public float TheLift()
{
    float liftF;
    liftF = AeroForce() * FinalLiftCoef();
    theLift = 1 * liftF;

    return theLift;
}

// GRAVITY

public float TheGravity()
{
    Fgrav = mass * earthGravity;

    theGravity = -1 * Fgrav;

    return theGravity;
}
```

FIGURE 77 LIFT AND GRAVITY FORCES

7.5.2.7 TRACKABLES AND WAIST ROTATION

There were used either 4 or 6 trackables, depending on the condition. Trackable1 was HMD.

Trackabe2 was attached to the waist. In order to rotate the virtual bats body synchronously with test subject's rotations I used the following function below, which included quaternion, representing rotation.

bat.transform.rotation = Quaternion.LookRotation[57](Trackable2.transform.forward * Time.fixedDeltaTime[58]);

7.5.2.8 ANIMATIONS - FORWARD MOVEMENT THROUGH THE ENVIRONEMENT

In order to control animations in Unity 3D through scripting, animator component should be created, by defining the parameters inside the animator. I used Booleans, presented in Figure 78. I divided the movements into UpStroke and DownStroke state. I also used Idle as a default state. If the test subjects entered either Up- or DownStroke state, afterwards they could only

---

[57] http://docs.unity3d.com/ScriptReference/Quaternion.LookRotation.html

[58] Time.fixedDeltaTime - is an interval for fixed frame rate updates. It plays application meters per second instead of frames per second. http://docs.unity3d.com/ScriptReference/Time-fixedDeltaTime.html

change between these two states. Animation speed was changed to 0.5f (1.0f is the normal speed), shown in Figure 79.

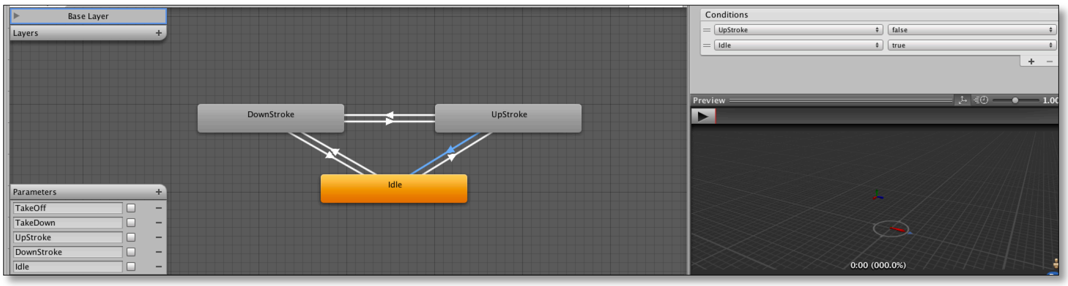

FIGURE 78 ANIMATOR COMPONENT FOR MOVEMENT THROUGH THE ENVIRONMENT

```
if(calibIsDone && meanAngle > 0.2f)
{
    animator.SetBool("UpStroke", true);
    animator.speed = 0.5f;
    animator.SetBool ("Idle", false);
}

else if(calibIsDone && meanAngle < 0.0f)
{
    animator.SetBool("UpStroke", false);
    animator.SetBool ("Idle", false);
}

if(calibIsDone && meanAngle < -0.2f)
{
    animator.SetBool("DownStroke", true);
    animator.speed = 0.5f;
    animator.SetBool ("Idle", false);
}
```

FIGURE 79 ANIMATOR STATES FOR MOVEMENT THROUGH THE ENVIRONMENT CODED

7.5.2.9 ANIMATIONS - LIMBS MOVEMENTS (NO MOVEMENT THROUGH THE ENVIRONEMENT)

Since limb movements included not only virtual wing movement but also virtual wrist movement, it had to be animated and exported to Unity, as other fbx files. Animator component had to be created. I decided that wrist movement would be possible to access from “Any State” that is why it has connection from Any State to Idle. Thereafter from Idle it was possible to either make the wing forward- or the wing backwards movements, as presented in Figure 80.

Boolean parameters were used also for this part. Animation speed was set to 0.5f. Audio was playing only once per stroke with changed pitch and volume, as it was too loud sample, but it had to suit the overall experience, and considering that other sounds might be louder in nature, as waterfall, for example. Pitch was changed here due to the fact that only 1 audio sample was used for Up- and Down Stroke. In order to make a randomized effect I had to change pitch in this function, but I did not change it in another one – Animation Backwards State. Randomized effect would not be heard as too much repetitive. The code is shown in Figure 81.

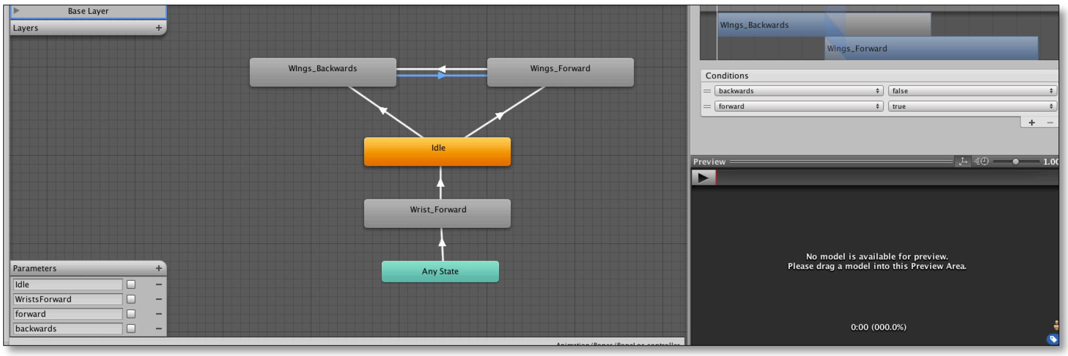

FIGURE 80 ANIMATOR COMPONENT FOR LIMB MOVEMENT

```
// ANIMATION - FORWARD STATE

if(meanAngle < 0.0f)
{
    //animator.SetBool("Idle", false);
    animator.SetBool("forward", true);
    animator.speed = 0.5f;

    soundDown = true;

