Testing the Variation of the Pupil Diameter Dilation as Measure of the Sense of Embodiment

Liang Zhang
University of Twente
PO Box 217, 7500 AE Enschede
the Netherlands
l.zhang-11@student.
utwente.nl

ABSTRACT
The Sense of Embodiment (SoE) is defined as the experience of perceiving an external body, or part of it, as one's own. This research focuses on validating a novel way to assess the SoE: the variation of the pupil diameter dilation (PDD). We test it by manipulating the SoE in an out-of-body experience in a between group design. We administer visuo-tactile synchronous stimuli to one group (the embodied group) and visuo-tactile asynchronous stimuli to the other (not embodied group). There is not a standard way to measure the SoE. Usually, a combination of explicit and implicit measures is the most reliable way to assess it. The most common physiological measures used to assess the SoE are the Skin Conductance Response (SCR) and the Heart Rate (HR), which are recorded during our experiment and compared with the PPD detection. Moreover, we combined the implicit measures with an explicit measure (a questionnaire). A setup involving a VIVE Pro Eye HMD is designed for the user study. The questionnaire and PDD results confirmed that the synchronous group experienced a higher SoE than the asynchronous group. This confirmed the proper design of the two conditions. However, the SCR and HR data report the opposite trend. The detection of the SoE and its components (sense of ownership, sense of agency, and sense of self-location) levels and variations is subject of a current debate due to its importance to understand the levels of self-attribution and control of an external body, especially in research fields such as teleoperation and cognitive science. Our results show that the PDD is a potential measure of the SoE, but the comparison with SCR and HR suggests that we are still far away from an *ad hoc* measure of the SoE.

Keywords
Sense Of Embodiment; Virtual Reality; Pupil Dilation; Physiological Assessment; Objective Measurement; Out-of-body-experience; Human-machine Interaction; Heart Rate; Skin Conductance Response

1. INTRODUCTION
Cognitive science has been focusing on how we can experience what is inside and outside our body. Out-of-body experiences (OBEs) have been used to test this cognitive perception and Human-Computer-Interaction, Robotics, Psychology, Social Sciences, and others. Manipulating the Sense of Embodiment (SoE) of an individual is one of the ways to create an OBE. On the base of [8], we present the SoE as described by three components: the sense of body ownership (SoO), the sense of agency (SoA) and the sense of self-location (SoSL).

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The focus of this study is on the validation of a novel measure of the SoE: the variation of the pupil diameter dilation (PDD). A standard assessment of the SoE is still an open debate. There is no explicit and standardized methodology to test and measure the three components of the SoE as disentangled. Moreover, there is still not an answer on the weight that each component has on the overall SoE. Generally, measurement of the SoE can be divided in 1) explicit approaches, which measures what people say they actually experience (e.g. standardized questionnaire[13]) and 2) implicit approach, which refers to the body response when people are asked to perform a task (e.g. Skin Conductance Response(SCR)[5]).

In this study we propose the variation of the PDD as an explicit approach to measure the SoE. In order to test this assessment measure, we design an OBE in which we focus on the manipulation of the sense of ownership (SoO) and sense of self-location (SoSL) in a between group design with two conditions. One group experiences visuo-tactile synchronous stimuli (high SoE condition) while the other experiences asynchronous stimuli (low SoE condition). As a baseline to compare the novel measure, we record the SCR and heart rate(HR), and we collect the answers to a questionnaire (explicit measure) on the SoE to validate the two designed conditions. During the OBE, participants wear a head-mounted VR device (VIVE Pro Eye) to show them the pre-recorded video of the embodiment illusion and to record the PDD. Moreover, a E4 wristband is used to record the SCR and HR. This design allows us to understand if the observed variation of the PDD is related to the embodiment experience.

The structure of the paper is as follows: in section 2 we review the related works on testing and assessing the SoE. Section 3 entails the research questions and hypotheses to be investigated in this research. Section 4 presents the experiment design. Finally, in section 5 we present the results followed by the Discussion, Conclusions and Future Work sections.

2. RELATED WORK
In [8], the SoE is described by three components: the sense of ownership, the sense of agency, and the sense of self-location. The subsections below illustrate each component and how they are usually tested and measured. We also provide an overview on the physiological measures adopted in this study. The

reviewed literature is the baseline for the experiment design and provided a theoretical foundation.

