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Hand Temperature Is Not Consistent With Illusory Strength During the Rubber Hand Illusion

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***Abstract*— The rubber hand illusion is known to invoke a sense of ownership of a rubber hand when a person watches the stroking of the rubber hand in synchrony with their own hidden hand. Quantification of the sense of ownership is traditionally performed with the rubber hand illusion questionnaire, but the search for reliable physiological measurements persists. Skin temperature has been previously suggested and debated as a biomarker for ownership. We investigated hand temperature as a measure of rubber hand illusory strength via thermal imaging of the hand during the rubber hand experiment. No relationship was found between reported illusory strength and skin temperature.**

***Clinical Relevance*— Our results indicate that skin temperature is not a suitable biomarker for rubber hand illusory strength.**

I. Introduction

The rubber hand illusion (RHI) [1] is the gold standard experiment to study the sense of ownership. Studying the sense of ownership can increase our understanding of how limb loss or prosthetic use affect our perception of what is part of our own body. Through visual occlusion of a participant's own hand and careful placement of a visually congruent rubber hand, followed by synchronous stroking of both the biological and the rubber hand with a brush, participants can perceive the rubber hand as being their own. Conversely, asynchronous stroking does not lead to the rubber hand being perceived as part of one's own body. To better quantify the subjective experience evoked by the RHI, a multitude of physiological variables have been investigated and compared to the RHI questionnaire (see [2] for a review), which is the most common measure used within the RHI paradigm. However, some of the primary measures correlating with the RHI questionnaire have recently been called into question, amongst them, the change of skin temperature. Initially, a participant's skin temperature was shown to decrease during an ownership illusion [3], [4]. A recent study comparing automated and manual stroking, however, found no temperature change during the automated stroking [5]. The manual stroking condition did reveal a temperature difference, but during both synchronous and asynchronous stimulation, further conflicting with previous reports.

A noteworthy limitation of all previous temperature studies has been the thermal measurement device used, with resolutions between 0.1-0.2°C and accuracies of ±1°C. In comparison, the reported temperature changes were below 1°C.

In this experiment, we aimed to contribute to the ongoing debate on whether skin temperature change is influenced by ownership over a rubber hand, using a thermal measurement device optimized for medical screening.

II. Methods

A. Participants

All participants signed an informed consent form approved by the Swedish Ethical Review Authority (Dnr 2019-05448). Data privacy and management complied with the EU General Data Protection Regulation 2016/679 (GDPR).

Eleven healthy participants were recruited for this study, of which 6 were male and 5 were female, with the average of 29.7 (SD = 3.8). Exclusion criteria included the volunteer's self-report of abnormal vascular conditions and medications that would affect vasoactive tone. Sunburn and abrasions to the skin of the right hand and arm were disqualifiers to participation.

B. Rubber Hand Illusion Experiment

Participants entered the experimental environment 5-20 minutes prior to the start of the experiment. Each participant was placed in a comfortable seated position with the left arm naturally resting on the left thigh. The participant's right arm was placed on a table at a comfortable height and remained at ease for 10 minutes for the purpose of environmental acclimation, while thermal images were taken at one-minute intervals. Following the acclimation period, the participant's right arm was positioned next to a visual barrier in the same position as the rubber hand on the other side of the barrier. Each participant experienced five minutes of synchronous manual stroking and five minutes of asynchronous manual stroking on the dorsal area of the proximal phalanx of the index finger, then asked to complete a modified RHI questionnaire [6] after each stroking condition. Participants rested for five minutes after completing the questionnaire before proceeding with the second stroking condition. Images

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were recorded at one-second intervals for the duration of both stroking conditions. The order of the stroking conditions was randomized between participants. The stroking administrator remained the same for all subjects, used a flat one-cm-wide paintbrush, and had previous experience inducing the RHI [6].

C. Thermal Equipment and Analysis

Thermal images were acquired using the Meditherm Iris 380 (Meditherm, Wyoming, USA) camera with measurement sensitivity of 0.01°C. The camera was controlled with Meditherm WinTES3 camera software on a personal computer. Using the same software, the thermal images were analyzed by drawing a rectangular region on the center of the hand. All drawings were completed by a single researcher to avoid differences in drawing technique. Figure 1 shows an example of the region drawing.