    if(!audio.isPlaying && (meanAngle < -0.5f) && (meanAngle > -0.8f))
        {
            //SoundDown();
        audio.PlayOneShot(wingsUp, 1.0f);
        audio.pitch = 1.2f;
        audio.volume = 0.5f;
        //Debug.Log ("DOWN");
            }
        else
            {
                soundDown = false;
                audio.Stop();
            }
}
else
{
    animator.SetBool("forward", false);
    animator.SetBool("backwards", true);
}
```

FIGURE 81 ANIMATOR STATES FOR LIMB MOVEMENT CODED

7.5.3 ISSUES AND SOLUTIONS

7.5.3.1 TRACKING TOOLS

Several times through the whole test the system needed recalibration as a solution to the following problems:

Bat was facing a wrong direction due to a different previous calibration (Z-axis on the plane was chosen with a different direction).

Second time due to the marker expending on the screen (from 3 to many). Trackables use 3-marker calibration system. Restarting the program on the computer dis not help.

Lastly due to the constant change of direction bat was facing each time when program started. Recalibration made the system more stable and changes of the direction did not occur each time a new test subject was tested.

8 EXPERIMENT II - RESULTS

This chapter will show how the results are processed. To start with I would present the results of mean, median, standard, deviation and variance in each group as well as for each questions separately in each group, which would help to see some tendencies in order to determine the path to proceed the analysis. Then all data scores would be checked for normality in order to see, which test should be applied. Furthermore correlation coefficients should be found. Finally, after determining, which test to apply, the necessary test should be done and conclusions made.

8.1 PRESENTATION OF THE RESULTS

As was described in chapter 7 experiment measured VBO and Agency quantitatively with the help of the designed questionnaire. VBO questions were questions 1-5; agency questions were 6-18. In order to be able to work with data – make statistical analysis, I will treat the results as ordinal data.

Visualization makes it possible to determine some tendencies for the future analysis. The difference in means could be clearly seen as soon as I made visualization for all 4 conditions disregarding division into Agency and VBO questions. The results could be seen in Figure 82, where it is clear that means have a difference. For condition 1, 2 and 3 mean is 2.36, while for condition 4 mean is 6.08. The rest of the plots are on digital PDF version of the Results for Experiment II.

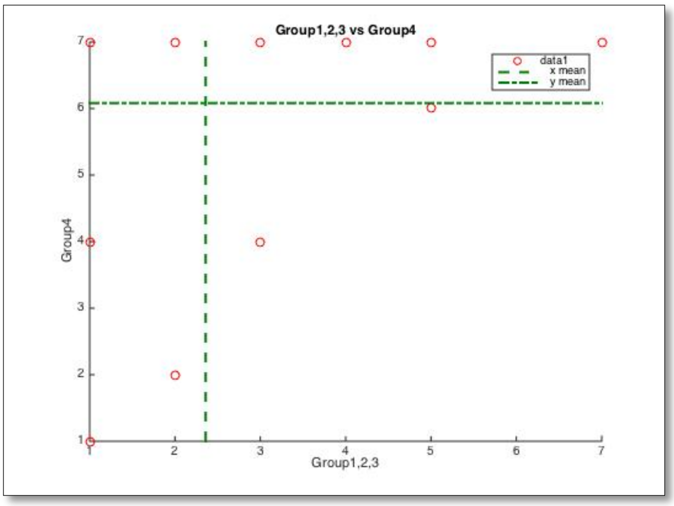

FIGURE 82 MEANS FOR CONDITIONS 1, 2, 3 AGAINST A CONTROLLED CONDITION (GROUP 4)

The results for calculating mean, median, standard deviation and variance for each condition for all questions together per condition, are the following and are presented in Table 10.

Results	Condition 1	Condition 2	Condition 3	Condition 4
MEAN	2.3889	3	3.2222	6.1667
MEDIAN	2	3	2.5000	7
STD	1.6499	1.7489	2.3653	1.8550
VAR	2.7222	3.0588	5.5948	3.4412

TABLE 10 MEAN, MEDIAN, STD, VAR FOR EACH OF THE 4 GROUPS

According to Likert scale (and after correcting possible bias discovered in Experiment I) scoring 1 would show the total agreement and 7 - total disagreement with the questions. As Table 10 shows, results scores for Condition 1 were the highest from all 4 groups. Condition 3 is in the middle but still on the positive side of the questionnaire (if we split 7 point into 2, it would give us 3.5 which will be a scaring point for positive/negative side of the scale).

Mean of Condition 4 is situated very close to 7 and far away from the other 3 groups, which indicates that there is a difference between them. Condition1/ Group1 tended to rate questions closer to score 2 in their answers, while in condition 4 the tendency is 7, which also explains the mean value of 6.1.

The smallest standard deviation (std – how much scores deviate from mean) belongs to Group 1 indicating that the quantity of the data samples of Group 1 differs from group mean value only at 1.6, while the highest belongs to Group 3 – 2.3653 and not to Group 4. This might mean that perception of the movements and the environment was very contradictory, as test subjects could move with the limbs but not move through the environment. Higher std might indicate that there is a bigger difference between the test subjects perception of movements. The highest variance (how spread out is data distribution) has Group 3. One of the explanations might be a difference in perception among the test subjects. Furthermore this large number might have had some influence from the technical problems experienced during the test (system needed rebooting as was described before in section 7.3.4). Nevertheless the lowest data spread belongs to Group 1, where test subjects´ score does not have that big variance in scores as for Group 3.

Before looking at Table 11 there should be noted that questions 11 and 17 were inverted and the closer rating were to 7 the more positive they were, whereas for the rest of the questions – the less positive scores were.

Table 11 presents mean per each question in 4 conditions. As one could see the highest mean has condition 1 (apart from Question 4, which is worse than in condition 2). The question is the following "*During the experiment there moments when I felt as if I was located inside the bat´s body*". This might mean that Group 1 did not feel that they were "inside" the body, even though they got a stronger feeling of owning the body than Group 2. Both Group 1 and Group 2 got similar score for question 3 "*During the experiment there were moments when I felt as if the virtual wing was my own hand*". The explanation might find place in the proceeding analysis, as Group 2 did not have a virtual body. Though they saw a shadow and that might have influenced their perception. Another explanation might be that since they felt control over the body it was enough for them to assume that they had a body. And finally some test subjects, having previous conditions, remembering that they had a virtual body assumed that they still have a body, even without seeing one on the screen.

Questions	Condition 1	Condition 2	Condition 3	Condition 4
Question1	2.3600	2.8800	3.0400	6.0800
Question2	2.2000	2.6000	3.2800	6.2000
Question3	2.6400	2.6400	3.2000	6.2000
Question4	3.3600	3.2800	3.5600	5.2000
Question5	2.6000	3.2400	3.2800	5.4000
Question6	2.2800	2.6400	4.2000	4.3200
Question7	1.9200	2.4000	3.5600	6.0000
Question8	1.8000	2.0000	2.2000	5.9600
Question9	2.3200	2.6800	3.6800	4.1600
Question10	2.6400	2.9600	4.1600	6.0000
Question11	5.0000	4.6800	4.7600	4.0800
Question12	2.4000	2.8800	3.3200	6.1600
Question13	1.8400	1.9200	5.1200	4.1600
Question14	2.4400	2.8000	3.8800	4.0000
Question15	2.0800	2.2800	5.2800	5.3200
Question16	2.6800	3.2400	5.1200	5.4000
Question17	4.6800	4.5200	4.3600	4.5200
Question18	2.0000	2.2400	3.6000	4.8400

TABLE 11 MEANS PER EACH QUESTION FOR ALL 4 CONDITIONS

The biggest difference between Group 1,2 and 3 was Question 6 "*Sometimes during the experiment I got a feeling that I myself could fly*" – where Group 3 was deprived from flying through the environment. For the same question Group 3 and 4 scores did not have big difference. This might indicate that even though in condition 4 there was uncontrolled movement involved test subjects estimated it right – they were simply not in control of the movement, even when being moved through the environment and in regards to this they did not get the amount of VBO as the first 2 groups did, as could also be seen in Table 12, when Groups were divided into VBO and Agency. However agency was still higher than VBO for Group 4.

Group 3 considered that they were more in control than Group 2 though in regards to Question 11 "*I felt that it was hard to control the virtual body in the environment due to the difference in shapes between my body and the virtual body*". This might be explained through the condition, where test subjects were able to control the limbs in condition 3, but could not see their body and neither limbs in condition 2, which might indicate an importance of seeing the virtual body in IVE, when a non-human avatar is involved.

Concerning Question 17 "*It was difficult for me to move in the air*", scores were the same for condition 2 and 4, as Group 2 could not move through the environment and Group 4 could not control the movement through the environment, but was moved through it.

Overall results for mean, median, standard deviation and variance (for each condition, all questions) are presented in Appendix 12.6.

Table 12 presents means for two groups VBO and Agency separately (spitted according to the questions from the questionnaire).

Means in Conditions	VBO	Agency
Condition 1	2.6320	2.6215
Condition 2	2.9280	2.8646
Condition 3	3.2720	4.0954
Condition 4	5.8160	4.9938

TABLE 12 MEAN FOR VBO AND AGENCY GROUPS

In both conditions 1 and 2 (when test subjects moved through the environment) generally agency is slightly higher than VBO. In the 3d condition (no movement through the environment) VBO is higher than agency. It also should be noted that test subjects in condition 3 had a chance to see their limbs very close (as they had to move HMD in order to see limbs on the left or right side of the virtual body). This might have happened because test subjects did not have to pay attention to the surrounding environment, move through it and avoid collisions but fully concentrate on their virtual body, even though they were asked to move their virtual limbs. In condition 4 - agency got better results than VBO since test subjects were moved through the environment (unintentional movement that could not be controlled). This type of movement did not include proprioceptive sense though and therefore it is still discussable if and under what conditions unintentional movement might belong to VBO in VR when proprioception is absent, which the results from Experiment I also showed. Both agency and VBO are though on negative side of the scale (closer to 7) in condition 4.

These results suggest that agency is higher when there is a controlled movement through the environment and lower when there is only movement of the virtual limbs, even though it was also a controlled movement. Also the highest VBO is, when there is movement through the environment and the lowest when there is no control of the movement at all. However in the last condition the body was not present in the scene, but if we compare the 2nd condition (also without the body present) it could be seen that agency – as controlled movements- plays the leading role, when virtual body is absent.

Table 13 presents medians for VBO and Agency groups for all 4 conditions. The results from Table 13 show no difference in medians for condition 1 and 2. In condition 3 there is a difference between medians, but it is still in the middle of the Likert scale. Scores for condition 4 are on the negative end of the Likert scale.

Medians in Conditions	VBO	Agency
Condition 1	2	2
Condition 2	2	2
Condition 3	3	4
Condition 4	7	6

TABLE 13 MEDIAN FOR VBO AND AGENCY GROUPS

8.1.1 DATA DISTRIBUTION

Hereunder box plots present the data[59].

[59] Boxplot splits data into quartiles. The bottom line of the box represents 25th percentile, the middle presents median, which is the measure of central tendency and the middle score of the data. On the top there is a third quartile, which is 75th percentile. Whiskers at the bottom of the plot indicate the lowest value of the data, while at the top they indicate the highest value of the data that is not an outlier. The crosses on the plot above show data, which is outlier. The most important thing is that boxplot shows the central tendency – middle score of the data

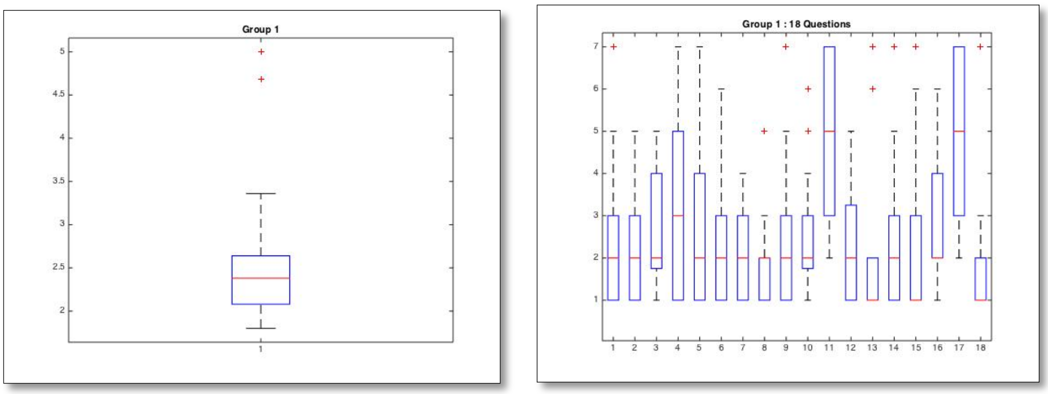

FIGURE 83 GROUP 1 ALL AND SEPARATE QUESTIONS

Group 1 shows that data is asymmetrical and skewed to the left, could be seen in Figure 83, meaning that the majority of the test subjects felt positive VBO and agency. Closer to 1 is the highest score, closer to 7 is the lowest score, except for questions 11 and 17, which both of them have the best score closer to 7 and the lowest score closer to 1. Outliers outside of the data above the upper whiskers might represent these 2 questions. Data range is neither that big, which also means that most of the test subjects experienced similar perceptions of VBO and agency. Median is almost in the middle of the boxplot.

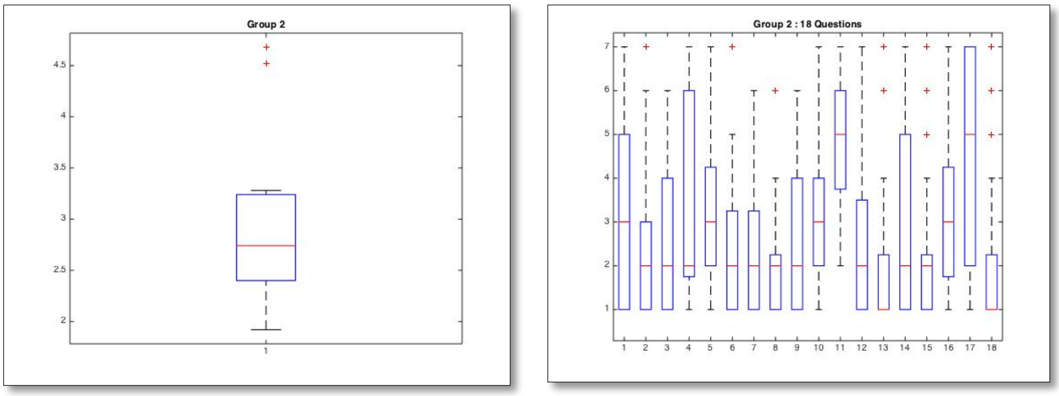

FIGURE 84 GROUP 2 ALL AND SEPARATE QUESTIONS

Group 2 data scores as shown in Figure 84 are a little bit above data score from Group 1 in Figure 83. The upper whisker is also very close to the box itself, meaning that and more

---

(median) and the variability of the data - the range, which is between lower whiskers and the upper outlier. Furthermore it is possible to guess the shape of the distribution by looking at the boxplot, specifically the skew (measure of the asymmetry)[59] of the distribution by showing where is the box in the figure, while the tail could be seen also from the boxplot towards higher or lower scores. http://www.statisticshowto.com/skewed-distribution/

skewed to the top. Here the data is more spread in the box (as box size is bigger than in the previous group). It has tendency to against negative scores, but it lays in the positive field of view (before 3.5, which might be the middle of the data score from Likert scale). The same 2 results supposedly presented by questions 11 and 17 are represented by 2 outlier crosses, which indicate that participants did not have any difficulties moving the body in the air as described in section 7.2.4 about the design of the questionnaire. Median of Group 2 in Figure 84 is more towards the bottom, though closer to the middle still.

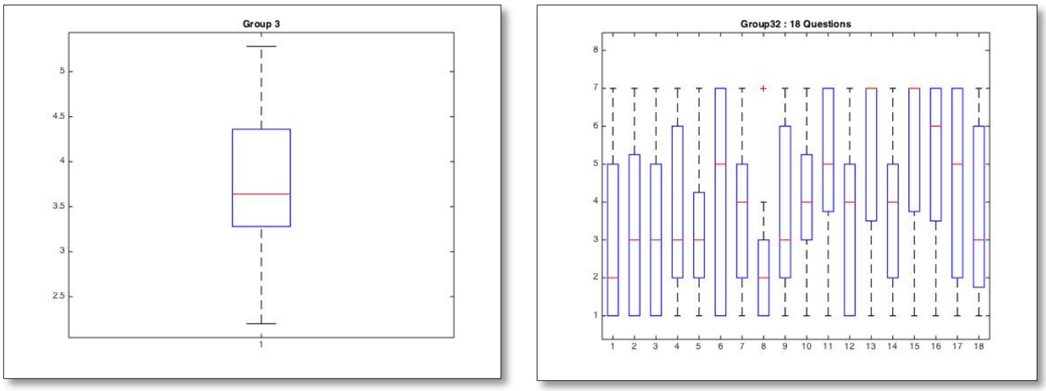

FIGURE 85 GROUP 3 ALL AND SEPARATE QUESTIONS

For Group 3 data is almost not skewed as shown in Figure 85, though median is facing towards bottom direction. The results are more spread than for Group 1 in Figure 83. And now question 11 and 17 are in the range.

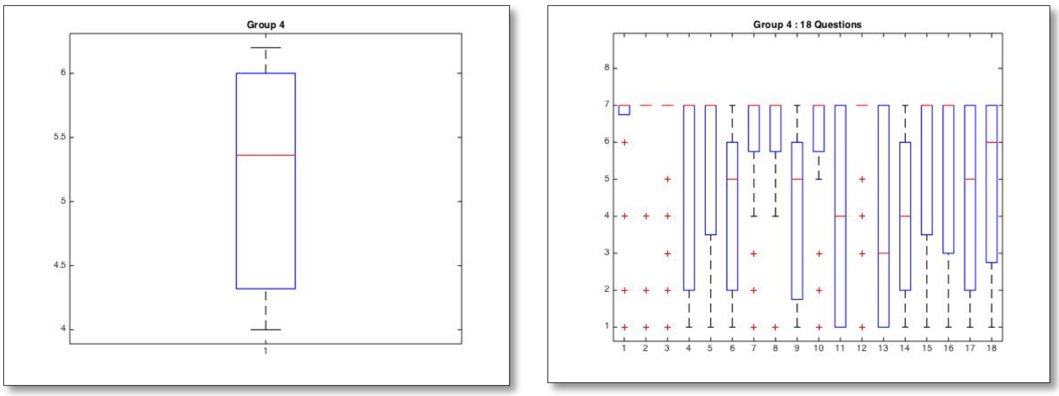

FIGURE 86 GROUP 4 ALL AND SEPARATE QUESTIONS

Group 4 (controlled condition) presented in Figure 86 shows that the results are spread with the median more to the top. Whiskers are almost the same from the top and bottom, though low range is a little bit more that the higher range.

When comparing all these images it is possible to say that there might be a difference between the groups. Though Group 1 and 2 do not have that big difference than the difference between Group 1 and Group 3 or 4.

8.1.1.1 NORMAL DISTRIBUTION TEST

In order to test if data scores is normally distributed one-sample Kolmogorov-Smirnov test was performed in Matlab[60].

In order to find out if data is normally distributed we need to state the hypothesis:

H_0 =

The data from Group 1 comes from a standard normal distribution.

H_1 =

The data from Group 1 does not from a standard normal distribution.

Same hypothesis were made for each condition/group individually.

```
Command Window
>> h = kstest(gr1)

h =

     1

>> h = kstest(gr2)

h =

     1

>> h = kstest(gr3)

h =

     1

>> h = kstest(gr4)

