Being Superman

Effects of superhero embodiment in virtual reality on exertion capabilities

Maarten Lodewijk
Graduation Thesis, August 2016
Media Technology MSc program, Leiden University
Thesis Advisors: Maarten H. Lamers, Robin S. Rosenberg
mail@maartenlodewijk.nl

Abstract— Studies into Virtual Reality (VR) and embodied cognition reveal that VR is capable of altering one's behavior, body schema and body image. This study aims to determine whether the particular trait of "super strength" commonly associated with superheroes can be induced in males by using Virtual Reality. Specifically, it is hypothesized that embodiment in the body of Superman through VR leads to increased exertion capabilities. In an affordance test, male participants were asked to estimate how long they thought they would be able to perform a planking exercise. They then had to perform this exercise for as long as possible. This was done three times: setting up the baseline, after being embodied in an Average Body (AB), and after being embodied in a Superman Body (SB). The order of the AB and SB conditions alternated per participant. Sense of presence was measured through a questionnaire after each condition. No significant effects that support the hypothesis were found within the affordance test results, but a significant relation in support of the hypothesis was found between average presence and the change score of SB Exertion. Further experimentation is needed in order to confirm this effect, see whether it exists in females, and to come to definitive conclusions about the effects of embodiment on exertion capabilities.

I. Introduction

The modern concept of the superhero is an archetype of which the roots can be found in the early 20th century. It was popularized by the play "The Scarlet Pimpernel" (1903) and the novel based on this play which was published in 1905 (Hutchinson, 1905). It tells the story of a masked vigilante saving condemned people from the guillotine. During the 1940's, in the middle of what is often referred to as "The Golden Age of Comic Books", superheroes were endowed with powers or abilities that were considered to be superhuman or unnatural when compared to the capabilities of a normal human being. Although a superhero does not need to have superpowers or abilities by definition (For example, Batman [*DC Comics*, 1939] is widely regarded as a superhero yet possesses no superhuman powers at all), it is a characteristic that is often associated with superheroes. The most famous example of this modern definition of the superhero is the character Superman (*Action Comics #1*, DC Comics, 1938), who has the ability to fly on his own and has superhuman strength.

Superheroes, and in particular Superman, are nowadays pop-culture icons that are so widely popular that they have a significant cultural presence in western society [1]. This makes them relatable to many people, and it can be argued that this makes them a great tool for exploring and communicating scientific concepts to the general public [2]. Robinson [3] shows in her study that there is a correlation between superhero knowledge and the level of moral judgement in children, primarily for boys. This implies that superheroes have a big influence on the way that children learn about morality, which could be used to communicate more efficiently with children about this topic. Moreover, in a study done by Rosenberg, Baughman & Bailenson [4], it was shown that exposure to the superhero archetype can have a direct effect on prosocial behavior in real life situations, triggering adults to display altruistic traits that are commonly associated with superheroes.

It is therefore of interest to investigate how the superhero archetype can influence human cognition when it is communicated through a medium that involves a high level of embodiment and immersion, such as Virtual Reality (VR). VR has already been proven successful in utilizing embodiment to produce genuine first-person experiences that provide a sense of ownership over a virtual body. For example, Peck *et al.* [5] successfully utilized VR to facilitate a body transfer illusion that put light-skinned participants in a dark-skinned body. Implicit racial bias of participants towards dark-skinned people measured after the VR experience was significantly lower than before the experience. Research subjects within the combined fields of VR, embodiment and body transfer are very diverse, ranging from the effects of gender change [6] to how the size of one's body influences one's perception [7]. The effects of embodiment in VR can even last outside the VR experience itself [4]. The application of this knowledge has already been proven to be effective in the treatment of body image disturbances associated with eating disorders such as anorexia [8].

With the knowledge that the superhero archetype can be used to influence behavior, and that experiencing body transfer illusions with VR has a huge influence on human cognition as well, the question can be posed whether a combined effect can be facilitated. Rosenberg, Baughman & Bailenson [4] give insight into this topic with the triggering of prosocial behavior, but one could wonder whether this also works for other traits that are commonly associated with superheroes. Take for example the trait of super-strength. While no human could possibly match the fictional strength of Superman, it might be

possible that being embodied in a virtual Superman body makes people perform better at tasks that require physical strength, by breaking through the mental barriers imposed by the image one has of his own body.