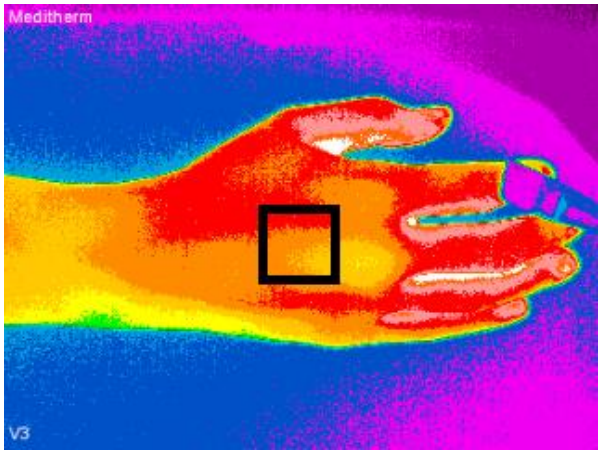

Figure 1 Region drawing for temperature analysis.

D. Statistical Analysis

To approximate the temperature trends during the acclimation and stroking periods, the mean temperature at each time point across all subjects was calculated. A linear regression was performed on these mean temperatures in order to approximate temperature change over time.

In order to compare the synchronous and asynchronous stroking conditions, a paired t-test between mean temperatures across the stroking duration was performed. A paired t-test was also used to compare ownership scores following the two conditions.

To be able to compare the temperature and ownership scores, the temperature measurements for each subject and condition were first characterized by their change over time using a linear regression. The Pearson correlation coefficients were then calculated between these temperature slopes and respective ownership scores.

III. Results

Local skin temperature at future site of stroking during the acclimation period increased slightly, contrary to our expectation that temperature would decrease due to lack of muscle activity. However, this trend was accompanied by a wide standard deviation, seen in Figure 2. A linear regression analysis of the acclimation data approximates a 0.04°C

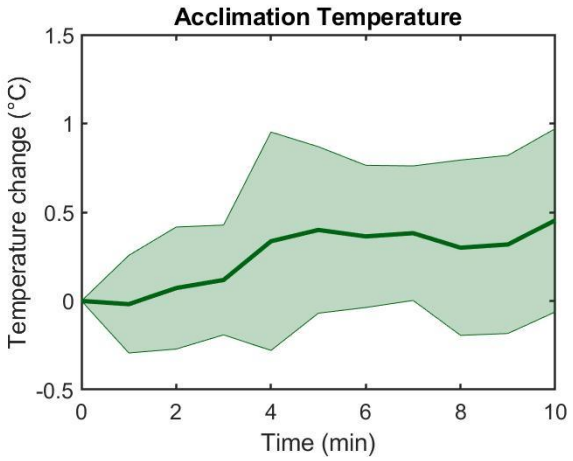

Figure 2 Change in skin temperature during acclimation period from time zero hand temperature. The green line shows the average temperature change across all subjects, accompanied by upper and lower standard deviation lines.

increase per minute through the 10-minute acclimation period.

The synchronous and asynchronous stroking conditions showed similar trends, shown in Figure 3. A linear regression analysis gave a 0.06°C increase per minute for both stroking conditions. A paired t-test showed that the synchronous and asynchronous regression slopes are not significantly different ($t(10) = 0.18$, $p = 0.86$).

All subjects reported higher illusory strength following synchronous stroking than asynchronous stroking (Figure 4). A paired t-test showed that the scores for the two conditions were significantly different ($t(10) = 5.53$, $p < 0.01$).

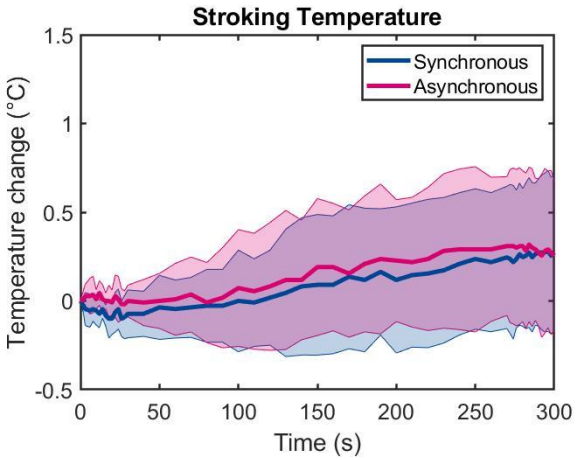

Figure 2 Stroking temperature change from time zero hand temperature. The bold lines show the average temperature change across all subjects, accompanied by upper and lower standard deviation lines.