h =

     1
```

FIGURE 87 KOLMOGOROV-SMIRNOV TEST FOR NORMAL DISTRIBUTION, 4 GROUPS

Results showed that the test rejected null hypotheses in each condition individually (h=1) at 5% significance level, which means that data does not come from a normal distribution.

Visually data for the 4 groups is presented in Figure 88, Figure 89, Figure 90 and Figure 91. Data in Group 1, 2 and 3 are not that far from the group means and is almost within 1 standard deviation. Group 4 visually and statistically (mean and

60 http://se.mathworks.com/help/stats/kstest.html?requestedDomain=www.mathworks.com

standard deviation) is different from the above-mentioned groups. Its data is spread over 2 standard deviations and is far from the mean. This might have happened due to the participants' perception of the environment, which to the majority was natural and realistic, however they described it as "a realistic film, which" participants "were part of"[61]. Another probable cause is the difference in perception of the test subjects.

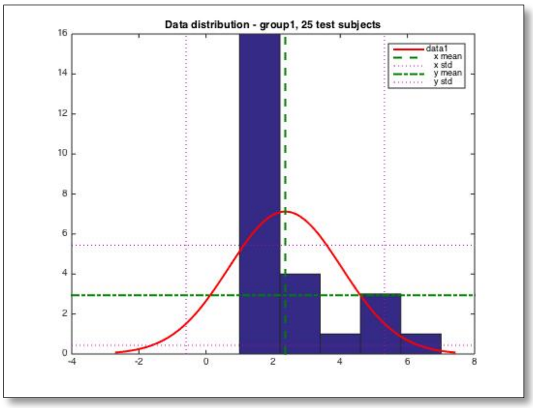

FIGURE 88 DATA DISTRIBUTION GROUP 1

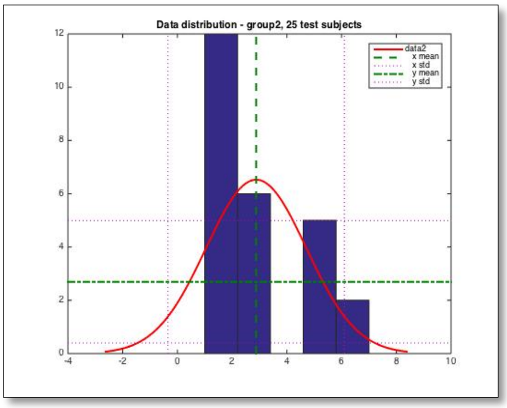

FIGURE 89 DATA DISTRIBUTION GROUP 2

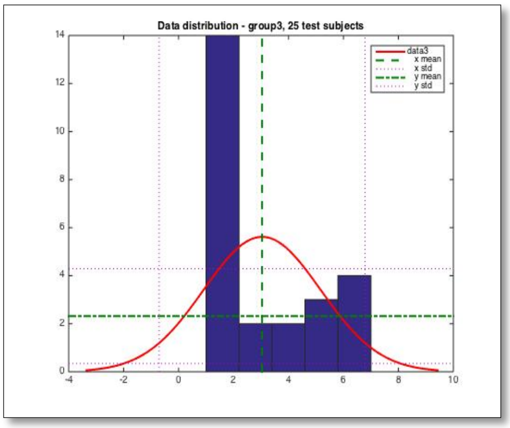

FIGURE 90 DATA DISTRIBUTION GROUP 3

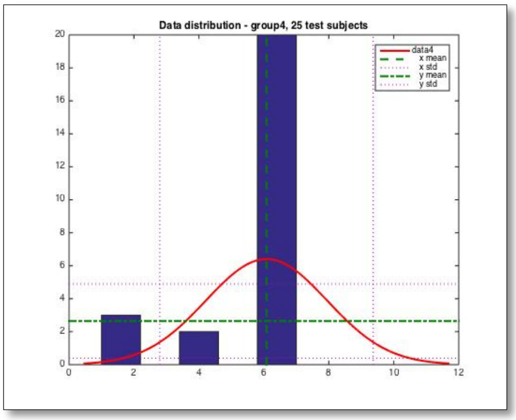

FIGURE 91 DATA DISTRIBUTION GROUP 4

8.1.2 LINEAR CORRELATION

Correlation allows identifying variables that have simple relationship. This could also be done with the help of scatter plots of the scored data. Correlation analysis estimates a sample correlation coefficient R, ranging from -1 to 1, which tells us about the direction (positive or negative) and linear association between two variables. If R is close to 1 it indicated a strong positive correlation. Correlation closer to 0 indicated only some association between two

[61] Some of test subjects´ comments from the test

variables. Though there is possibility that even without correlation, variables might have a strong nonlinear relationship (Mathworks 2015).

In order to see how much data co-vary and vary covariance matrix calculations were done for each group. Covariance matrix computes the strength of the linear relationship between two variables in units relative to their variance by measuring the variability of the two pairs of samples around their mean [62] (Mathworks 2015). The diagonal elements contain the variances of the variables and the non-diagonal elements present the covariance between all variable pairs. Variance represents how much data is spread (dispersion) (Mathworks 2015). Figure 92 shows that variance, which is on the diagonal from left to bottom right and covariance values that are not on the diagonal. The smallest variance is presented in Group1 VBO and Agency. Data tend to co-vary for this group in a positive way. If covariance is 0 there is no possible predictable relationship between the variables (Mathworks 2015). For Group 1 predictability is very low.

The smallest difference between the variance variables is in Group 2 VBO and Group 2 Agency. It might have been probably due to the absence of the body on the screen. Though covariance is also very low but higher than in Group 1. For the last to groups variance and covariance grow ending with the highest values for Group4. Nonetheless it is the only group with the higher VBO than Agency, which is understandable, since Agency was absent in this condition, but having HMD on might have given a feeling of presence in IVE instead.

```
>> cov(group_VBO_1,group_Agency_1)

ans =

    2.7282    0.0386
    0.0386    3.3594

>> cov(group_VBO_2,group_Agency_2)

ans =

    3.3575    0.2394
    0.2394    3.7162

>> cov(group_VBO_3,group_Agency_3)

ans =

    4.2663    0.3024
    0.3024    5.1236

>> cov(group_VBO_4,group_Agency_4)

ans =

    9.6258    1.7453
    1.7453    5.2963
```

FIGURE 92 COVARIANCE MATRIX FOR VBO AND AGENCY GROUPS

Next, covariance matrix was calculated for the groups/conditions in general, without split into VBO and Agency groups. The description of these groups comes from Figure 93. Covariance matrix indicated how much dependent variables are associated with independent variables. The highest variance is noticed between Group1 and Group4, which indicate that there is a big difference between the groups; and the lowest is between Group 3 and Group 4. If we look at

[62] http://sphweb.bumc.bu.edu/otlt/MPH-Modules/BS/BS704_Multivariable/BS704_Multivariable_tocx.html

covariance in Group 1 and 4 it is negative, which means that these variables move into opposite inverse directions, meaning that there is not so much-perceived VBO and Agency in Group4 as in Group1. Closest to 0 covariance is between Group2 and Group4, which will not give predictability to these variables. The highest covariance has Group1 and Group2, which is around 2, meaning that these groups experienced VBO and Agency the most. Group1 and Group3 do have also a big difference in variances; this group is next after Group 1 and Group4 variance.

```
>> cov(gr1,gr2)

ans =

    3.2061    2.0626
    2.0626    3.6364
```

```
>> cov(gr1,gr3)

ans =

    3.2061    0.9387
    0.9387    5.0780
```

```
>> cov(gr1,gr4)

ans =

    3.2061   -0.1324
   -0.1324    5.1086
```

```
>> cov(gr2,gr3)

ans =

    3.6364    1.1624
    1.1624    5.0780
```

```
>> cov(gr2,gr4)

ans =

    3.6364    0.0040
    0.0040    5.1086
```

```
>> cov(gr3,gr4)