This study thus aims to determine if the particular trait of "super strength" commonly associated with superheroes can be induced on men by using Virtual Reality. Does one's strength increase after embodiment in the body of a superhero archetype? If such an effect exists for both men and women, this research could possibly be implemented in the development of exertion games that aim to motivate people in physical exercise and making physical exercise itself more effective. It might also be of particular interest in the case of motivating children to develop a more active lifestyle as the superhero archetype does seem to communicate very well with younger age groups. Coming from the aforementioned ideas and concepts of this section, it is hypothesized that embodiment in the body of Superman through Virtual Reality leads to increased exertion capabilities in men.

II. Related Work

A. Body image and affordance perception

Studies into VR and embodied cognition reveal that VR is capable of altering one's behavior, body schema and body image. The body image of an individual influences the perception of affordance one has of his or her body. An example of a study examining this effect of body image on affordance perception was done by Dennis Profitt. Profitt executed multiple studies into how body image affordance influences height [9] and slant perception [10]. Participants in these studies who were physically exhausted or were encumbered by wearing a heavy backpack estimated these heights to be much higher and slants to be much steeper than they actually were. VR has means of distorting the body image, and it is therefore possible to distort the affordances one has of his or her body by using VR.

For example, Piryankova *et al.* [11] show in a study in which women have to perform an affordance test while being embodied in a virtual underweight or overweight body that people quickly form affordances for such a virtual body. Many studies focus on replacing or modifying a specific body part in VR, such as exposing participants to an enlarged or shrunken view of their own hand which resulted in participants modifying their grasping movements during reach-to-grasp tasks [12]. Similar techniques have proven successful in utilizing VR to help patients rehabilitate after suffering from a stroke, such as by amplifying hand movements in VR which resulted in increased use of the impaired limbs for a period outside the virtual environment [13].

B. Full body transfer illusions in VR

The illusion of full body transfer is also possible with VR, and even gender swaps produce an increased feeling of body ownership when using VR. Slater *et al.* [6] conclude from their gender swap study that this is one of the most extreme circumstances of body swapping for humans, as gender categorization in human cognition is known to be persistent. Therefore, since gender swapping with VR has proven to be successful, body transfers with less radical differences to the participant's body should be possible as well. In other research, participants who were embodied in a virtual body of a small doll were found to perceive object sizes and distances to be much larger [7], which shows that VR can distort the body image to extreme lengths.

A full body transfer illusion can also cause subjects to project traits they imagine to belong to the virtual body onto their own body-image. In the study of Kilteni, Bergstrom & Slater [14], participants were asked to perform drumming exercises within VR while being embodied in either a casual dark-skinned (CD), formal light-skinned (FL), or a baseline condition white-skinned avatar. Participants in the CD group reported that they felt their virtual bodies to be more appropriate for drumming than their real bodies. They also reported themselves to be more expressive than usual than reported by participants in the FL condition and baseline condition groups. The participants of the CD group were also the only ones to show significant increases in their movement patterns for drumming. Osimo *et al.* [15] investigated the effects of counselling oneself while being embodied in a virtual body representing Sigmund Freud in contrast to being in a virtual body representing oneself. Improvements in reported mood and happiness were present in both conditions, but these improvements were greater in the Sigmund Freud condition. While the research could not determine whether these effects come from using Freud's body specifically, the difference with the self-body condition suggests that cognitive changes do happen when a different body form with positive traits associated to counselling is being used.

Although first person perspective is an important feature of VR for the facilitation of embodiment [6], visuo-tactile synchrony is also an important aspect in order to reach the highest embodiment potential during these full body transfer illusions [16]. Visuo-tactile synchrony entails the tactile stimulation of a particular spot on the body of a subject, while he or she observes the same stimulation on a virtual body. The effect has mainly been examined in so-called Rubber Hand Illusion studies, where a rubber hand is placed on a table in an anatomically correct position in relation to the subject, while the subject's real hand is hidden out of sight. The rubber hand is visibly being stroked while the participant's hand is synchronously stimulated tactilely. This way a strong illusion of ownership over the rubber hand is achieved with the participants. The principle of visuo-tactile synchrony has been extended to include other modalities [17]. For example, the synchrony of virtual limb movement with the movement of the corresponding limbs of the subject also induces ownership over the virtual body.