2.1 Sense of Ownership

There are different definitions of body ownership in the literature. In [16], the SoO is described as one's self-attribution of an external body, and in [8] the external body is referred to as "the source of the experienced sensations". Thus, a human with strong SoO would claim to be the owner of the external body and to know everything s/he experiences is conducted by the body's senses'.

The illusory SoO experience over a fake body part (e.g.rubber hand) is commonly tested with a rubber hand illusion(RHI). In [1], participants observe in a VR environment virtual fingers moving while their real fingers do not move so as to measure their SoO. The results show that SoO is evoked over the hand and most participants believe their real fingers never moved. Moreover, SCR and interview are adopted to evaluate the SoO and SoA respectively, and results show that SoO and SoA cooperate together to influence the embodiment rather than working independently. In [3], the authors produce the interaction between vision and touch illusion using model arms, paintbrushes and rubber hands. In the questionnaire, Eight of ten subjects use terms of ownership to describe their feeling in this experiment such as "I found myself looking at the dummy hand thinking it was actually my own.".

2.2 Sense of Agency

In [2,p.7], the sense of agency (SoA) is defined as the "global motor control, including the subjective experience of action, control, intention, motor selection and the conscious experience of will". Thus, a person has strong SoA if s/he believes to be in full control of the external body; otherwise, the external body parts will be perceived as moving with their own intentions.

For the measurement of SoA, [6] divides the SoA into two components: the feeling and the judgement of agency, and later manipulates and measures SoA in VR using ElectroEncephaloGraphy (EEG). Hand movements are chosen as focus of the study since hands are the main body medium for interaction in VR environments and hands have a bigger degree of freedom. Results reveal that *locus of control*, namely the perception that what happens in the future can be controlled or influenced subjectively, influences the level of immersion and SoA. In [7], participants are asked to move the right index finger to control the movements of the index finger of a model hand. They experience dissociated SoA and SoO in a RHI design. The timing of finger movements (synchronous versus asynchronous) and mode of movements (active versus passive) and position of the model hand (anatomically congruent versus incongruent) are controlled. The results show that SoO and SoA are distinct cognitive processes, differently from [1].

2.3 Sense of Self-Location

In [8,p.375], the SoSL is defined as "one's spatial experience of being inside a body and it does not refer to the spatial experience of being inside a world (with or without a body)." Usually, SoSL is associated with the term OBE, in which people see their body parts outside their physical body.

In [4], participants wear a pair of head-mounted displays that are connected to two video cameras placed side by side 2m behind the participant's back. Participants are immersed in the illusion that they are watching their body from outside. The result from the questionnaire shows that SoSL can be determined by visual perspective and stimulation on the body. In [11], participants see a virtual body in front of them in a VR environment, and they are stroken synchronously or asynchronously at the back. The results from the questionnaire show that, during the stimulation, participants are immersed in the illusion that the virtual body is their own body, proving that SoSL can be manipulated by influencing sensory and cognitive processing of bodies. Also in [10] participants's back or chests are stimulated with either synchronous or asynchronous strokes while watching a video played in a VR environment. The results from the questionnaires show that participants localize themself where they perceive to be touched even if they saw their body part in a different position. Hence, in similar experiments with OBE, participants are not influenced by their real body position, but by the body part in which they see that they are stimulated. Generally, the conflict of visual and tactile perspective make the embodiment illusion less convincing.

2.4 PDD to Monitor Emotional Changes

PDD is generally considered as a signal to reflect autonomic arousal raised by emotional stimuli of an individual [23]. The measure of the PDD is usually applied in VR environments. In [18, 19], the authors show that VR environments can elicit emotions. In [18], participants' emotional states are manipulated using three virtual environments (anxious, natural and relaxing parks). The results confirm that effective VR environments can affect emotion of individuals and higher levels of "emotional" environments will more likely influence emotional state. In [17], five emotion segments, including happiness, sadness, fear, disgust, and anxiety, are used to evoke specific emotions of participants experiencing a VR environment, while PDD is collected. The results show that synchronous visuo-tactile cues produce an increase in PDD.

There are a few advantages of using PDD to measure emotions compared to other physiological measurements: one is that eye-tracking system is embodied in the VR glasses and no extra attachment is required; the other is that it cannot be voluntarily controlled by people because it belongs to an involuntary index of the autonomic nervous system [20].