ans =

    5.0780    0.7869
    0.7869    5.1086
```

FIGURE 93 COVARIANCE MATRIX FOR DIFFERENT GROUPS

It is interesting to see if there is a correction between VBO and Agency within each group separately, though it is important to have in mind that correlation expresses only linear relationship between two variables – an average degree of corresponding change between them, but not a direct dependency.

R is a correlation coefficient (on diagonal axis). If it is significant it´s value is close to 1. P – is a probability value, as was described in section 6.1.3. If probability is lower than 5% ($P<0.05$) the correlation coefficient is statistically significant, if it is higher - it is insignificant.

To start with it is essential to state test hypothesis:

H_0 =

The data scores within the group do not show a significant difference in correlation.

H_1 =

There is a significant correlation between the data scores within the group.

Results of the correlation test are presented in Figure 94, Figure 95, Figure 96 and Figure 97. If the correlation is significant it shows R-values in read, if it is insignificant it shows R-values in back. The table should be read starting from X-axis and finding corresponding values on Y-axis. Note that VBO questions go from 1 to 5, Agency question are 6-18. R and P values in detailed could also be read from the tables presented in Appendix under the section 12.7.

From this Figure 94 there are many pairs that have correlation. Even though some of them are weak, they are still significant. Such as, R = 0.75 and is significant for:

> Question 5 (VBO) "*Even though the virtual body I saw in the environment might not have had the same physical shape that I have, I felt as if the virtual body belonged to me*" is strongly correlated with Question 6 (Agency) "*Sometimes during the experiment I got a feeling that I myself could fly*".

Another very strong significant correlation R = 0.83 is between:

> Question 5 (VBO) and Question 8 (Agency) "*I felt as if it was me who caused the movement*"

One more example of significantly strong correlation (R = 0.71) is between:

> Question 1 (VBO) "*During the experiment there were moments where I felt as if the virtual wings belonged to me, despite the differences in physical shape between the wing and the hand*" and Question 12 (Agency) "*I felt that I could control the wings as if they were part of my body*"

The last example where R = 0.70 is between:

> Question 4 (VBO) "*During the experiment there moments when I felt as if I was located inside the bat´s body*" and Question 10 (Agency) "*My virtual body moved in the environment as I wished it to move*"

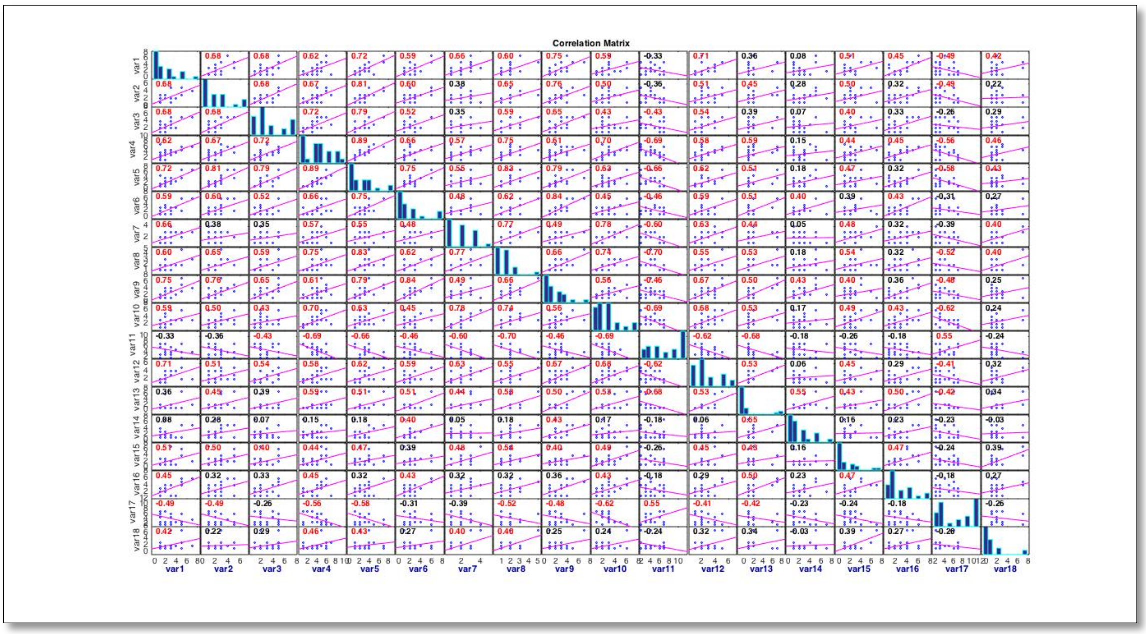

FIGURE 94 PAIRED CORRELATIONS, CONDITION 1, EXPERIMENT II

As another example, when comparing the same questions as before (correlation coefficient), between Condition 1 and 2, would give the following results for condition 2:

Questions 5 and 6 : R = 0.49 (lower than in condition 1, where R = 0.75)

Questions 5 and 8 : R = 0.50 (lower than in condition 1, where R = 0.83)

Questions 1 and 12 : R = 0.65 (lower than in condition 1, where R = 0.71)

Questions 4 and 10 : R = 0.62 (lower than in condition 1, where R = 0.70)

In general correlation coefficients in Condition 2 are lower in values than in Condition 1 and there are less significant correlations than in Condition 1.

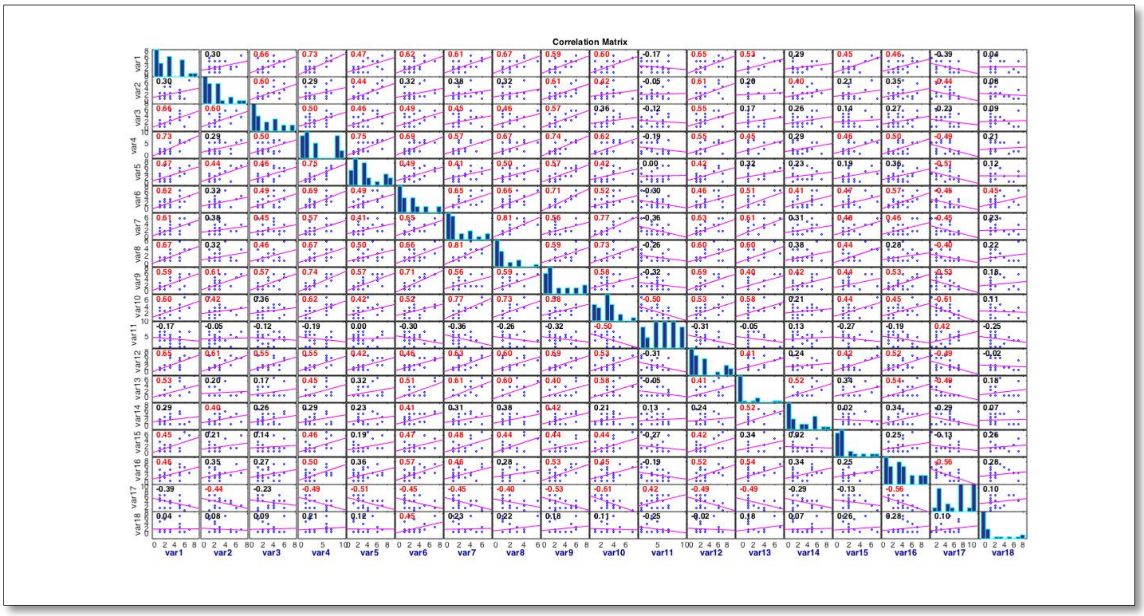

FIGURE 95 PAIRED CORRELATIONS, CONDITION 2, EXPERIMENT II

Furthermore comparison of the same questions (correlation coefficient), between Condition 1, 2 and 3, showed the following results:

Questions 5 and 6 : R = 0.55 (higher than in condition 2, where R = 0.49, but lower than in condition 1, where R = R = 0.75)

Questions 5 and 8 : R = 0.78 (higher than in condition 2, where R = 0.50, but lower than in condition 1, where R = 0.83)

Questions 1 and 12 : R = 0.80 (higher than in condition 2, where R = 0.65 and higher than in condition 1, where R = 0.71)

Questions 4 and 10 : R = 0.56 (lower than in condition 2, where R = 0.62 and lower than in condition 1, where R = 0.70)

In general there are less significant correlation in Condition 3, presented in Figure 96, than in Condition 1. Nonetheless some of the correlations are strong.

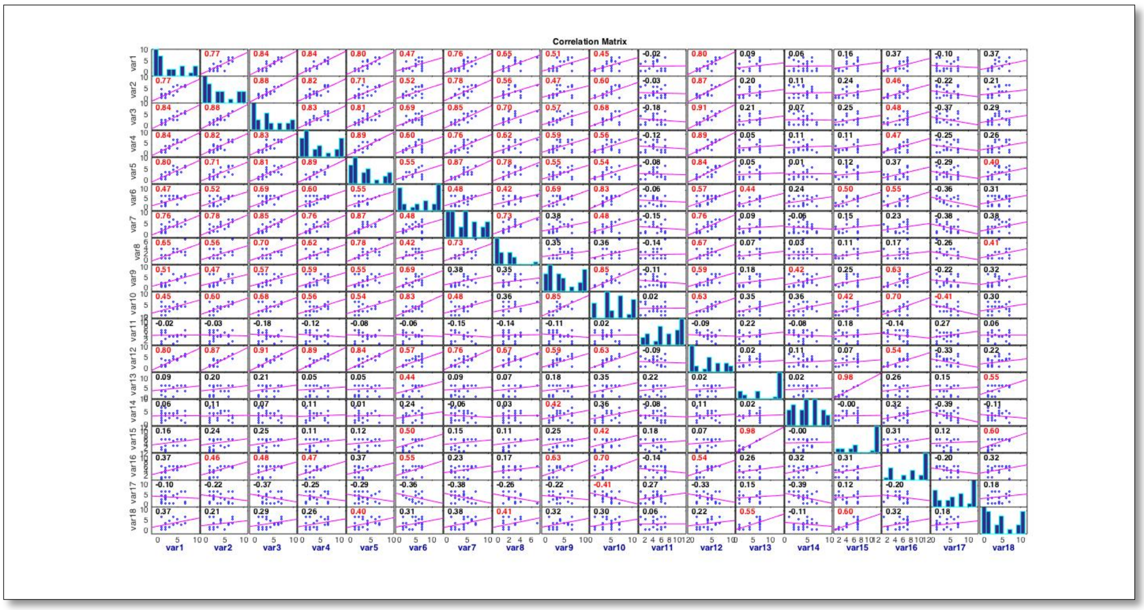

FIGURE 96 PAIRED CORRELATIONS, CONDITION 3, EXPERIMENT II

Although VBO and Agency were absent in condition 4 there are still some relationships between the variables, shown in Figure 97.

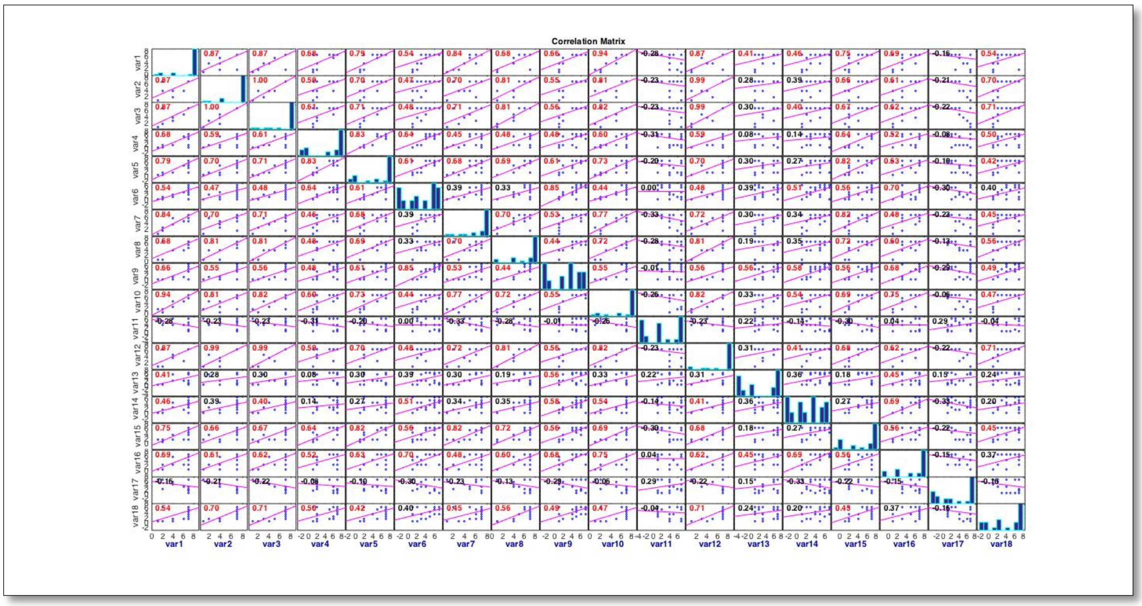

FIGURE 97 PAIRED CORRELATIONS, CONDITION 4, EXPERIMENT II

As an example, statistically very strong significant correlation (R = 0.99) was found between:

Questions 3 (VBO) “*During the experiment there were moments when I felt as if the virtual wing was my own hand*” and 12 (Agency) “*I felt that I could control the wings as if they were part of my body*”;

Question 4 (VBO) “*During the experiment there moments when I felt as if I was located inside the bat´s body*” and 12 (Agency)

This might indicated that, owning the virtual body has a very strong significant correlation with controlled movement of the virtual body, that they have linear relationship. If both are absent no virtual body awareness illusion could be experienced. When almost all test subjects rated both of these questions with 7 - the relationship was created.

8.1.3 FRIEDMAN´S TEST

Since the data does not have a normal distribution, Likert scale could be treated as ordinal data scores, which showed the skewed curve in section 8.1.1 and there are some variables on the outside outlier (mean is sensitive to outlier values, while medians tolerate it better) [63], a non-parametric test (used to test group medians [64]) should be applied.

In Matlab medians could visually be very good presented by Kruska-Walles test (one-way anova for non-parametric data). These results are only used for presentation of medians and not data analysis, since in my case I would need to use a test, which is similar to repeated measures Anova, but for non-parametric data.

As Figure 101 group 4 differ very much from other groups. Group 1 and 2 are very close, while group 3 is also different from the rest of the groups, shown in Figure 98, Figure 101 and Figure 100 down below.

[63] http://blog.minitab.com/blog/applying-statistics-in-quality-projects/why-you-should-use-non-parametric-tests-when-analyzing-data-with-outliers

[64] http://blog.minitab.com/blog/adventures-in-statistics/choosing-between-a-nonparametric-test-and-a-parametric-test

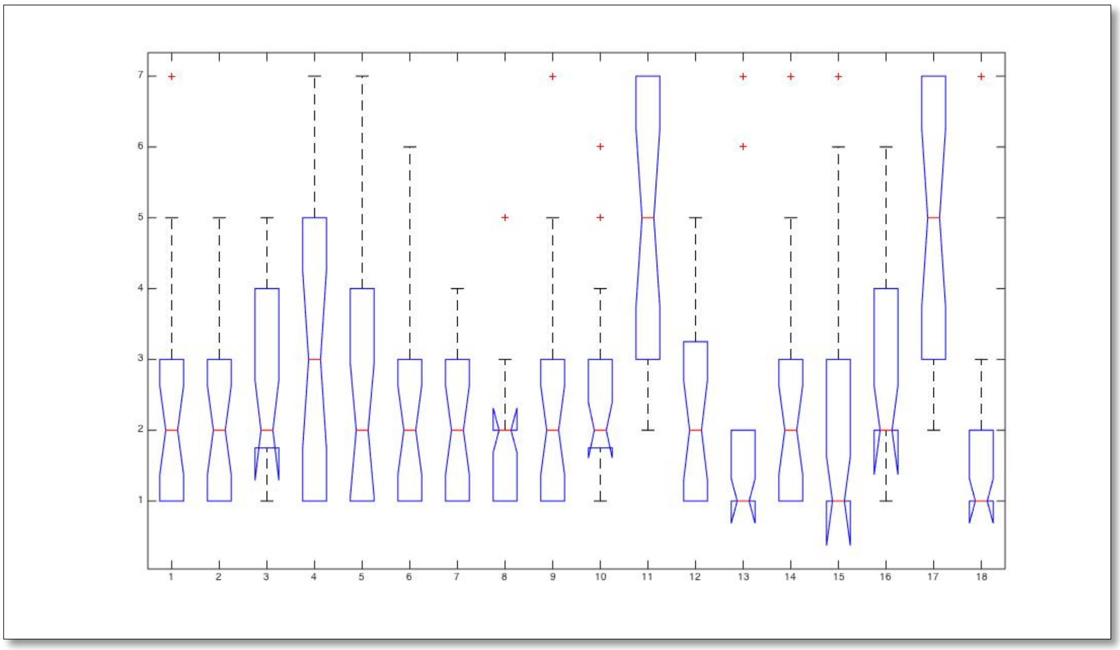

FIGURE 98 COMPARISON OF MEDIANS, CONDITION 1, EXPERIMENT II

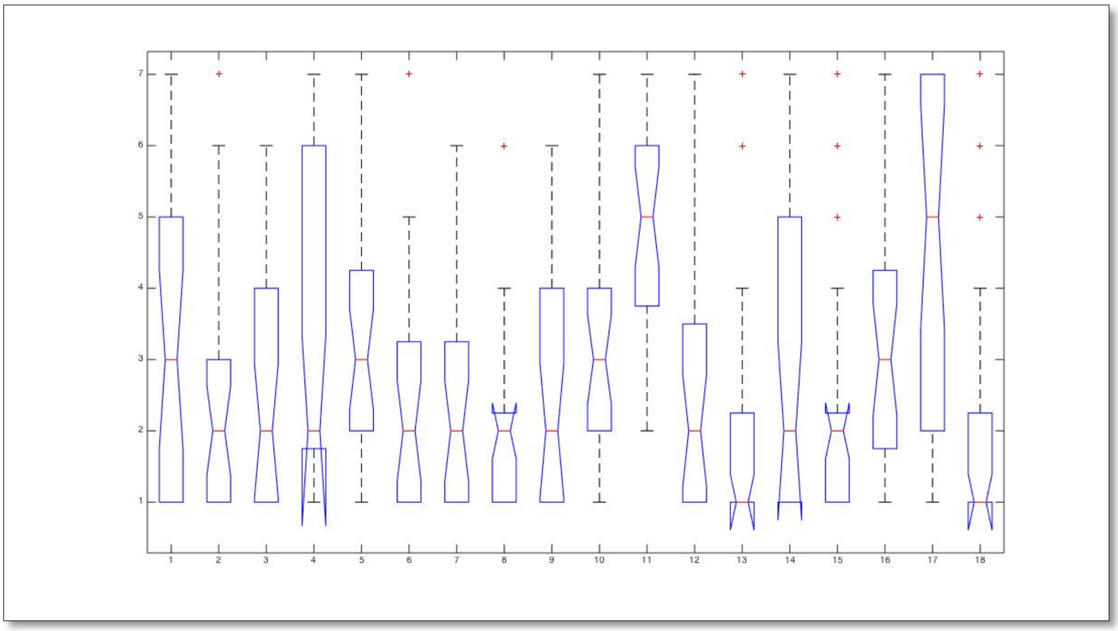

FIGURE 99 COMPARISON OF MEDIANS CONDITION 2, EXPERIMENT II

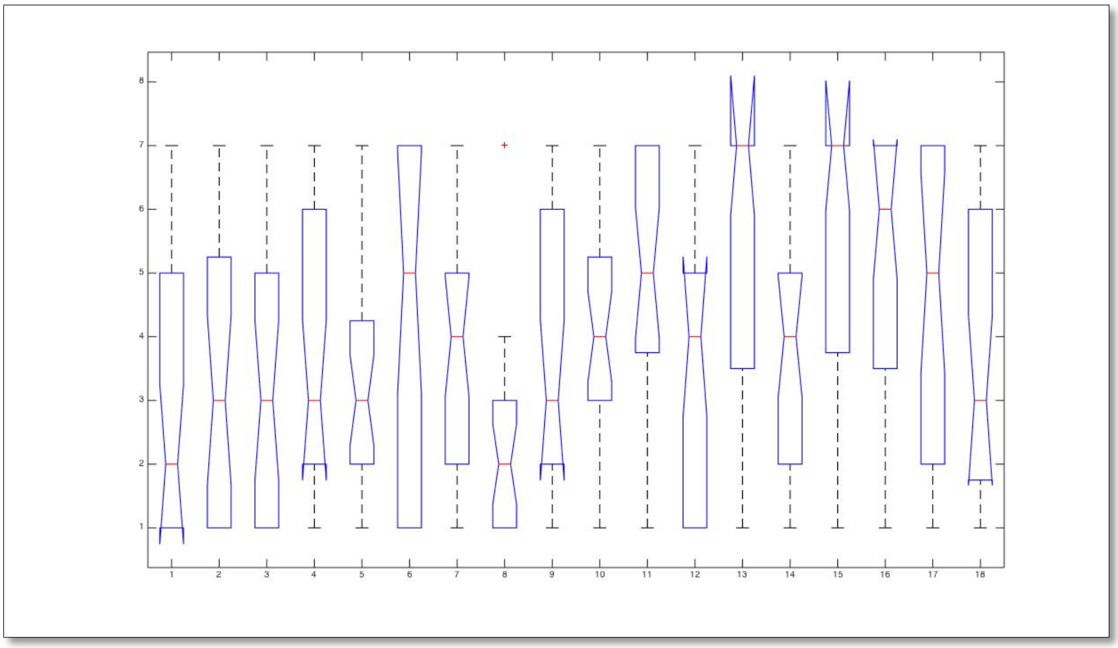

FIGURE 100 COMPARISON OF MEDIANS CONDITION 3, EXPERIMENT II

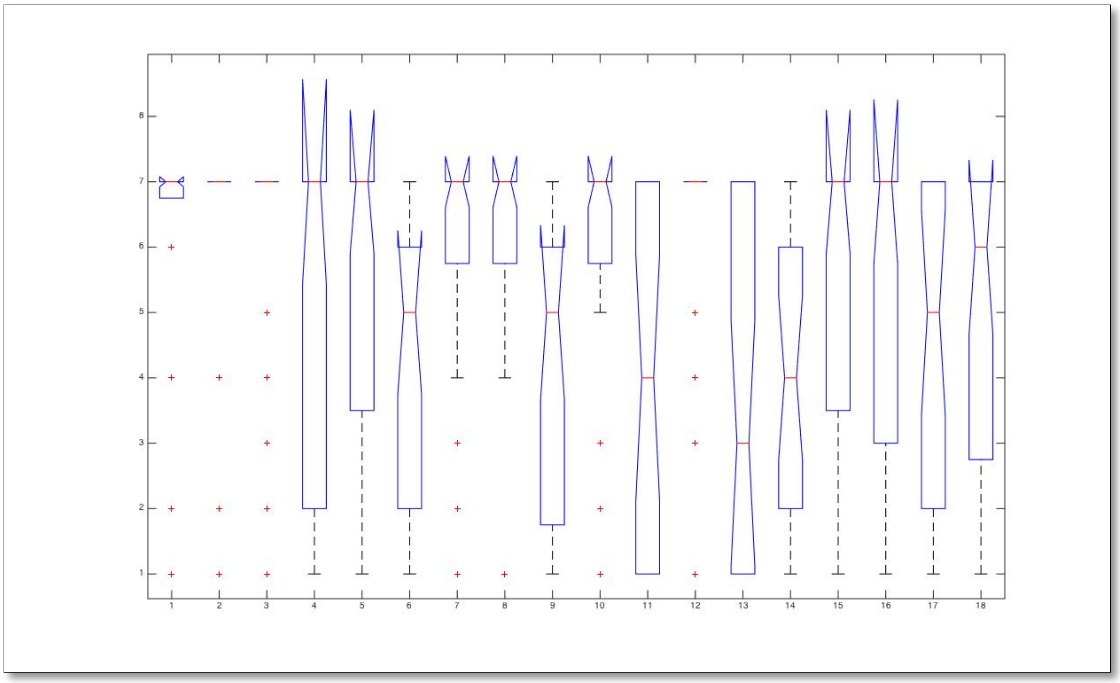

FIGURE 101 COMPARISON OF MEDIANS CONDITION 4, EXPERIMENT II

The closest to repeated measures ANOVA in nonparametric analysis is Friedman´s test, processing ordinal values. Values were measured by on four different occasions. Dependent variables were measured at the ordinal level and they were not normally distributed. There were 72 samples (18 questions for each of the 4 groups).

The following hypotheses were defined:

H_0 =

There are no differences in medians between the groups.

H_1 =

There is at least 1 median that is significantly different in the groups.

Friedman's test was conducted to compare the effect of controlled movements through the environment and only controlled movement of the limbs without movement through the environment, when the virtual body was present and absent, on agency and virtual body ownership. A significant effect of controlled movement through the environment and controlled limbs movements was found on agency as well as an effect of virtual body present and absent was found on VBO, both are at the $p< .05$ level for the 4 conditions [$F(71,1704) = 559.76$, $p = 4.86e-77$].

Since statistical significant results were found, it allows to perform Mann-Whitney-Wilcoxon rank sum test (post hoc test). It showed that there was a significant difference between Condition 1 and 3, Condition 1 and 4, Condition 2 and 3, Condition 2 and 4, Condition 3 and 4.

In all 5 tests H_0 with confidence level of $P< .05$.

Between Condition 1 and 2 there is no significant difference was found, as $P = 0.0571$, therefore H_0 was not rejected. However, P is very close to .05.

8.2 OBSERVATIONS

All observations were taken as notes on the conductor´s computer for each test subjects. At the end of each experiment they were also asked if some of the found gestural inputs were better to use than suggested for the experiment.

8.2.1 GESTURAL INPUTS

Through the test it was discovered that for some test subjects it was physically challenging to stay in the air with suggested gestural inputs (taking arms up and down). Another challenge was to make movements even faster. That is why test subjects found their own pace and could not understand why they could not go faster sometimes, even though it was explained to them from the beginning what do they have to do in order to accelerate.

It was also discovered that the most convenient to the majority of the test subjects were the movements not of the whole hands, but only of the arms, keeping the elbows at rest, which allowed acceleration process without bigger physical challenges.

8.2.2 VIRTUAL BODY

Some of the test subjects did not notice that virtual body was missing in the second condition. This had happened due to several reasons.

First of all HMD´s field of view was very small (60 degrees), which did limited visual perception of the environment, including the wings that were suppose to be seen by the test subjects. Albeit technical limitation it was still possible to see the tips of the wings. However, if the test subjects would be staying and not moving, this problem would not occur. But since they were allowed to change the direction (and body followed) they at the same time moved either further in the scene to the tip of the wings or away, so that the wings area was rendered more and wings could be seen better. This happened due to the HMD was not set as a child of the body in Unity 3D, as physical engine did not allow this (when it was tried, the body started rotating on the spot in a very high speed).

Second of all, since I already made skeleton system and animation for the whole body beforehand, I could not remove the head at the end (I had to redo everything again from the scratch including animations, which would take a long time). Since it was a prototype and I could place the test subjects at a specific spot in the lab and moved the virtual body closer to participants´ height the head was not noticed by the majority of the participants. They could notice it only if they moved, as was described above.

8.2.3 PRESENCE

Presence was disrupted due to the technical issues of the system, described in section 7.3.4 and 7.5.3. In the cases when I had to restart the system test subjects had to adjust again to the environment.

8.2.4 ADAPTATION AND LEARNING PERIOD

Through the experiment it was discovered that test subjects needed a longer adaptation and learning period for the flight. Since the system was not that simple they had to be sure that they would pass the zero angle in order to lift themselves up or loose the lift, but at the same time move forward in the environment.

But when they learned how to use the physical system they wanted to stay longer and fly more.

8.2.5 ABSENCE OF OBSTACLES

Unfortunately there were no obstacles preset in the conditions. This was not a problem, since there was a city present in the environment and test subjects made a challenge for themselves to get acquainted with the environment and fly into the city. The city had clothes beams/rails on a street, which worked as obstacles for the test subjects, since in order to get to the end of the street they needed to fly either under or above them.

8.2.6 SYNCHRONICITY OF THE MOVEMENTS

Movements were mapped synchronously to test subjects´ gestural inputs. Even though the mapping was synchronous to the movements anatomically it was still different from a general interpretation of how the flying movements should be. Normally flying movements are replicated by humans as moving hands on the sides up and down in the air. Bats do almost a whole circle, moving their wings very far behind the shoulders, which is an impossible movement for us.

In general test subjects did not notice that there was anatomical difference between the movements of the virtual wings and the hands. Those who by accident moved more behind the bat could better see the movements and a couple of the test subjects were wondering why the wings were moving "odd", as " - synchronous and at the same time a bit different". When these test subjects were asked to show how would bats fly they all showed the described movement – up and down in the air. Nonetheless the majority did not notice any differences in the controlled movements.

In the 3d condition the movements of the body were 100% synchronous to gestural inputs and therefor test subjects got a feeling that it was they, who controlled the body.

8.3 DISCUSSION OF THE RESULTS

If Questions 11 and 17 were formulated in the opposite manner, which I was afraid might create confusion and misunderstanding, but it did not and the test subjects were reporting that they had to use a different side of the Likert scale in order to answer "right", which I already knew. Besides, if questions were formulated the other way around they would not create outliers on the side of the boxplots. Outliers, though, appeared only in the 1st and the 2nd condition

8.3.1 BODY MOVEMENT THROUGH THE ENVIRONMENT

Group 1 got the best scores out of all conditions, which showed that for a non-human virtual body it is important to deliver a visual representation to the users as otherwise they were not sure how they fly and how they look, which most probable might have an influence on the perception of a non-human virtual body.

Synchronicity of the movements is also important, but it was not tested, therefore it should be left for the further tests. Deviations from synchronous mapping and difference in gestural inputs should also be tested.

In the 1st condition test subjects were concentrated more on the environment and tried to avoid obstacles, instead of looking at the wings. Some of the test subjects did not even paid attention to their wings visibility. However, the majority noticed their bat shadow, moving through the environment, which seemed to make an impact on test subjects, as it functioned as their virtual representation.

According to the results the highest score of agency and VBO had condition 1 – movement through the environment in comparison to condition 3 – movement of the limbs. This might indicate that agency could be enhanced by giving a full control of the virtual body, by giving a possibility to use this body, which might have taken virtual body function on the higher level of body awareness.

8.3.2 LIMBS MOVEMENT

The group with only limbs movement showed a significant difference from the group when the test subjects moved through the environment. Even though this condition did not involve full sense of agency it was possible to notice that test subjects experienced a closer emotional relation to the virtual body and body movements by addressing to the wings as “my wing/my wrist is moving”, “I have a beautiful wing”, or “Oh, my god, I am moving”. From their comments it was notice that for representation and identification with a non-human avatar body as belonging to test subjects it is essential for them to see their virtual body in order to relate more to its form than just giving them locomotion possibilities inside IVE.