C. Cognitive effects of superhero embodiment in VR

Closely related to this research, in the study done by Rosenberg, Baughman & Bailenson [4], participants who flew around in a virtual environment in a manner usually associated with superheroes showed greater helping behavior afterwards in the real world compared to participants who used a different method of flying in the virtual environment. Significantly, the

experimenter never mentioned to participants any terms or concepts related to superheroes towards the participants. Instead, the virtual experience of flying with arms extended was used to prime concepts and stereotypes related to superheroes in general and Superman in particular. As a result, participants seemed to take over the altruistic traits related to these concepts and stereotypes. The behavioral dependent variable was collected by having an experimenter knock over a cup of pens, under the guise of an accident, and measuring how much time passed until participants started helping and the number of pens picked up.

D. Effects of virtual and augmented reality on physical activity

The level of interface embodiment that VR has to offer can also have effects on physical activity. A study done by Kim, Prestopnik and Biocca [18] found that participants of exertion games had an increased level of energy expenditure when the exertion game was being played within a VR environment. Another research showed how the energy usage of participants while lifting dumbbells can be influenced by altering the brightness of the dumbbell in Augmented Reality [19], and that virtual visual cues that are implied on an object can influence the perception of weight of that object.

E. Key findings

Given that this study focuses on how being embodied in the body of a superhero can affect the physical capabilities of an individual, the following key findings are relevant for this study.

[F1] Embodiment in VR can influence behavior, body-image and body-schema of an individual [4, 5, 6, 7, 8, 12, 13, 15, 19].

[F2] Therefore, VR can be used to change the perception one has over his or her affordances of the body [11, 14].

[F3] VR has the ability to make the most extreme full-body transfer illusions convincing [6, 7].

[F4] Visuo-tactile synchrony is essential for an effective full-body transfer illusion [7, 16, 17].

[F5] There are certain traits that are commonly associated with the superhero concept and are primed by people when embodied in a superhero body [4].

[F6] The superhero concept can be used to influence people's thoughts and behavior [3, 4].

[F7] Applying a VR interface to Exertion Games can have a positive influence on energy usage. Therefore, there are possibilities for VR to influence physical aspects of the body [18].

[F8] Visual cues can be used to manipulate one's usage of physical capabilities [19].

[F9] Gender can modulate cognitive effects caused by exposure to superhero archetypes [3].

III. METHODS

A. General experimental design

To test the hypothesis, an experiment was set up in which male participants underwent two sessions (one for each condition) within a Virtual Reality Environment (VRE). The experiment followed a counterbalanced measures design with two conditions, in which the ordering of conditions varied over participants. With the counterbalanced measures design, the aim was to mitigate the problem of the ordering effect. In a repeated measures design the subjects would over time become less productive and more tired, which influences the results, especially those of the second tested condition. In order to

Figure 1: The Superman Body (SB) Condition

Figure 2: The Average Body (AB) Condition

minimize the required number of participants for finding statistical significant results, the experiment was performed with male subjects only. Minimizing variation of confounding effect in the subjects group works to this effect. Moreover, if an effect is found, the conditions under which it is exhibited can be studied in wider context.

In the experimental condition, participants viewed a VRE through a head-mounted display (HMD). In this VRE the participants were embodied in the body of Superman, the Superman Body (SB) condition. In the control condition VRE, participants were embodied in the body of an average human male, the Average Body (AB) condition. In both the SB and AB conditions, which are depicted in Fig. 1 and Fig. 2 respectively, the VREs in which the virtual bodies were placed consisted of a small room with multiple mirrors in which the participant could view the virtual body by moving around his head. Visuo-tactile synchrony was used to strengthen the body-transfer illusion. Further details regarding the VREs and the use of visuo-tactile synchrony are provided in the following sections.

After each VRE session, participants immediately had to fill in a questionnaire regarding their experience in the VR, report how long they think they would be able to perform a planking exercise in an affordance test, and perform this planking exercise in order to test the effects of the conditions on the physical endurance of the participant. This exercise was also done at the start of the experiment, before entering any of the VREs, in order to acquire baseline results for comparison with the two conditions. In this planking exercise the participants had to assume a prone position with the body's weight borne on forearms, elbows, and toes (Fig. 3). This position had to be maintained for as long as possible. Each time the exercise was done, the experimenter made sure that there was at least 5 minutes of recovery time until the next exercise.