We explore if running an experiment using a VR setup and manipulating the level of SoE of participants triggers emotional changes, such as being scared or curious, and influences the PDD.

2.5 PDD, HR, and SCR as Physiological Measures

PDD, HR and SCR are all considered as physiological measures and employed in this research reflecting the functions and reactions of the human body or any living system to the change of outside environment.

SCR and HR are the main measures used to assess the SoE. This is why we collect them as a baseline to compare the PDD variation. The increasing values of the SCR and HR reflect sympathetic nervous system changes, resulting in emotional change or sweating [12]. Using a combination of physiological approaches to measure human behaviors, not specifically the SoE, is not novel [21, 22]. For example, in [21], PDD, SCR, and HR are proven to have trial-by-trial positive correlations before face presentation, with larger PDD observed on trials with higher HR or SCR. In [22], PDD, SCR, and HR are applied to measure user experience of subjects under three experiment conditions: active gaming, observing a game and no-game. The results show that only the PDD is a suitable indicator of positive emotional reactions to game events; even though self-reports show that the active game condition is the most interesting.

2.6 Implicit and Explicit Approaches to Measure the SoE

It is common that both implicit and explicit approaches are applied to assess the SoE in a more reliable way. In [14], SCR and A questionnaire are collected in a RHI designed in VR. The SCR did not report a significant difference between conditions, while the questionnaire scores did. However, a relationship between SCR and questionnaire data is found: participants with low questionnaire responses correspond to low-medium SCRs, while high questionnaire response corresponds to low-high SCRs. Even though implicit and explicit approaches may fail to give consistent results, it is worthwhile to research and discuss the internal relationship between them to deepen the understanding of user study and experience.

3. PROBLEM STATEMENT

For the first time, to the knowledge of the author, we validate the PDD as a measure of the SoE. Our study is led by a series of research questions and sub-questions which we report following.

3.1 Research Questions

On top of the problem statement, the main research question is:

RQ: Is PDD a good measure of the sense of embodiment?

The main research question will be answered sequentially using the following sub-questions:

- RQ1: Can PDD variation be properly collected during an OBE using an eye-tracking system along with a VR setup? And which are the experimental setup limitations due to the use of PDD as a measurement?
- RQ2: Which components of the sense of embodiment can be assessed by the PDD measurement?
- RQ3: Will the PPD variation data confirm the answers to the SoE questionnaire and of the other implicit measurements?

3.2 Hypotheses

We developed three hypotheses:

H1: the PDD will result as a feasible measure of the embodiment.

H2a: the pattern observed from the PDD data will be confirmed by the SCR and HR data.

H2b: The explicit approach will confirm the implicit approaches results.

4. EXPERIMENT DESIGN

4.1 Participants

Participants are invited by Facebook announcement at least a week before the participation. The announcement includes a simple description of this topic and what they could expect during the experiment. 33 participants are recruited from the student body of the University of Twente, with 5 Euro as a raffle. The experiment is approved by the ethics committee of the EEMCS Department of the University of Twente (reference number: RP 2021-111).

The average age is 23 (range 20 to 34), 17 male, 16 female. Participants are divided into two groups: 17 participants in the first group experience synchronous visuo-tactile stimulation. In contrast, 16 participants in the other group experience asynchronous visuo-tactile stimulation.

4.2 Material and Apparatus

Fig. 1 shows the experiment setup and materials: a head-mounted VR device, a bracelet, a blue plastic glove, a pen, and a cup of water. Other pieces of material not visible in the picture are: the screen on which the experimenter is checking the video in order to properly manipulate the stimulation; a stereo-camera (brand ZED M) used to record the embodiment illusion (75 seconds of duration). The head-mounted VR device(brand Vive Pro Eye) is calibrated using the computer application SteamVR in Unity version 2019.4.10f1. The SCR bracelet (brand E4 wristband) is attached to the left hand of participants, in which SCR and HR per participant are recorded and uploaded by an application called "E4 realtime".

The change of lightness could also influence PDD, hence the experiment is conducted in a room with smooth brightness, which minimizes the impact of brightness. A computer is used to run the software Unity which plays as an interface to run the video in the VR headset and to collect the PDD of participants.