8.3.3 LIKERT SCALE BIASES

It is not totally clear if reducing the bias of the Likert scale provided the best possible results, as was discussed in section 6.3.2.1. In order to prove or disprove that changes in order might have caused differences it should be tested again by providing a different order Likert scale (1 - totally disagree and 7 totally agree).

8.3.4 RELIABILITY

Randomization of the conditions helped to avoid bias and therefore for this matter the results got a certain level of reliability.

Since the experiment relied on subjective experiences, test subjects could not learn anything from the previous tests, only got more aquatinted with the environment, therefore within group designed could not influence the results in a negative way. Even though some of the test subjects had had VR experience, testing their feelings and senses would not have had a bigger impact on reliability.

Furthermore, taking some of the test subject's results out of the group, due to technical problems, and only leaving the ones that were not influenced by it, gave better chances to process more reliable data scores.

Finally according to the theory a slightly asynchronicity of the movements (see section 4.6.2.2) were not suppose to influence the whole test as was described before. It was also mentioned that the majority of the test subjects did not notice it therefore in this sense results might be reliable enough.

8.3.5 RESULTS USABILITY

The results might be used for further study of agency and VBO. It is still unclear what is the most efficient way to enhance agency for a human avatar, therefore the approaches that were used in this experiment might be expended for a future tests on a human avatar body.

Previous discussions about visibility of the virtual body might also be studied further, if and when it is enough to use shadow or reflection of the virtual body in IVE and how that would impact on the test subjects. In this study only wings were animated, but it might also be interesting to see if test subjects´ reaction on the movement of the whole non-human body might be different or not.

Methods and approaches from this study might also be used for implementations of the non-human avatar bodies of different species.

Future steps might go into direction where gestural inputs should be studied. It might be useful to study if gestural inputs should replicate the movements of particular specie or if differences from sign replications play a significant role towards association or further disassociation with a potential virtual non-human body.

The difference in mappings of the movements has neither been studied properly in this paper, since it was not the primary aim but rather an approach. Different mappings of the limb movement might produce different results. For example, with the help of rotoscoping technique this experiment replicated almost the exact bat´s locomotion of flight. These movements were mapped to the gestural inputs of the test subjects. However if the movements would have been different – the exact movements of the gestures (up and down movements) – the effect might have been different, which might have lead to different results.

Furthermore, implementation of the physics engine helped to replicate the realism of the flight – the flight was realized as a sinusoid forward movement, while the realism was achieved only through the audio-visual feedback. If tactile feedback would have been implemented with the help of the sensors attached to the body that might have given a different insight on the VBO and agency, since the interview from the first experiment partly showed (see section 12.3) that the closest VBO experienced was achieved during the parts of the test when tactile input was involved.

Finally it is still unknown how agency might influence the perception of presence in IVE and therefore there should be more research done within this area. Besides one question still remains opened for the future research – does agency structure virtual non-human body ownership and to what extent. This question could be answered only when comparing agency and VBO over several non-human avatars studies.

8.3.6 CONCLUSION ON THE RESULTS FOR EXPERIMENT II

Results showed a significant difference between the 4 groups. After processing of the results visualization it was clear that non-parametric tests should be used. Kolmogorov-Smirnov test showed that data was not normally distributed.

There was not found significant correlation between the pairs within each particular condition. Some of the correlations were even strong. Condition 1 showed the most correlation between the aired variables.

Friedman’s test proved that there was a significant difference between the medians of the groups with probability range of 95% ($P<0.05$). This means that it might be likely that an unknown population sampling fall within a confidence interval of 95% of the area of the normal density curve, while the probability of the observing value outside of the curve is less than 5% in this specific test. Post hoc Mann-Witney u test showed significant difference between all the conditions but one, which was – between condition 1 and condition 2.

9 DISCUSSION

Two experiments have been tested with two following problem statements in mind:

1) *Is it possible to achieve a virtual body ownership illusion over bat´s avatar with the help of visuotactile stimulation in IVE?*

2) *Would voluntary controlled movement of bat´s avatar through the environment enhance the sense of embodiment in IVE?*

THE PROBLEM OF VISUOTACTILE STIMULI AND IT´S INFLUENCE ON VBO

VBO concept is a very tricky one, since there are a lot of factors that influence human´s perception - cognitive, physiological and psychological, working together. VR creates realistic experience therefore its main contributors are human experiences and technological immersion, together creating the sense of presence and a believable illusion of being in the environment and owning the virtual body. There are two main senses that make it possible to achieve an illusion of VBO – visuotactile sense and sensorimotor correlations – correlated senses and actions that are bind together, in other words VBO and agency that are contributing factors of self-attribution that create body awareness.

Theoretical discussions of splitting BO and agency are still continuing. Though practically it is impossible, as these two are working together. Since one can get another body - virtual body - using the existing rules for building human VBO to a virtual one in VR, it might seem possible to split VBO from agency. If these two concepts are separable, at least theoretically, it is questionable what shapes embodiment in VR, if it is VBO or agency.

On these background thoughts and taking into consideration that there were no researches done concerning non-human avatar in VR, an experiment was conducted, where virtual bat´s body was used as an avatar. Overall three conditions were tested with different visuotactile input applied. It was interesting to see if alterations of tactile location in correspondence to anatomical differences between the physical and the virtual body influence the amount of ownership over virtual bat´s body. Significant difference was found between the three conditions. Moreover it was noticed that unintentional movement did not have the same effect it would have had in real world, as in virtual one no proprioceptive feedback was involved. Furthermore, there were discrepancies between answers from the questionnaire and personal interview. Test subjects did not seem to get enough amount of VBO as was expected. The majority felt only as observers, as the absence of continuous visuotactile feedback broke the illusion. Nonetheless, the more anatomically correct touch (between the physical hand and the virtual wing) was, the more believability test subjects achieved as they described it.

Based on the results from the 1st experiment it might be possible to conclude that to some extant it was possible to achieve some VBO, although it was not strong. Especially VBO was increased at the exact moments when the wand was touching test subjects´ hands. All this leads to a conclusion that visuotactile feedback is not enough to create a stable VBO over a non-human avatar.

Taking into consideration that test subjects wanted to move almost through the whole experiment due to threat being present in virtual scenario, it might also be concluded that VBO and agency are very difficult to separate for a non-human body representation in VR. There might be several reasons for this assumption.

First of all only visuotactile feedback was involved in this experiment, which might have limited the illusion in general. Second of all test subjects did not have enough time to adjust to IVE and neither got used to see their hand representation as a virtual wing. Finally they could not perceive unintentional movement, as movement of their own body, since they were deprived from proprioceptive sense. All this might lead to another conclusion – if there is no interaction with the environment during absence of agency, it might be hard to establish VBO illusion over a non-human body due to morphological differences starting with shape. Moreover, if there is a morphologically different virtual body present, a purpose should be given to its usage. This might infer that if agency is missing there might be impossible to stabilize the illusion of VBO over a virtualbat´s body. Therefore it should be still researched if agency structures the whole VBO illusion in VR.

IF VOLUNTARY CONTROLLED MOVEMENT THROUGH THE IVE ENHANCES VIRTUAL EMBODIMENT AND INFLUENCE VBO ILLUSION

Taking into consideration that body ownership also includes unintentional movements, as described formerly, agency, on the other hand - is an intention and controlled movements of the body. For me in was motivating to study if body movements in general might generate en effect of owning the virtual bat´s body. Specifically I wanted to research, if movement through the environment versus only limbs movement with virtual body present or absent might enhance VBO over bat´s body. Based on that 4 conditions were tested – moving through the environment with the virtual body, moving through the environment without virtual body, moving the limbs without moving through the environment with the body. A controlled condition it was - unintentional movement through the environment without the body.

In view of discrepancies between the results of Likert scale and personal interview, it was decided to invert the scale from negative to positive - starting from positive ratings – for the second experiment.

Significant differences were found between the conditions, except for condition 1 and 2. Though the result of significance level was very close to rejecting the hypothesis, which might indicate that in the future it should be studied if there were no differences due to the fact that test subjects might knew that they were supposed to have a virtual body and just assumed that they had one, or due to the fact that they did not need a virtual body, since they were in control of the movements through the environment.

Observation of Condition 3 – limb movements – showed that test subjects had more emotional attachment to the virtual bat´s body than in the other conditions as they were observing their wings closely, which might have indicated that it is necessary for the body to be present, especially because of the morphological differences. It is important for the test subjects to see how a different from human virtual body could move in IVE. This might create more powerful emotional bond to a non-human virtual body in general. Nevertheless, further tests need to be done in order to see if observations and speculations are true.

Agency got higher mean scores than VBO; therefore it might be possible to assume that VBO ratings depended on agency ratings. A general comparison of means showed that the higher agency was the higher VBO was. A correlation test studied if there was any linear relationship between these two variables. The results revealed that there was a correlation between some pairs within each group. Though visually and from correlation calculations it was possible to see that most pairs were presented in condition 1, suggesting that these two concepts have an interconnection, sometimes even a strong one. This might lead to a speculation that agency shapes VBO in IVE (higher agency, more amount of VBO), specifically for a virtual bat´s body. This might be different with respect to a human avatar. Nevertheless further tests are needed in order to be able to resolve this question.

The highest sense of embodiment, as results showed, was in the condition 1, therefore the answer to the second part of the final problem statement might be affirmative – more interaction with IVE, as being in control of the virtual movements through the environment might increase body awareness in VR. Aside from this research involved only bat´s body, it is still unknown if enhancement might be the same for a different non-human virtual shape. Additionally, if it might be possible to enhance this illusion by giving test subjects a possibility to observe their limb movements and create a further emotional connection to the virtual body.

10 CONCLUSION

VR creates a possibility for different believable self-representations under some specific settings. For a human avatar these conditions have been already examined, and in this research they were used as the main approaches to study the final problem statement. Based on the anatomical similarities between bats and humans and an interest in human´s perception and control of a different locomotion than of ours (flight), bat was chosen as a virtual avatar to represent human´s body in VR.

The effect of the virtual bat´s body and controlled movements in terms of VBO illusion showed that VBO and agency are working together and might be correlated, depending on the conditions. It also revealed that it is possible to enhance agency if test subjects are given a navigation control over the virtual bat´s body in IVE.

It is still unclear though to what extent agency influences the amount of VBO. In the first experiment tactile input was used, which did not create a stable VBO illusion. In the second experiment there was no tactile feedback, which also might have influenced the amount of virtual embodiment.

Another uncertainty is unintentional movements, if they might enhance VBO or if they do not influence it at all. Nonetheless it was discovered that an absence of proprioceptive feedback might have resulted in seeing and perceiving movement as optic flow. Therefore they should be researched further.

Moreover Likert´s scale influencing ratings should be taken into consideration. Other physiological measurements, as measurements of muscle activity, should be considered.

Different mapping systems might also influence VBO perception and therefore they should not be disregarded. Asynchronicity paradox, where active movements are being perceived as more synchronous than they actually are, should be researched further for a non-human VBO.