B. Participant characteristics

A total of 30 males completed the experiment. Eighteen participants were recruited among students of the Institute of Advanced Computer Science at Leiden University, nine among employees of the company LaserMaxx Lasergames B.V. Three participants were recruited from the social circle of the principal experimenter. All participants read and signed an informed consent form and were compensated with a piece of candy after the end of the experiment. Four of the participants experienced an unintended horizontal calibration anomaly of ~10 degrees during the VRE simulation, which was caused by technical issues. Their data was not included in the statistical analysis. The age of the participants ranged between 19 and 45, with a mean of 24. The mean BMI of 23.93 in this study is lower than that of the national male average of the Netherlands (25.47).

Figure 3: A participant performing the planking exercise

C. Procedures

Upon arrival the participants were given a consent form about the procedures of the experiment, which were also explained to them verbally. If they agreed to participate (none refused), they were alternately assigned to the order of conditions that they went through (SB condition first and AB condition second or vice versa).

For acquiring baseline results, participants were asked to fill in an affordance test in which they estimated how long they would be able to perform the planking exercise. The form they were given for this explained the procedure of a planking exercise in both words and a photo. In preparation of executing the planking exercise, participants lay down on an exercise mat face-down with their body stretched and their elbows beneath their shoulders. To ensure that the exercise was performed consistently in the baseline test and both conditions, the position of each participant's feet and elbows were marked with tape on the exercise mat. After this the participants were asked to perform a planking exercise for as long as possible. The timed variable was measured in seconds from the moment the participant assumed the planking position until the moment the participant stopped the exercise. During the entire experiment it was made sure that there was a period of at least 5 minutes between each planking exercise to ensure recovery from the exercise.

After the baseline tests, participants were asked to report their age, body mass and height, which were used for correction in the statistical analysis. A measuring tape attached to the wall and scales were present in order to measure the height and body mass.

In order to gain insight into the participants' knowledge related to Superman and their exposure to media involving Superman, they were asked to fill in a pre-experiment questionnaire. The first part of this questionnaire (the Superman Knowledge Test, or SKT) consisted of three questions in which the participants were quizzed about several aspects of Superman's story: his alternate identity name, his alternate identity job, and his real name at birth. The second part of the questionnaire, the Superman Strength Estimation (SSE), asked the participants to estimate the strength of Superman by showing five different objects (a car, a plane, a skyscraper, a mountain, and a planet) and asking to mark the heaviest object that they thought Superman would be able to lift. The third part of the questionnaire, the Superman Exposure Test (SET), consisted of 4 questions that questioned the participants on their exposure to media involving Superman such as movies, series, comic books and toys. Both the SKT and SET were based on similar tests used by Robinson [3], however the tests used in this study were altered to focus on Superman instead of superheroes in general, and involved two extra questions to accommodate an older target group than Robinson's. This pre-experiment questionnaire is available as appendix to this paper.

Next, the participants were instructed to stand in the middle of the room with their feet placed on the marked spots. Before entering the VRE, they were told that they were only allowed to look around by moving their head. All other body parts were to be left in place for visuo-tactile synchrony. Following this, they were asked to put on the HMD as well as a pair of safety headphones which were intended to muffle sounds from outside the VRE.

In the VRE, participants were in either the SB condition or the AB condition. They could use their head to look around the room, which allowed them to see the reflections of their virtual body in the mirrors. Once the experimenter had checked whether everything was working accordingly and a period of 1.5 minutes of looking around in the VRE had passed, the visuo-tactile synchrony was activated. A virtual brush would appear in the VRE and stroke the virtual bodies on the shoulders and stomach with soft strokes that take 3 seconds each. This action was synchronously carried out on the real body of the participants with a brush. To aid the experimenter in synchronizing the brush strokes on the real bodies with those inside the VRE, the experimenter could view the VRE from the perspective of the virtual brush on a secondary screen. The visuo-tactile synchrony was repeated for the duration of 90 seconds total. A photograph of the experimenter executing the visual tactile synchrony is pictured in Fig. 4.

After the visuo-tactile synchrony was completed, the HMD was taken off and the participants were asked to complete a questionnaire consisting of 5 questions in order to evaluate the feeling of presence experienced by the participants in the VRE. These questions were scored by means of a 1-7 Likert scale and were based on those used by Rosenberg [4] and by Kilteni, Bergstrom & Slater [14]. After completing the questionnaire, the participants were asked to fill in another affordance test and repeat the planking exercise. Then, the HMD was put back on for the alternate condition and the process was repeated.