In order to create the OBE, a video was pre-recorded using the ZED mini and then shown during the experiment to the participants. The full video can be seen at this link: https://drive.google.com/file/d/1gtLpkzfMzHCUCXTSxMVywkiD-LBmLqiA/view?usp=sharing. The video has four phases of stimulation to the hand (See Tab. 1). The video is recorded in the same room and using the same objects (table, chair, glove, tissue, glass) that the participants see when entering the experiment room. Even the position of the objects was the same in the real room and in the video. The difference is that the participants observe the hand in the video from a third person perspective. This was done in order to observe if our condition could manipulate the SoSL.

(a)Front view of experiment - (b)participant's view of experiment

Fig1. Experiment Setup. The participants are seated at a table with their right hand extended in front of them, while wearing a blue latex glove. The left hand is under the table on their legs, and a bracelet is attached to record SCR and HR. During stimulation, participants see another right hand with blue rubber gloves performing stimulation using pen, fingers, and by pouring water.

4.3 Procedures

The experiment lasts twenty minutes in total. The first five minutes are dedicated to ask the participants to read and sign the Covid Health-Check form and the experiment consent form. Then, five more minutes are required to prepare the participants for the OBE experience. An SCR bracelet is attached to the left wrist of the participants, then they are asked to wear a blue rubber glove on the right hand and to comfortably put it on the table. A white tissue is used to cover their wrist (same as in the OBE video) in order to avoid them to focus on the different features of their skin or clothes with respect to the one in the video. A cup of water is placed next to their right hand. Finally, the HMD device is put on the participants' head. After that, an experimenter calibrates the device to ensure a correct collection of the PDD data. During the whole experiment, all participants are asked to look at their real hand without moving (since the virtual hand in the VR video remains in the same position for all the OBE). Some participants asked how to focus on their hand while the HMD blocks their sight, and they were suggested to look at where they think their right-hand lies on the table. After the preparation phase, participants experience either C1 or C2, both of which have four different stimulation phases: Pen cross, Pen tab, Finger touch, and pour water (See Table 1). After 75 seconds of stimulation, the water in the video is holded above the hand for 3 seconds and falls on the hand suddenly. Then all devices are removed and we stop to collect implicit data from the participants. Finally, participants have to fill in a questionnaire on the SoE and the OBE.

Table 1. The Stimulation Used in two compared groups

Condition	Stimulation in video	Stimulation in real	Visual-tactile
C1	Pen cross Lunate	Pen cross Lunate	Synchronous
	Pen tab Trapezium and Lunate	Pen tab Trapezium and Lunate	Synchronous
	Finger touch each fingertip	Finger touch each Fingertip	Synchronous
	Water pour on the hand	No Stimulation	-
C2	Pen cross Lunate	Skip 1st,4th, and 6th touch Delays with 2th, 3rd and 5th	Asynchronous
	Pen tab Trapezium and Lunate	Reverse the tab position and no touch at the 3rd times	Asynchronous
	Finger touch each Fingertip	Touch with delay and messed position on fingers instead of fingertips	Asynchronous
	Water pour on the hand	No Stimulation	-

4.4 Measures

We manipulated two conditions (see Table 1) between groups. In order to assess the effect of the manipulation, we collected both explicit (questionnaire) and implicits measures (PDD, SCR, HR).

4.4.1 Questionnaire

We used the updated questionnaire from [13]. From [15] in 2018 to [13] in 2021, quality and precision of the questionnaire increased, and 16 out of 25 questions of the standardized questionnaire remain, the questionnaire in [13] shows a higher sensitivity at the subscale level: Appearance, Response, Ownership, Multi-Sensory, and Embodiment. We only excluded the question "I felt like I was wearing different clothes from when I came to the laboratory" since it is not applicable to our experiment. Therefore, 15 questions remain. Those questions are scored using a 7-point Likert scale ranging from "strongly disagree" to "strongly agree". Questions are numerically categorized, and the sub-scales are weighted.

4.4.2 PDD

PDD of both eyes are collected by a Head-mounted VR device (brand Vive Pro Eye) at a rate of 90 sets per second.

4.4.3 SCR and HR

SCR and HR are collected by bracelet (brand E4 wristband) at a rate of 5.3 sets and 1.2 sets, respectively.