Finally this research might be a first step in the future investigations of what structures non-human VBO in VR, if it is agency or some other factors; to what extant do agency and VBO interrelate.

Finally it is interesting to see if VBO illusion might be obtained over non-living objects. With the living objects we are creating an emotional connection, since we know their behavior and we observe them in nature. The differences between living and non-living objects might be interesting to study in case of interaction in VR.

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12 APPENDIX

12.1 TERMINOLOGY TABLE

Perception Terms	*Perception Definition*
Embodiment	A necessity of physical body experiencing sensory-motor processes, which result in cognition. Embodiment experience is problematic to replicate, due to the impossibility of dissociating the body from one´s self (Varela et al. 1991). Kilteni and Slater defined the sense of embodiment as "*assemble of sensation that arise in conjunction of being inside, having and controlling a body*"(Kilteni, Groten, et al. 2012).
Spatial representation characteristics of being in a body	Location inside the body, self-attribution and that the body obeys the intentions of one´s self under enactment (Kilteni, Groten, et al. 2012).
Self-attribution	The body that is "*my own*" and has always been presented in "*my life*" (Tsakiris 2010). It includes: - *Ownership*, which is subjective - *Agency*, which is objective
Body Ownership (BO)	Feeling of the body that is my own, achieved through afferent sensory input, such as vision, touch, audio, smell, etc. and involuntary movements, and experienced through both active and passive movements preserving temporal and spatial visuo-somatosensory synchronicity. (Graham and Stephens 1993; Tsakiris et al. 2007; Tsakiris 2010).
Involuntary movements	The knowledge of body being moved, but not producing this movement by oneself (Tsakiris et al. 2007).
Voluntary movements	The knowledge that my body moved, where I am the creator of the movement. During voluntary movements though the sense of BO is created by sensory feedback (Haggard 2005; Wolpert

	1997).
Agency	Agency is the intention of executing actions, feel of controlling body movements and making an impact on the environment through these movements (Tsakiris, Longo, et al. 2010). The sense of agency is realized through motor commands, sent to the muscles - only through active (voluntary) movements (Tsakiris et al. 2007; Tsakiris 2010).
Active actions	One is in control of his own actions (Tsakiris et al. 2007; Tsakiris 2010)
Passive actions	Involuntary movements (Tsakiris et al. 2007).
VR Terms	***Definitions***
VBO	Complex sensations from different senses, such as vision, touch, proprioception, motor control and vestibular sensation working together, experienced by physical body (Maselli and Slater 2013). For creation of the full VBO illusion visual perspective and visuo-tactile stimulations are necessary factors (Maselli and Slater 2013).
Visuotactile stimulations	Afferent information from the outside stimuli (vision and touch), sent to the brain.
Visuomotor correlation *(Efferent information)*	A correlation between visual and proprioceptive sensations, inferring visual information based on motor function of the body. Visuomotor correlation is one of the most important factors for linking physical and virtual body movement even more prior than synchronous feedback (Slater 2014).
Agency in VR	Bodily motor control actions and intentions in IVE, including the subjective experience of such actions under the condition of synchronization of visuomotor correlation (my own definition).

	Agency can produce impact on IVE, when interacting with it. Moving the virtual body, being the creator of one´s own actions in IVE, would infer agency and not necessarily VBO. Agency can also required only movements but not necessarily the body itself (Gallagher 2000).
Progressive Embodiment *(Virtual Embodiment)*	Embodiment of the user´s body via close coupling to the interface and representations of coupled body via first person avatar geometry and behavior (Biocca 1997). Mapping the embodiment includes: - Motor Flow – users´ actions; - Sensory Inflow - sensory feedback; Mismapping would form intersensory conflict (Biocca 1997).
Virtual Body	The representation of the user´s body inside the virtual environment (Biocca 1997).
Virtual Body mapping	Mapping between the controlled motion of the user´s limbs in the real world and the effected motion of the virtual limbs in the immersive environment (Poupyrev and Billinghurst 1996).

12.2 LETTER OF CONTENT – EXPERIMENT I[65]

Date 25.01.2016

Title of Project

Virtual Body Ownership illusion over a non-human avatar body in Immersive Virtual Environment

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Multisensory Lab

[65] The inspiration for this form is taken from: https://uwaterloo.ca/research/office-research-ethics/research-human-participants/application-process/samples-and-other-supporting-materials/information-consent-samples/sample-information-letters

Study Overview

You are invited to participate in the study assessing the impact of virtual body ownership on a user in Virtual Reality (VR). Past VR researches have shown that users have adopted a human-looking avatar body as their own body representation in VR. This study extends previous researches by investigating the impact of subjective self-attribution to a non-human body ownership form using visual and tactile stimuli.

Test Procedure

Test participant will be asked to put on a head-mounted display, which allows experiencing virtual reality environment. Headphones will be provided for the further immersion into virtual environment, through which participants will hear surrounding soundscape and the touch of a wand.

During the test participants will be asked to lay down on the floor with their hands stretched in front of them. The conductor will be touching the left hand of the participant with the wand. The wand would do no harm to the participant´s body at any time.

The whole procedure will be recorded.

At the end of each session the participant will be given digital questionnaire to fill in. Finally at the end of the test each participant could provide personal comments about the sessions to the conductor.

Participation and Remuneration

There is a voluntary participation in the study containing 4 sessions, which will take approximately 30 minutes of the participant´s time. Each session will take approximately 7 minutes.

Participants may withdraw from the study at any time, also during the test procedure. Furthermore participants may decline to answer any questions during the study.

There is no remuneration for participation in the study provided by university or the conductor.

Risks to Participation in the Study

There will be no physical risk during participation in the study. However there are known cases of nausea for some people using VR. If this is the case, the participant should report it straight away to the conductor and the test procedure will be stopped immediately.

Participants should take glasses off in case they use them due to incompatibility with the provided version of the head-mounted display in the lab.

Confidentiality

All information collected through the study will be kept strictly confidential. None of the information will be distributed to public or private use, neither will be posted on any website.

Questions and Research Ethics Clearance

This study has been reviewed and received ethics clearance through the study supervisor. However, the final decision about participation is yours. If you have any comments or concerns about the study, please contact the study supervisor through information on the1st page.

Thank you for your interest in the research and for your assistance with this project.

Consent of the Participant

I have read the information presented in the information letter about a study being conducted by Anastassia Andreasen, MED 10, under the supervision of Niels Christian Nilsson of the Department of Architecture, Design and Media Technology at Aalborg University Copenhagen. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study at any time by advising the researchers of this decision. I was also informed that if I have any comments or concerns resulting from my participation in this study, I might contact Niels Christian Nilsson.

I agreed to record my actions during the whole test procedure and I give my permission to record the test and use data for the future studies.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

Participants´ Name **Signature** **Date**

____ _______________________________________

12.3 INTERVIEW WITH THE PARTICIPANTS

Questions from the interview:

1. Did you feel presence in the environment?

2. Did you feel VBO over the bat´s body?

3. To what would you attribute movement that you experienced in the environment?
(Concepts were explained to all test subjects)

> 1. VBO;
>
> 2. Presence;
>
> 3. Agency as controlling movement of your body;

Participant 1 (Andreas: 3, 2, 1), very good VR experience, was working with VBO:

1. I felt presence to some extant – why to some extant as I felt that I was an observer only. As an observer because I did not move, only was looking through the camera.
2. I did not feel VBO at all. I consider VBO as the control of the body and responding with movements to the events in the environment. I think you might achieve any VBO illusion if you would be able to control the object.
3. I would attribute movement to the camera movement, through which I could see the environment that is why I said that I was feeling as an observer. Since I was moved (pushed by the bed forward) in the environment I would consider this question as "Movement belonging to presence".

Participant 2 (Nico: 1, 3, 2), tried VR before:

1. Definitely yes, I was present in the environment. I was in a very big room, which I liked.
2. No, I did not, since I could not move the wings.
3. To presence, as I could follow what was going on – optic flow on the screen gave me a possibility to follow what is going on that is why it is presence.

Participant 3 (Kristin: 2, 1, 3), no VR experience:

1. I felt present in the environment, since I could see myself being in another room that the multisensory lab. However I missed the whole field of view, which diminished my feeling of presence – I could not see the whole body.
2. I did not feel the VBO, since my hands were in a position, where I felt helpless and not in a control. There are different positions of the body, where people feel more control: in a laying position, being on a belly with arms to the sides there is no feeling of control of a body. If hands are stretched more in forward direction there is more feeling of control. There are different types of people: kinesthetic people, audio people, and visual types of people. I am a kinesthetic type and being in control of a body means a lot to me.
3. I would attribute it to presence, since I did not have control over the body.

Participant 4 (Lisbeth: 3, 2, 1), tried VR before:

1. Yes, I was present in the environment
2. No, I definitely did not feel VBO illusion. I felt helpless, as my hands were stretched to the sides and I needed more control that is why I wanted to move hands more in front. That is also why I felt that my hands were at a wrong place, not where the wings were. Having hands in front would give me a control.
3. To presence, as I did not have control over the movement.

Participant 5 (Sveta: 1, 2, 3), no VR experience:

1. I was very present in the environment. The more I was in the environment the more feeling of presence I got.
2. No, as the wings were not alive and did not move even when the ball was hitting them (they were suppose at least to stretch a bit under the touch). No VBO illusion.
3. To presence, as I could not control the wings and they did not feel like my own.

Participant 6 (Ira: 3, 2, 1), no VR experience:

1. I was present in the environment.
2. No I did not, but I felt like I was on this body as the follower or observer, like an Aladdin on a carpet. And I also felt that bat on which I was sitting was pushing me forward to the knives.
3. To presence.

Participant 7 (Lyubomir, tourism student: 2,3,1), no VR experience:

1. Yes, I was there in the computer environment.
2. Unfortunately I did not feel VBO even for a second.
3. I felt as I was observing the scene that is why I could put movement that was there to presence, since I could not control them and could not identify them with the wings.

Participant 8 (Gerda, tourism student: 1, 2, 3), no VR experience:

1. I was definitely present there.
2. There was no VBO illusion, I even did not understand that the wings were suppose to be mine, as they looked like plastic. If they moved, at least asynchronous I would consider them. But not in the given condition.
3. I felt as I was there watching what is happening that is why I could place movement to presence category.

Participant 9 (tourism student :1, 3, 2), no VR experience:

1. I felt very strong sense of being there.
2. I consider the body that belongs to me when I can move it. If I´m moved I don´t feel VBO. That is why I will not agree with the statement that I felt VBO illusion. I had more feeling that I was bodiless.
3. I would say that was more presence than anything else.

Participant 10 (tourism student :1, 2, 3), no VR experience:

1. Definitely very present in the computer environment.
2. No feeling of any body whatsoever.
3. It should be presence, not body or controlled movements of my body, because I was only there and watched what happened.

Participant 11(Elvira: 1, 2, 3), no VR experience:

1. I felt very present there, in the environment.
2. I did not feel VBO at all, however I felt the touch of the yellow ball very definite on my physical body, like the yellow ball from the screen touched my physical body. When

knives moved very close to me I was thinking that they might hurt my physical head, I even did not consider the wings or bat body at all.

3. Since I felt that it was not my body that was moving, but in stead the knives were moving towards me, I could definitely say that I did not have control over the movements. I would identify movement to presence more than to the body, since I felt that wings did not move at all.

Participant 12 (Christian: 3, 2, 1), no VR experience:

1. I felt strong presence in the environment. I also liked the hammer since it was huge in size and moved, like it was controlled by somebody, which made the scene alive and gave even more presence.
2. I felt VBO only when I started flying with the body at the end of one of the tests, and I really liked the experience (note: there was a mistake of a system, when hammer started flickering it collided with the body and the body started freely moving in the environment).
   At the other test when the test subject did not experience the system mistake of a flying body, he did not experience VBO illusion, but he graded question 1 on scale from 1-7 as 3. His explanation to it was that he saw the wing on the screen, where his hand was and he assumed that it was possible to control it, but the conductor made a request not to move, that is why he gave 3 points for this question, but in general he did not experience VBO illusion.
3. No control over movements, but I would place these movements more to presence in the environment than to the body.