Figure 4: The experimenter executing visuo-tactile synchrony on a participant.

D. Materials

The VRE was made with the Unity 3D game engine and consisted of a small room with white walls, with two mirrors placed in the room in which the participants could see the virtual body. An Oculus Rift DK 2, which has a resolution of 960×1080 per eye, a Field of view 100° nominal and 84° horizontal, was used to display the VRE to the participants. Both the Superman and Average Male characters were animated with subtle idling animation and their heads rotated relative to the rotation of the HMD.

The character model of Superman was obtained through the website turbosquid.com. However, due to copyright issues it cannot and will not be distributed to the public domain through this study. The model of the average human male was downloaded from the website mixamo.com, the brush model and the raw motion capture footage used in the animations for the characters were obtained through the Unity asset store.

IV. Results

With the exclusion of the data from participants who experienced the aforementioned calibration error, analysis was done with a sample of $n = 26$.

A. Pre-experiment questionnaire results

The means, range and standard deviations for the SKT, SSE, and SET are provided in Table I.

TABLE I: PRE-EXPERIMENT DESCRIPTIVE STATISTICS

Variable	Mean	Range	Standard Deviation
Superman Knowledge Test	2.067	3	0.823
Superman Strength Estimation	3.033	4	1.245
Superman Exposure Test	2.400	5	1.522

B. Baseline versus SB and AB conditions

A repeated measures ANOVA was used to compare the baseline affordance test results and baseline exertion test results to those of the AB condition and SB condition. The models controlled for BMI and age.

For the affordance test results, Mauchly's test indicated that the assumption of sphericity had been violated for condition $\chi^2(2) = .695$, $p = .018$. Therefore, degrees of freedom were corrected using Huynh-Feldt's estimates of sphericity. There was no significant effect of the different conditions on affordance test score ($F_{1.53} = 7.87$, $p > .05$).

For the exertion test results, Mauchly's test also indicated that the assumption of sphericity had been violated for condition $\chi^2(2) = .599$, $p = .004$. Degrees of freedom were corrected using Greenhouse-Geisser's estimates of sphericity. Again, no significant effect of the different conditions on exertion test score was found ($F_{1.43} = .82$, $p > .05$). Fig. 5 shows the AB exertion results versus the SB exertion results.

C. Presence versus SB / AB exertion

A regression analysis was used to see whether there was a significant relation between the average presence score (which was derived from calculating the combined average score of the five questions regarding presence) and the change scores of both conditions. The change scores are either "AB exertion score minus baseline exertion score" (how much exertion capability changed between baseline and after the AB VRE) or "SB exertion score minus baseline exertion score" (how much exertion capability changed between baseline and after the SB VRE). The AB and SB exertion change scores per average presence scores are shown in Figs. 6 and 7. No significant relation was found between the AB presence score and the AB exertion change score (β = .125 and p = .985). However, a significant relation between SB presence score and SB exertion change score was found (β = 7 and p = .039). It is important to note that the minimum & maximum values and standard deviations are very high, as shown in Table II.

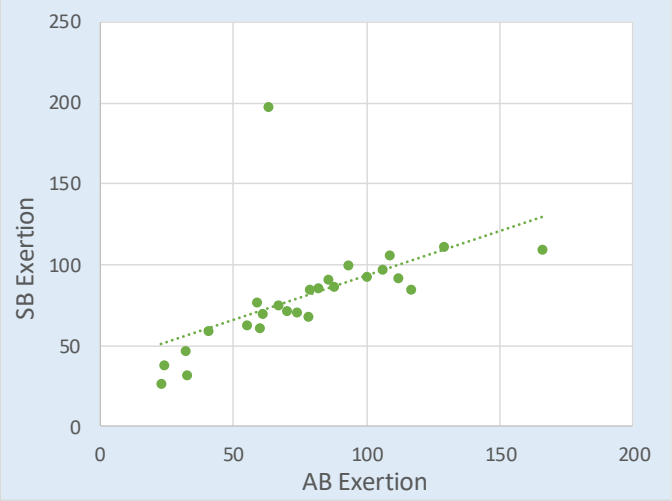

Figure 5: AB exertion versus SB exertion

TABLE II: CHANGE SCORES DESCRIPTIVE STATISTICS

Variable	Mean	Min	Max	Std. Deviation
AB exertion change score	-23.538	-144	38	30.674
SB exertion change score	-19.923	-45	10	17.127

A statistical outlier in the AB exertion score influenced these values. The descriptive statistics without this outlier are shown in Table III.