5. RESULTS

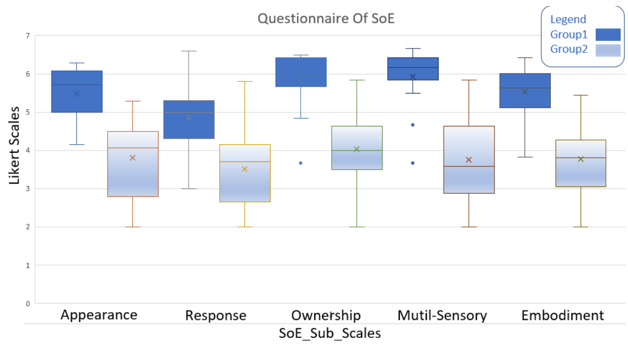
5.1 Questionnaire Data

Questionnaire results are numbers scaling from 1-7, where “strongly disagree” corresponds to 1, and “strongly agree” corresponds to 7. All questions except question 6 are used to check for the t-test. (See Table 2 and Fig 2) for the results.

Table 2. Questionnaire results. Overview of the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the SoE sub-scales.
Legend: **DF** = Degrees of freedom; **SD** = Standard deviation; **M1** = Mean of the responses of group 1; **M2** = Mean of the responses of group 2; **P** = p-value.

SUB-SCALES	DF	SD	M1	M2	P
Appearance	31	0.863	5.479	3.804	<0.001
Multisensory	31	0.969	5.931	3.760	<0.001
Embodiment	31	0.808	5.530	3.777	<0.001
Response	31	0.950	4.847	3.513	<0.001
Ownership	31	0.849	5.863	4.031	<0.001

Fig 2. Questionnaire BoxPlot. Box plots show the overview of the minimum score, first (lower) quartile, median line, third (upper) quartile, maximum score, and mean markers on the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the SoE sub-scales.



An independent-samples t-test is conducted to compare the 5 Sub-Scales of the questionnaire in synchronous stimulation condition (Group 1) and asynchronous stimulation condition (Group 2). The analysis reports a significant difference in the scores between groups for all the sub-scales. Particularly, Group 1 is more embodied than Group 2. Our results suggest that the two conditions are properly manipulated.

5.2 PDD Data

The VR video shown to participants has 75s, consisting of 4 sessions of stimulation: 0-30s, 31-44s, 45-66s, 67-75s.

To inspect the changes of the four phases of stimulation, five steps are applied to compute the results:

1. The VR video has 75s, but effective stimulation time is 70s, which corresponds to 6300 rows of data, and hence all data is cut from the beginning to save the remaining 6300 rows of data.
2. Replacing all "-1" values by making them equal to the last non-zero value. This abnormality happens because participants may blink unintentionally.
3. Replacing all abnormal values that deviate more than 10% of the last value. The new value equals the average value of the former four values and the latter four values. This is done because there are 6300 rows of data; hence, adjacent values should not deviate more than 10%.
4. The average value per row of data of all participants in the synchronous group is calculated as marked as G1, while The average value per row of data of all participants in the asynchronous group is calculated as marked as G2.
5. An independent-samples t-test is conducted to compare the 6300 rows of PDD data in G1 and G2.

The analysis reports a significant difference in the scores between groups for PDD (See Table 3). Particularly, Group 1 has a higher average value than Group 2. Our results suggest that participants in G1 are more embodied than that in G2.

Fig 3. Pupil Diameter Dilation(PDD) LinePlot. Overview of the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the PDD during OBE. Horizontal coordinate is stimulation phases from S1 to S4, and vertical coordinate is PDD in mm.
Legend: **G1** = Group 1; **G2** = Group 2; **S1** = Stimulation phase 1; **S2** = Stimulation phase 2; **S3** = Stimulation phase 3; **S4** = Stimulation phase 4.