Hammer mistake was fixed after participant 12. Mistake was “flying” after collision with the body! However nobody else experienced this mistake.

Participant 13 (Andreas, graduate master student from Global management and Operations 3, 2, 1), no VR experience:

1. Yes, I felt present. However, if everything had been more realistic (colors, materials, etc.) I would feel more presence. But definitely I was present there.
2. To a very minimum extent, almost not.
   I felt very small in this big room, the wings were bigger than my arms. I felt though control over my physical body, as the position on the floor was very comfortable and this position gives me full control over my physical body. Due to that fact I felt that not

the wings were moving to the knives, but the knives were moving towards me in stead.

3. I did not have control over the wings neither the bat´s body. I would place this movement to a presence category, since I was having a feeling that I watched/observed what was going on around me in the environment.

Participant 14 (Casper, MED 6: 3, 1, 2), has VR experience :

1. Yes, I felt presence - I was in a huge room.
2. To be honest, I did not. But since I know that touch and threat is sometimes parts of the experiments it helped me to realize that this is affecting the virtual body and it helped me to summon feeling from physical body and place them on virtual body, and to a minimum extent I got a feeling of VBO illusion. But generally speaking this did not give VBO feeling.
3. I would place this forced movement it to presence, not to VBO, as having VBO equals to having control over it, as otherwise it will not give any sense, like it did not to me at first. I also wanted to avoid knives very much, but I could not, I felt I was there, but could not do anything about it, I felt helpless.

Participant 15 (Mikkel, MED10: 2, 3, 1), has VR experience:

1. Yes, I definitely felt presence, I was there in the environment.
2. No VBO at all.
3. I would say this unintentional movement belonged to presence, since there was no control over a Game Object – bat´s body.

Participant 16 (Sergej: 1, 2, 3), no VR experience:

1. Yes, I felt presence.
2. I did not experience it, as first I even did not understand that the wings were supposed to be mine. The problem was that I did not feel control over my body and neither control over my movement, since I felt at the same time I should have been, as I was there and my arm was at the same position as my hand (as I understood eventually it during the test).
3. I would definitely say that this movement belongs to presence rather than to anything else (also referring to the previous answer)

Participant 17 (Anastasia Arp: 1, 3, 2), no VR experience:

1. Yes, I felt presence.
2. Definitely not. Even if they were mine, since I could not use them/control them I could not identify wings as part of being mine.
3. When I was moved I felt presence, nothing else, as I was there and watched what happened.

Participant 18 (Jacob: 3, 2, 1), no VR experience:

1. Yes
2. Only a very little, as I felt that the knives were moving towards me and were going to hit my head, and since I´ve been told not to move, I could not control the wings and of course could not move. The hammer was though very realistic.
3. I would say that the movement should be placed to presence.

Participant 19 (Nora: 2, 3, 1), no VR experience:

1. Yes, I felt present in the environment. Physically of course I knew I was lying down in the lab, but at the same time I felt that I was in this huge room with high ceiling and it impressed me a lot.
2. I little bit:
   I´m a visual person, for me it was important that in some of the conditions the ball was hitting the wings anatomically correct places (though if the hammer would be hitting instead of a yellow ball it would have been better). During these moments I felt as if I was in this body, but as it was impossible to move the moments were gone and I lost the feeling of this body straight away. I missed control over movements, as I wanted to move my thumb away from the ball and the hammer all the time.
3. It should belong to presence, as again I could not control this movement and I could not feel the body. I would also place the knives to presence, as I felt that they were going to hit my head for real, not bat´s wings in the environment.

Participant 20 (Nicolai Egede: 1, 3, 2), has VR experience (VR sound design):

1. Yes, I felt presence

2. I felt very strange, as the experience was broken, if the yellow ball did not touch me. I felt that the first condition (1:1) was the best, as I felt that the ball was touching me exactly at the same place anatomically as it touched the wing that is why during these moments I felt the wings were mine. Otherwise I did not feel VBO.
3. I felt as an observer that is why I would place unintentional movement that I experienced under presence, but definitely not under VBO, as I needed to control the wings, but they felt stiff (I felt a need to use them).

Participant 21 (Sarune: 3, 1, 2), has VR experience;

1. In general/to some extant I felt presence, but I was not immersed much
2. No, I did not feel VBO at all.
3. I felt as an observer that is why I could identify this movement as I was moving myself without any connection to neither the body nor the wings. I would say that I experienced this movement as part of presence in the environment.

Participant 22(Erik: 2, 3, 1), has advanced VR experience:

Question nr. 8 – was totally bias. Also mentioned that if the scanner, when moving, would have had a sound attached, there would have been more immersion into the environment. Besides, according to him, if participants have had a chance to stay in the environment for some minutes, the chance for increased presence would have been higher.

Erik also used grading like the rest of the participants, he graded one of the questions as 5 points, but described it as “a little bit”.

Problems with audio feedback were due to the problems with tracking cameras, which needed to be restarted. Also due to that the hammer was not working optimally through all the conditions, only in condition nr.3.

1. I felt some presence in the environment; I needed to stay there longer in order to get higher feeling of presence.
2. I did not get much of VBO illusion, since there was no controlled movement.
3. I would place it to presence, since I felt as an observer and felt that I was on top of the bat.

12.4 LETTER OF CONTENT – EXPERIMENT II

Date 5.04.2016

Title of Project

Virtual Body Ownership illusion over a non-human avatar body in Immersive Virtual Environment

Study Supervisor

Niels Christian Nilsson

Department of Architecture, Design and Media Technology

Phone: 99402869, email: ncn@create.aau.dk

Student Investigator

Anastassia Andreasen, MED10

Email: aandr11@student.aau.dk

Place of Study

Aalborg University Copenhagen

A.C. Meyers Vænge 15, 2450 København

Multisensory Lab

Study Overview

You are invited to participate in the study assessing the impact of virtual body ownership on a user in Virtual Reality (VR). Past VR researches have shown that users have adopted a human-looking avatar body as their own body representation in VR. This study extends previous researches by investigating the impact of movement on a non-human avatar body in Immersive Virtual Reality.

Test Procedure

Test participant will be asked to put on a head-mounted display, which allows experiencing virtual reality environment. Headphones will be provided for the further immersion into virtual environment, through which participants will hear surrounding soundscape and the touch of a wand.

During the test participants will be asked to stay in a T-pose with their hands stretched to the sides to start with in order to calibrate the system. Afterwards, they will be asked to control the avatar with the help of their hands.

The whole procedure will be recorded.

At the end of each session the participant will be given digital questionnaire to fill in. Finally at the end of the test each participant could provide personal comments about the sessions to the conductor.

Participation and Remuneration

There is a voluntary participation in the study containing 4 sessions, which will take approximately 40 minutes of the participant´s time. Each session will take approximately 7 to 10 minutes.

Participants may withdraw from the study at any time, also during the test procedure. Furthermore participants may decline to answer any questions during the study.

There is no remuneration for participation in the study provided by university or the conductor.

Risks to Participation in the Study

There will be no physical risk during participation in the study. However there are known cases of nausea for some people using VR. If this is the case, the participant should report it straight away to the conductor and the test procedure will be stopped immediately.

Participants should take glasses off in case they use them due to incompatibility with the provided version of the head-mounted display in the lab.

Confidentiality

All information collected through the study will be kept strictly confidential. None of the information will be distributed to public or private use, neither will be posted on any website.

Questions and Research Ethics Clearance

This study has been reviewed and received ethics clearance through the study supervisor. However, the final decision about participation is yours. If you have any comments or concerns about the study, please contact the study supervisor through information on the1st page.

Thank you for your interest in the research and for your assistance with this project.

Consent of the Participant

I have read the information presented in the information letter about a study being conducted by Anastassia Andreasen, MED 10, under the supervision of Niels Christian Nilsson of the Department of Architecture, Design and Media Technology at Aalborg University Copenhagen. I have had the opportunity to ask any questions related to this study, to receive satisfactory answers to my questions, and any additional details I wanted. I am aware that I may withdraw from the study at any time by advising the researchers of this decision. I was also informed that if I have any comments or concerns resulting from my participation in this study, I might contact Niels Christian Nilsson.

I agreed to record my actions during the whole test procedure and I give my permission to record the test and use data for the future studies.

With full knowledge of all foregoing, I agree, of my own free will, to participate in this study.

Participants´ Name **Signature** **Date**

____ _______________________________________

12.5 TABLE OF MEAN, MEDIAN, STD AND VAR PER EACH QUESTION IN 3 CONDITIONS (EXPERIMENT II)

Questions	Mean	Median	Std	Var
Question 1	3.7273	4.0000	1.6954	2.8745
Question 2	4.5909	4.5000	1.7904	3.2056
Question 3	3.9091	3.0000	1.8493	3.4199
Question 4	3.1818	3.5000	1.8679	3.4892
Question 5	3.6818	4.0000	1.5240	2.3225
Question 6	4.2727	4.0000	1.8305	3.3506
Question 7	4.7727	5.0000	1.6015	2.5649
Question 8	4.6364	5.0000	2.0129	4.0519
Question 9	3.8182	4.0000	2.2176	4.9177
Question 10	3.5455	3.0000	2.1980	4.8312
Question 11	3.5455	3.0000	2.3038	4.9524
Question 12	4.8182	6.0000	2.3631	4.0455
Question 13	3.0000	3.0000	1.7995	3.6126

TABLE 14 MEAN, MEDIAN, STD, VAR PER EACH QUESTION IN CONDITION 1, EXPERIMENT I

Questions	Mean	Median	Std	Var
Question 1	3.3182	3.0000	1.6729	2.7987
Question 2	4.7273	5.0000	1.6954	2.8745
Question 3	3.2727	3.0000	1.5791	2.4935
Question 4	2.8636	2.0000	1.9098	3.6472
Question 5	2.9545	3.0000	1.8381	3.3788

Question 6	4.5909	5.0000	1.9678	3.8723
Question 7	3.9091	3.5000	1.9978	3.9913
Question 8	4.9091	5.0000	1.5090	2.2771
Question 9	4.1818	5.0000	2.2176	4.9177
Question 10	3.6364	3.5000	2.1722	4.7186
Question 11	3.5909	3.0000	2.3230	5.3961
Question 12	4.7727	5.5000	2.2024	4.8506
Question 13	2.6818	1.0000	2.0791	4.3225

TABLE 15 MEAN, MEDIAN, STD, VAR, PER EACH QUESTION IN CONDITION 2, EXPERIMENT I

Questions	Mean	Median	Std	Var
Question 1	3.3636	3.0000	1.8138	3.2900
Question 2	4.4545	4.0000	1.7383	3.0216
Question 3	3.1364	3.0000	1.8847	3.5519
Question 4	3.0000	2.5000	2.0931	4.3810
Question 5	3.0455	3.0000	1.8381	3.3788
Question 6	4.0909	4.0000	2.1582	4.6580
Question 7	3.2273	2.0000	2.3080	5.3268
Question 8	5.0909	5.0000	1.5402	2.3723
Question 9	3.8636	4.0000	2.0070	4.0281
Question 10	3.1364	2.5000	2.0070	4.0281
Question 11	3.0000	2.0000	2.2254	4.9524
Question 12	5.0455	6.0000	2.0113	4.0455
Question 13	2.2273	1.0000	1.9007	3.6126

TABLE 16 MEAN, MEDIAN, STD, VAR PER EACH QUESTION IN CONDITION 3, EXPERIMENT I

12.6 TABLE OF MEAN, MEDIAN, STD AND VAR PER EACH QUESTION IN 4 CONDITIONS (EXPERIMENT II)

Condition1	Mean	Median	Std	Var
Question1	2.3600	2	1.6803	2.8233
Question2	2.2000	2	1.3844	1.9167
Question3	2.6400	2	1.4686	2.1567
Question4	3.3600	3	1.8903	3.5733
Question5	2.6000	2	1.8257	3.3333
Question6	2.2800	2	1.6462	2.7100
Question7	1.9200	2	0.9092	0.8267
Question8	1.8000	2	0.9574	0.9167
Question9	2.3200	2	1.5470	2.3933
Question10	2.6400	2	1.4686	2.1567
Question11	5.0000	5	1.8930	3.5833
Question12	2.4000	2	1.2910	1.6667
Question13	1.8400	1	1.8637	3.4733
Question14	2.4400	2	1.6350	2.6733
Question15	2.0800	1	1.6563	2.7433
Question16	2.6800	2	1.4922	2.2267
Question17	4.6800	5	2.0149	4.0600
Question18	2.0000	1	1.6583	2.7500

TABLE 17 MEAN, MENDIAN, STD, VAR PER EACH QUESTION, CONDITION 1

Condition2	Mean	Median	Std	Var

Question1	2.8800	3	1.8330	3.3600
Question2	2.6000	2	1.6833	2.8333
Question3	2.6400	2	1.6803	2.8233
Question4	3.2800	2	2.1894	4.7933
Question5	3.2400	3	1.8991	3.6067
Question6	2.6400	2	1.8230	3.3233
Question7	2.4000	2	1.5811	2.5000
Question8	2.0000	2	1.3229	1.7500
Question9	2.6800	2	1.7253	2.9767
Question10	2.9600	3	1.4855	2.2067
Question11	4.6800	5	1.6763	2.8100
Question12	2.8800	2	2.0478	4.1933
Question13	1.9200	1	1.7301	2.9933
Question14	2.8000	2	1.9365	3.7500
Question15	2.2800	2	1.6207	2.6267
Question16	3.2400	3	1.9209	3.6900
Question17	4.5200	5	2.0640	4.2600
Question18	2.2400	1	1.9638	3.8567

TABLE 18 MEAN, MEDIAN, STD, VAR PER EACH QUESTION, CONDITION 2

Condition3	Mean	Median	Std	Var
Question1	3.0400	2	2.1307	4.5400
Question2	3.2800	3	2.1703	4.7100
Question3	3.2000	3	2.1409	4.5833

Question4	3.5600	3	2.2745	5.1733
Question5	3.2800	3	2.0314	4.1267
Question6	4.2000	5	2.5331	6.4167
Question7	3.5600	4	2.0429	4.1733
Question8	2.2000	2	1.4720	2.1667
Question9	3.6800	3	2.1932	4.8100
Question10	4.1600	4	2.0141	4.0567
Question11	4.7600	5	2.0265	4.1067
Question12	3.3200	4	2.1548	4.6433
Question13	5.1200	7	2.4379	5.9433
Question14	3.8800	4	1.8330	3.3600
Question15	5.2800	7	2.2083	4.8767
Question16	5.1200	6	2.1276	4.5267
Question17	4.3600	5	2.3431	5.4900
Question18	3.6000	3	2.2913	5.2500

TABLE 19 MEAN, MEDIAN, STD, VAR PER EACH QUESTION, CONDITION 3

Condition4	Mean	Median	Std	Var
Question1	6.0800	7	1.8690	3.4933
Question2	6.2000	7	1.7321	3.0000
Question3	6.2000	7	1.7559	3.0833
Question4	5.2000	7	2.3979	5.7500
Question5	5.4000	7	2.2913	5.2500
Question6	4.3200	5	2.2679	5.1433

Question7	6.0000	7	1.7321	3.0000
Question8	5.9600	7	1.8138	3.2900
Question9	4.1600	5	2.2301	4.9733
Question10	6.0000	7	1.8930	3.5833
Question11	4.0800	4	2.4819	6.1600
Question12	6.1600	7	1.8637	3.4733
Question13	4.1600	3	2.6407	6.9733
Question14	4.0000	4	2.1409	4.5833
Question15	5.3200	7	2.1932	4.8100
Question16	5.4000	7	2.2174	4.9167
Question17	4.5200	5	2.5515	6.5100
Question18	4.8400	6	2.2855	5.2233

TABLE 20 MEAN, MEDIAN, STD, VAR PER EACH QUESTION, CONDITION 4

12.7 CORRELATION RESULTS OF SPEARMAN TEST WITHIN THE GROUP VARIABLES