TABLE III: CORRECTED CHANGE SCORES DESCR. STATISTICS

Variable	Mean	Min	Max	Std. Deviation
AB exertion change score	-18.72	-50	38	18.743
SB exertion change score	-20.36	-45	10	17.332

A second regression analysis was done with another change score of "AB Exertion score minus SB Exertion score" and presence scores. No significant relations were found between this SB/AB change score and SB presence score (β = 7.463 and p = .243), nor between the SB/AB change score and the AB presence score (β = 4.809 , p = .461).

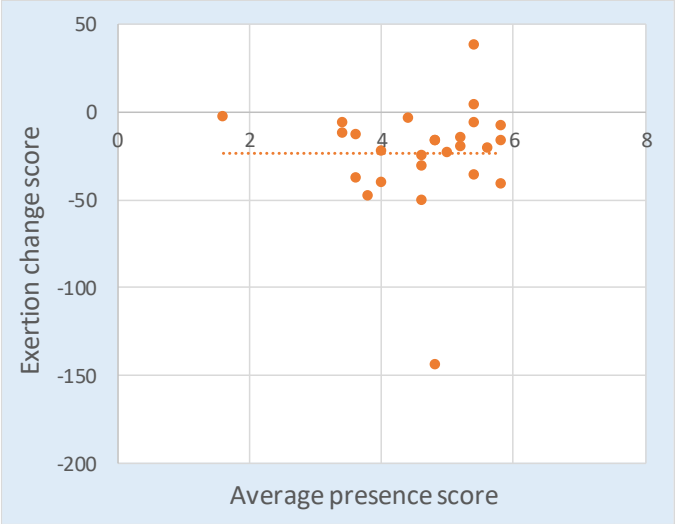

Figure 6: AB exertion change score per average presence score.

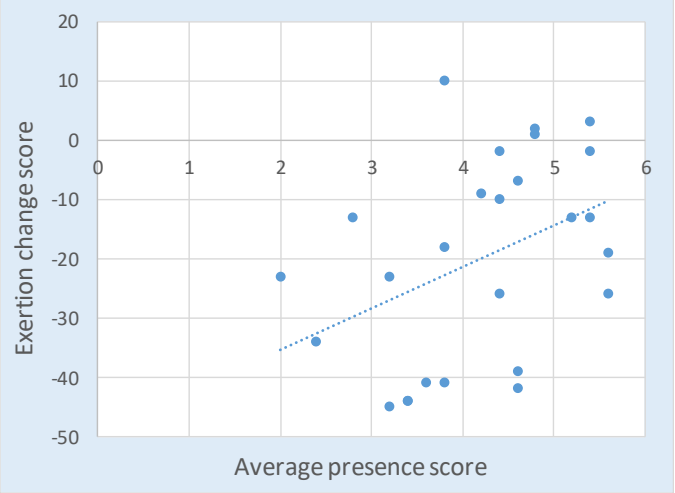

Figure 7: SB exertion change score per average presence score.

D. Pre-experiment versus SB exertion / affordance

Regression analysis between the SKT/SSE/SET test results and the SB exertion/affordance test results generated highly varied results (shown in Table IV), all with a $p > .05$.

TABLE IV: PRE-EXPERIMENT TEST CORRELATIONS

Regression variables	*β*	*p*
SKT versus SB Exertion	2.076	0.803
SKT versus SB Affordance	8.785	0.359
SKT versus SB Exertion change score	-0.674	0.876
SKT versus SB/AB Exertion change score	-3.173	0.687
SSE versus SB Exertion	0.540	0.924
SSE versus SB Affordance	-0.877	0.893
SSE versus SB Exertion change score	2.952	0.312
SSE versus SB/AB Exertion change score	3.498	0.398
SET versus SB Exertion	-1.791	0.683
SET versus SB Affordance	-0.903	0.859
SET versus SB Exertion change score	-0.729	0.749
SET versus SB/AB Exertion change score	8	0.128

V. DISCUSSION

The pre-experiment tests were less valuable than expected. The SKT would have given more valuable information with an increased score range: Of the 26 analyzed scores, 15 had a value of 2.0 (out of the maximum possible range of 0 to 3), which made it difficult to find a correlation between SKT scores and SB affordance/exertion scores.