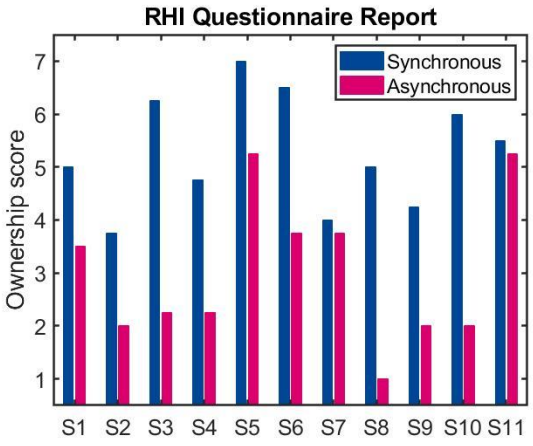

Figure 4 RHI questionnaire results show higher reports of ownership over the rubber hand following the synchronous stroking than asynchronous stroking.

Temperature change during the synchronous condition and its ownership score showed no significant relationship ($r = -0.18$, $p = 0.59$). Asynchronous temperature change and its ownership score showed a moderate positive relationship ($r = 0.48$, $p = 0.14$). Figure 5 plots the temperature change and ownership score for each condition and subject.

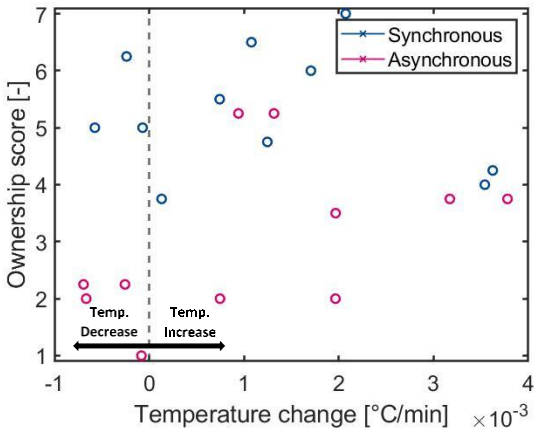

Figure 5 Temperature change versus ownership score per individual and stroking condition.

IV. Discussion

Previous literature have reported a decrease in local skin temperature during a successful RHI [3], [4], suggesting that the body downregulates metabolic efforts in the hand as the sense of ownership shifts away from one's own biological limb. However, a recent study [5] found no evidence for limb temperature decrease during a successful RHI.

We found no correlation between local skin temperature and RHI strength. In general, we found that hand temperature increased during the RHI experiment and that there was no temperature difference between the synchronous and asynchronous conditions. Our findings thus stand in contrast to the initial study on temperature change within the RHI [3], and support the findings of Rohde *et al.* [5], where no consistent relationship between temperature and ownership was observed.

Our experimental design utilized a fixed thermal camera that captured the temperature profile over the entire hand. A notable advantage of our measurement device over an infrared thermometer is the capability to select a region, rather than single points on the hand, as performed in previous studies where a correlation was found between RHI strength and temperature change [3], [5]. Furthermore, our thermal camera is sensitive to 0.01°C differences. Using a region instead of a single point facilitates more accurate measurements of temperature change as a function of time, due to the calculation of a thermal average over the region of interest. The pinpoint measurement collected with an infrared thermometer depends on correctly identifying the same point on the skin across subjects, while our imaging approach allows for less precision when identifying the region.

A limitation of our study is the low number of participants recruited. Additionally, the experiment would benefit from temperature measurements on the non-stimulated hand: using the temperature difference between the stimulated and non-stimulated hand, one could exclude thermal modulation unrelated to the RHI experiment.

In our experiment, both the synchronous and asynchronous stroking conditions showed similar temperature changes while achieving significantly different ownership scores with stroking administered by a brush. This indicates that hand temperature and illusory strength are possibly distinct phenomena.

V. Conclusion

Our findings indicate that temperature change does not correlate with ownership score in the RHI paradigm. We suggest caution in drawing strong inferences of ownership based on the skin temperature.

Acknowledgment

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