```
Command Window
  Columns 1 through 12

    0.5929    0.6570    0.6018    0.7466    0.5857   -0.3324    0.7067    0.3611    0.0791    0.5138    0.4476   -0.4948
    0.6042    0.3805    0.6547    0.7569    0.4957   -0.3602    0.5143    0.4472    0.2841    0.4994    0.3235   -0.4866
    0.5200    0.3510    0.5949    0.6463    0.4348   -0.4303    0.5357    0.3869    0.0735    0.4046    0.3266   -0.2559
    0.6650    0.5686    0.7505    0.6114    0.7019   -0.6873    0.5795    0.5893    0.1472    0.4428    0.4507   -0.5582
    0.7513    0.5461    0.8334    0.7919    0.6282   -0.6587    0.6196    0.5105    0.1774    0.4673    0.3206   -0.5822

  Column 13

    0.4172
    0.2240
    0.2899
    0.4635
    0.4264


PVAL =

  Columns 1 through 12

    0.0018    0.0004    0.0015    0.0000    0.0021    0.1045    0.0001    0.0761    0.7072    0.0086    0.0249    0.0119
    0.0014    0.0606    0.0004    0.0000    0.0117    0.0769    0.0085    0.0250    0.1688    0.0110    0.1147    0.0136
    0.0077    0.0854    0.0017    0.0005    0.0298    0.0318    0.0058    0.0561    0.7270    0.0449    0.1111    0.2169
    0.0003    0.0030    0.0000    0.0012    0.0001    0.0001    0.0024    0.0019    0.4826    0.0266    0.0238    0.0037
    0.0000    0.0047    0.0000    0.0000    0.0008    0.0003    0.0010    0.0091    0.3962    0.0185    0.1182    0.0023

  Column 13

    0.0380
    0.2817
    0.1599
    0.0196
fx  0.0335
```

FIGURE 102 RESULTS OF SPEARMAN CORRELATION TEST FOR CONDITION 1, EXPERIMENT II

```
Command Window
  Columns 1 through 12

    0.6248    0.6090    0.6698    0.5892    0.6035   -0.1656    0.6523    0.5286    0.2893    0.4516    0.4573   -0.3942
    0.3230    0.3829    0.3189    0.6082    0.4161   -0.0461    0.6113    0.2038    0.4033    0.2096    0.3489   -0.4374
    0.4864    0.4527    0.4581    0.5674    0.3553   -0.1241    0.5531    0.1708    0.2606    0.1434    0.2675   -0.2273
    0.6876    0.5686    0.6665    0.7402    0.6179   -0.1941    0.5515    0.4528    0.2904    0.4564    0.4953   -0.4861
    0.4901    0.4123    0.5006    0.5714    0.4185    0.0006    0.4181    0.3205    0.2280    0.1880    0.3563   -0.5123

  Column 13

    0.0412
    0.0812
    0.0917
    0.2051
    0.1199


PVAL =

  Columns 1 through 12

    0.0008    0.0012    0.0002    0.0019    0.0014    0.4289    0.0004    0.0066    0.1608    0.0234    0.0215    0.0512
    0.1153    0.0589    0.1202    0.0013    0.0386    0.8267    0.0012    0.3285    0.0456    0.3147    0.0873    0.0288
    0.0137    0.0231    0.0213    0.0031    0.0814    0.5544    0.0041    0.4145    0.2084    0.4941    0.1962    0.2745
    0.0001    0.0030    0.0003    0.0000    0.0010    0.3525    0.0043    0.0230    0.1591    0.0218    0.0118    0.0138
    0.0129    0.0405    0.0108    0.0029    0.0373    0.9977    0.0376    0.1183    0.2731    0.3682    0.0804    0.0088

  Column 13

    0.8450
    0.6997
    0.6628
    0.3255
fx  0.5679
```

FIGURE 103 RESULTS OF SPEARMAN CORRELATION TEST FOR CONDITION 2, EXPERIMENT II

```
Command Window
  Columns 1 through 12

    0.4708    0.7597    0.6464    0.5071    0.4478   -0.0233    0.8007    0.0936    0.0569    0.1553    0.3736   -0.0972
    0.5173    0.7773    0.5586    0.4690    0.5977   -0.0319    0.8665    0.2049    0.1122    0.2383    0.4578   -0.2225
    0.6900    0.8519    0.6981    0.5702    0.6754   -0.1810    0.9068    0.2050    0.0715    0.2498    0.4765   -0.3736
    0.6037    0.7564    0.6247    0.5855    0.5635   -0.1211    0.8893    0.0499    0.1078    0.1114    0.4670   -0.2495
    0.5460    0.8713    0.7780    0.5530    0.5400   -0.0818    0.8364    0.0481    0.0113    0.1238    0.3748   -0.2867

  Column 13

    0.3684
    0.2087
    0.2933
    0.2608
    0.4039


PVAL =

  Columns 1 through 12

    0.0175    0.0000    0.0005    0.0097    0.0248    0.9119    0.0000    0.6562    0.7870    0.4585    0.0658    0.6441
    0.0081    0.0000    0.0037    0.0180    0.0016    0.8796    0.0000    0.3258    0.5934    0.2514    0.0214    0.2850
    0.0001    0.0000    0.0001    0.0029    0.0002    0.3867    0.0000    0.3256    0.7342    0.2285    0.0160    0.0658
    0.0014    0.0000    0.0008    0.0021    0.0034    0.5641    0.0000    0.8127    0.6079    0.5961    0.0186    0.2291
    0.0047    0.0000    0.0000    0.0041    0.0053    0.6974    0.0000    0.8193    0.9572    0.5556    0.0649    0.1647

  Column 13

    0.0700
    0.3167
    0.1547
    0.2079
fx  0.0452
```

FIGURE 104 RESULTS FOR SPEARMAN CORRELATION TEST CONDITION 3, EXPERIMENT II

```
Command Window
  Columns 1 through 12

    0.5420    0.8372    0.6758    0.6556    0.9422   -0.2785    0.8668    0.4133    0.4615    0.7522    0.6865   -0.1606
    0.4688    0.7016    0.8069    0.5545    0.8095   -0.2315    0.9870    0.2766    0.3880    0.6572    0.6119   -0.2065
    0.4832    0.7102    0.8120    0.5626    0.8207   -0.2311    0.9933    0.2973    0.3986    0.6675    0.6194   -0.2230
    0.6406    0.4540    0.4827    0.4837    0.6007   -0.3071    0.5938    0.0839    0.1401    0.6448    0.5247   -0.0779
    0.6116    0.6830    0.6858    0.6085    0.7262   -0.2039    0.7047    0.2963    0.2744    0.8248    0.6329   -0.0952

  Column 13

    0.5446
    0.7009
    0.7066
    0.4968
    0.4177


PVAL =

  Columns 1 through 12

    0.0051    0.0000    0.0002    0.0004    0.0000    0.1777    0.0000    0.0400    0.0202    0.0000    0.0002    0.4432
    0.0181    0.0001    0.0000    0.0040    0.0000    0.2656    0.0000    0.1808    0.0553    0.0004    0.0012    0.3220
    0.0144    0.0001    0.0000    0.0034    0.0000    0.2663    0.0000    0.1490    0.0484    0.0003    0.0010    0.2841
    0.0006    0.0226    0.0145    0.0143    0.0015    0.1353    0.0018    0.6899    0.5043    0.0005    0.0071    0.7112
    0.0012    0.0002    0.0002    0.0012    0.0000    0.3283    0.0001    0.1503    0.1844    0.0000    0.0007    0.6508

  Column 13

    0.0049
    0.0001
    0.0001
    0.0115
fx  0.0377
```

FIGURE 105 RESULTS FOR SPEARMAN CORRELATION TEST CONDITION 4, EXPERIMENT II