The low overall SET values can be explained by one of the questions asking about items with the Superman branding which may be significantly more popular in the USA where the original questionnaire was developed and used than in the Netherlands. Also, the recent negative response to the latest Superman movies was given by many participants as the reason of why they gave a very low rating to the question about the likelihood of them seeing a new Superman movie in theaters. Comparison of both the SET and SSE versus exertion and affordance data did not give any indication of a possible effect, which points at a need for a more refined way of measuring Superman exposure.

There were no significant effects found within the affordance tests that support the hypothesis. A huge factor in this is that the baseline affordance test provided very inaccurate results compared to the second and third affordance tests. Most participants declared that they did not have any insight into their affordance at all prior to the experiment, and based their answers on the second and third affordance tests upon their performance of the baseline exertion test.

A significant positive relation was found between the SB presence and SB exertion change scores. This does support the hypothesis, as this shows that the Superman embodiment had a positive influence on the physical capabilities of the participants, while embodiment in an average male body did not seem to have any effect at all. However, the relatively large standard deviation and minimum/maximum values of the SB exertion change scores show that the scores were spread widely around the mean value. This points at the need for further experimentation with a more precise method, especially on the aspect of measuring exertion.

Multiple issues arose during the execution of the experiments. First of all, some issues with the use of a planking exercise as a method of testing exertion came to light during the experiments. The planking position involves many different muscles of the back, abdomen, arms and legs. Therefore, even a small adjustment in pose appears to give very different results in how long it takes until one is exhausted. Marking the elbow and feet position proved to be insufficient in controlling the pose of the participants. There were also issues with how participants handled the exercises. Some gave up as soon as they could not hold a *correct* planking position. Others were lowering their back after a couple of seconds but kept going on for a long period after that before giving up.

As expected, there was still a fatigue effect present in the experiment as participants got more tired after each exercise performance. While it was tried to mitigate this as much as possible through the counterbalanced measures design of the experiment, it seems like it still significantly impacted the results. It is a partial explanation as to why the exertion and affordance scores per average presence score are so varied.

Another partial explanation for this are the issues that came to light regarding the VR equipment and the VREs. Several participants noted that they did not feel immersed into the VRE as they were used to much higher photographic realism from videogames. While the VREs in this experiment are indeed not up to par with contemporary videogames in terms of graphic fidelity, this particular aspect is probably not as impactful as participants noted. Several studies came to successful results with the same level of graphic fidelity [4] [14] [15]. Instead, it is more likely that the level of graphic fidelity stood out more because of a combination of limited hardware and interaction. The Oculus Rift DK2 used in this study has a rather low resolution per eye (960 x 1080 pixels), which results in a pixelated rendering of the VRE, and is known to suffer from immersion-breaking screen tearing and screen door effects. Moreover, the interaction of the participants with the VREs was limited to head movement, whereas other studies gave the participant a more demanding task to perform while in the VRE, such as flying [4] or drumming [14]. Performing a more intensive task in the VRE seems very likely to be beneficial to the illusion of presence.

A few remarks from the participants were of particular interest. One participant remarked that he found it harder to identify himself with the avatars in the VRE when focusing on the face of the avatars. While looking down at the body was much more immersive according to him. Another participant remarked that, even though the visuo-tactile synchrony was almost perfectly synchronized, it did not feel as real with the Superman body as with the average body because of how muscular the Superman avatar is in relation to the participant himself.

VI. Future Work

Further experimentation is needed to come to definitive conclusions about the effects of embodiment on exertion capabilities and confirm the found effect of presence on exertion change score. Since the planking exercise seems to lack controllability, finding a more suitable method of exertion is of great importance. A suggestion would be to use wall squats, which forces the participant to assume a sitting position with his back straight against a wall and his legs in exactly 90 degrees. This would be more controllable, but focuses mainly on muscles in the thighs. This could have the implication of providing a smaller cognitive effect as Superman's power might be more associated with his strong arms. This exercise was also used by Gamble *et al.* [20], so it has some promise as being a reliable measuring method.