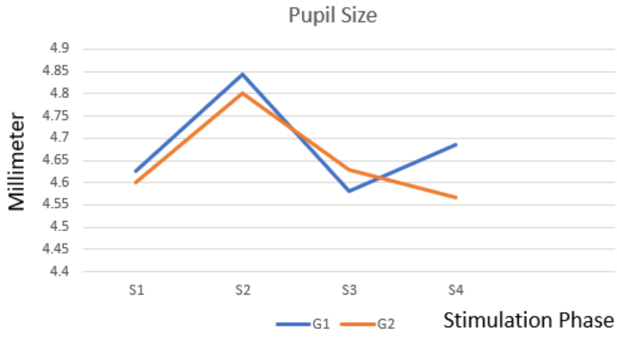


Table 3. Physiological measurements result. Overview of the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the three physiological measurements.
Legend: **DF** = Degrees of freedom; **SD** = Standard deviation; **M1** = Mean of the responses of group 1; **M2** = Mean of the responses of group 2; **P** = p-value; **PD** = pupil dilation; **EDA** = Electrodermal activity; **HR** = heart rate.

Physiological measurements	DF	SD	M1	M2	P
PD	12596	0.177	4.660	4.640	<0.001
EDA	740	0.039	1.455	2.126	<0.001
HR	166	0.956	76.327	79.243	<0.001

5.3 SCR and HR Data

Same steps of filtering and independent-test are applied to HR and SCR. The results (See Table 3, Fig 4, and Fig 5) report a significant difference in the scores between groups for SCR and HR(See Table 3). Conversely, participants in Group 2 have a higher average value than Group 1. This result shows that G2 is more embodied than G1.

Fig 4. Heart Rate(HR) LinePlot. Overview of the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the HR during OBE. Horizontal coordinate is stimulation phases from S1 to S4, and vertical coordinate is HR per minute.
Legend: **G1** = Group 1; **G2** = Group 2; **S1** = Stimulation phase 1; **S2** = Stimulation phase 2; **S3** = Stimulation phase 3; **S4** = Stimulation phase 4.

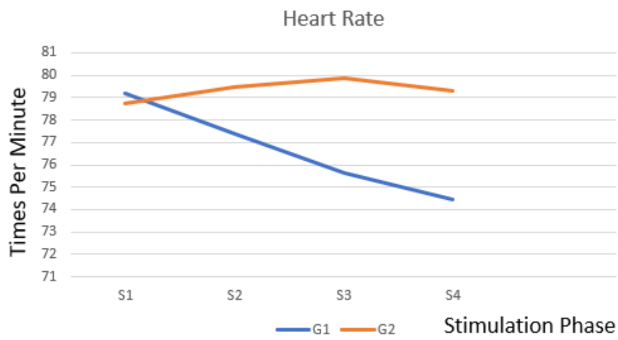
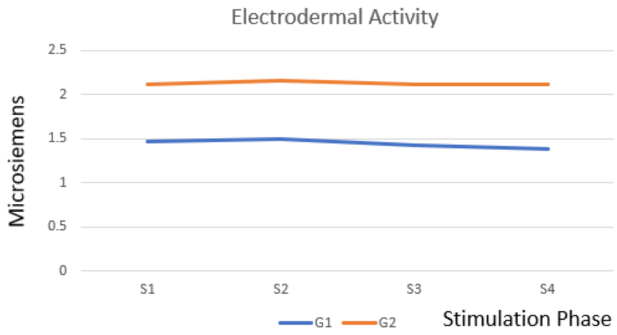


Fig 5. Electrodermal activity(EDA) LinePlot. Overview of the pairwise comparison between group 1 (synchronous stimuli) and group 2 (asynchronous stimuli) for the EDA during OBE. Horizontal coordinate is stimulation phases from S1 to S4, and vertical coordinate is EDA in microsiemens.
Legend: **G1** = Group 1; **G2** = Group 2; **S1** = Stimulation phase 1; **S2** =

Stimulation phase 2; **S3** = Stimulation phase 3; **S4** = Stimulation phase 4; **EDA** = Electrodermal activity.



6. DISCUSSION

Our findings show that not all the physiological measurements report consistent results with the questionnaire. More in detail, the questionnaire data regarding SoO and SoSL confirms that subjects in G1 are more embodied than G2. These findings are consistent with the PDD data. However, SCR and HR both present a higher value in the G2, therefore an opposite trend with respect to the previous measures.