A different way of researching this topic would be measuring exertion of force instead of measuring endurance. Force exertion can be measured accurately with Digital Force Meters. Measuring grip strength with the use of a dynamometer could particularly be useful as there is minimal muscle movement.

A definite improvement to the method, which was not implemented in this study due to time and resource constraints, is to have separate participant groups for each condition. By implementing this, the fatigue effect can be circumvented.

As for the VR implementation; adding more freedom of interaction with the avatar would be an improvement for the sense of presence of the participant. For example, using a Microsoft Kinect sensor would allow for complete freedom of movement in the VRE.

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APPENDIX A
Pre-experiment Questionnaire

Basic Subject Features

Please fill in the following information

*Required

1. **Gender** *
   Mark only one oval.
   - ◯ Male
   - ◯ Female

2. **Age (in years)** *

   .....

3. **Body Mass (in Kg)** *

   .....

4. **Length (in Cm)** *

   .....

Superman Knowledge

What follows is a series of questions to examine your current knowledge about the fictional character of Superman.

5. **What is Superman's alternate identity name?** *
   Mark only one oval.
   - ◯ Clark Kent
   - ◯ Ken Thomas
   - ◯ Curt Clark
   - ◯ John Smith
   - ◯ I don't Know

6. **What is Superman's job when he is not being a superhero?** *
   Mark only one oval.
   - ◯ Accountant
   - ◯ Journalist
   - ◯ Doctor
   - ◯ Architect
   - ◯ I don't Know

7. **What is Superman's real name given to him at birth?** *

Mark only one oval.

- Kar-El
- Ken-El
- Kal-El
- Jor-El
- I don't Know

Superman Strength Estimation

These images are ordered from not so heavy (A) to extremely heavy (E)

A.

B.

C.

D.

E.

8. **Which of these objects would you imagine to be the heaviest that Superman is able to lift up?** *

Mark only one oval.

- A
- B
- C
- D
- E

Superman Exposure

What follows is a series of questions to determine your exposure to media involving Superman.

9. **How many movies or TV series about Superman have you seen at the movie theater or at home?** *

Mark only one oval.

- ◯ None
- ◯ 1-3
- ◯ 4-6
- ◯ More than 6

10. **How many comic books about Superman have you read?** *

Mark only one oval.

- ◯ None
- ◯ 1-3
- ◯ 4-6
- ◯ More than 6

11. **How many items with the Superman branding do you own? (Clothes, video games, backpacks, toys)** *

Mark only one oval.

- ◯ None
- ◯ 1-3
- ◯ 4-6
- ◯ More than 6

12. **If a new Superman movie was coming out in theaters, how likely is it that you are going to see it in theater?** *

(1: Definitely won't) - (2: Probably won't) - (3: Probably will) - (4: Definitely will)

Mark only one oval.

	1	2	3	4	
Definitely won't	◯	◯	◯	◯	Definitely will

APPENDIX B
Affordance test

Affordance

What follows is a plank exercise, in which you will hold a push-up-like position for as long as possible. Your arms should be directly under your shoulders, with your elbows resting on the ground. Hold your entire body in a straight line (from toes to head) and your back completely flat, neither arched nor rounded.

A correctly executed plank exercise

Please indicate how long you think you will be able to hold this position *

.....

APPENDIX C

Presence Questionnaire

Presence

These statements concern your experience in the virtual world. Please read each statement carefully and choose the answer that best reflects your feelings.

I felt like I was really inside the virtual room. *

	1	2	3	4	5	6	7	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	Strongly agree

Even though the virtual body I saw did not look like me, I had the sensation that the virtual body I saw when I looked towards myself in the mirror was mine. *

	1	2	3	4	5	6	7	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	Strongly agree

Even though the virtual body I saw did not look like me, I had the sensation that the virtual body I saw when I looked down at myself was mine. *

	1	2	3	4	5	6	7	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	Strongly agree

I felt like the brush in the virtual world was touching my real body. *

	1	2	3	4	5	6	7	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	Strongly agree

Even though the virtual body I saw did not look like me, overall I had the sensation that the virtual body I saw when I looked at myself in the mirror or when I looked down at myself was my body. *

	1	2	3	4	5	6	7	
Strongly disagree	◯	◯	◯	◯	◯	◯	◯	Strongly agree