To answer RQ1, there are a few rules, which correspond also to the setup limitations, to be followed to collect PPD data in an OBE in order to avoid data loss: 1) it is important to keep a constant level of light in the experiment environment. Sudden or big changes in the level of light would affect the PDD and the observations would not be dependent on the manipulation of the experiment conditions. 2) Participants should keep their head static for the entire duration of the experiment. PDD data tends to be lost in experiments which require head movements. 3) A HMD needs to be included in the experiment setup. Currently, eye-tracking systems integrated in the HMD are the best and practical way to measure PDD during an experiment. 4) Participants wearing glasses should be either excluded or the experiment should allow them to experience the experiment without limitations considering their sight condition.

To answer RQ2, according to the results of the independent t-test and average plot line on PDD (See Fig 3 and Table 3), PDD variation has a correlation to the level of embodiment of the participants, especially regarding the tested embodiment components SoO and SoSL. On the basis of the results, we accept H1. However, as for the other physiological measures that are usually adopted to assess the SoE, it was not possible to properly disentangle the assessment of each embodiment component.

In response to RQ3, the questionnaire and the PDD variation confirm the same results, namely that the synchronous group felt embodied while the asynchronous group did not. Based on this finding, we accept H2b. On the other hand, both SCR and HR values of the asynchronous group are higher than the values of the synchronous group. Hence, PDD is not consistent with SCR and HR and H2a is rejected.

The PDD variation data, plotted in Fig. 3, show that the trend of both groups from stimulation phase 1 to phase 3 firstly rise and then decline, but the trend differs in phase 4, when G1 rises and G2 declines. As described in Table 1, all the first three phases of stimulation are directed to the hand of the participants, while in phase 4 a treat was presented (i.e. the water falling on the hand in the video). This is a significant difference, since most of the participants in G1 do not recognize they are watching a pre-recorded video (instead they think that they are staring at their real hand) until the water is poured. As expected, participants in group 1 are more embodied and hence more vulnerable to feel scared or frightened by the water, thus PDD increases. In contrast, in G2, tactile stimulation differs from visual stimulation in the video for phase 1 to phase 4, subjects feel less embodied and hence pupil size declines continuously after phase 1.

According to the literature review, higher embodiment is expected to result in higher HR and SCR values, as for the PDD. However, HR and EDA values have opposite effects. Possible reasons would be:

SCR, HR, and PDD are usually used to test similar behaviors (such as arousal, anxiety, attention, and engagement). Change of embodiment can influence human behaviors and emotions, however multiple human behaviors and emotions are mixed in an OBE, there is no standard way to measure how much impact each factor has on the physiological responses. In the previous studies which use multiple physiological measurements for emotional change, [21] shows SCR,HR and PDD have positive correlation while [22] shows only PDD is a good indicator. Contraction also happens in our study while PDD and SCR, HR suggest opposite levels of SoE. Nevertheless, this field is not mature, every paper will provide a novel method in terms of manipulation and measurement of SoE. Our findings could be explained by the fact that participants in G2 felt more stressed and anxious but less embodied than G1. Stress and anxiety, more than the embodiment effect, cause a higher arousal of the autonomic nervous system, resulting in higher value of SCR and HR in G2. These higher levels of stress in G2 could have been generated by the fact that they felt that the OBE was out of their control.

Another explanation could be that participants in both groups were deeply immersed and embodied in the OBE, and hence data from physiological measurements just measured their levels of stress and attention. Consciously, they confirmed the conditions through the questionnaire answers, but unconsciously they felt more immersed then they realized. However, this assumption suggests that none of those physiological measurements are good approaches to measure embodiment since those approaches fail to differentiate the change of SoE during the experiment.

7. CONCLUSIONS AND FUTURE WORK

This study investigates the feasibility of PDD as implicit measurement of the SoE using a VR setup. The experiment design allowed us to properly collect the PDD data. The tested measurement implies some limitation of the experiment setup: it is necessary to run the experiment using a HMD; the brightness of the environment has to be checked in order to be sure that the PDD is only affected by the manipulation of the conditions; to prevent data loss, it is better to design a task that does not require the participants to move the head during the experiment. The questionnaire results and the PDD confirmed the designed conditions between groups: group 1 experienced a good embodiment, while group 2 did not. However, SCR and HR showed an opposite trend. This study could become a reference to future researchers who are interested in assessing the SoE using a VR setup.

For future research, we propose to validate if there is a positive correlation of PPD variation towards the level of embodiment with further comparisons with SCR and HR. The next step would be to find an asymptotic regression formula for the solid relationship.

8. ACKNOWLEDGEMENTS

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