A body–conforming tactile jacket to enrich movie viewing

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ABSTRACT

Consumers are always searching for new ways to enrich their movie–viewing experiences. To increase immersion, electronics manufacturers have responded by improving display quality, extending surround–sound audio systems, and by developing products like Ambilight television. Adding haptic stimulation to movies is a next step in creating a emotionally fully immersive experience. We have therefore created a wearable tactile jacket that is used to deliver movie–specific stimuli to the viewer's body. Immersion was evaluated in a user test using questionnaires and physiological measurements. The findings show promising effects of the haptic stimuli that need to be substantiated in further more refined user tests.

KEYWORDS: Tactile stimulation, vibrotactile actuators, textile electronics.

INDEX TERMS: H.5.2 [Information Interfaces and Presentation (e.g., HCI)]: User interfaces – *Haptic I/O*

1 INTRODUCTION

In western society consumers pursue a more and more intense lifestyle [1]: people want more immersive experiences and they are looking for new "kicks". A more immersive movie–viewing experience can satisfy some of these desires with surround–sound audio systems, HD–quality big–screen TV's that are possibly enhanced with technologies like Philips' Ambilight.

However, the improvement in viewing experience that can be obtained by enhancing and optimizing the primary modalities of sight and hearing are reaching their limits. Therefore, we are looking into new ways to enhance movie viewing. Specifically, we want to involve the sense of touch. We have developed a body–conforming jacket that contains 64 tactile stimulators. The stimulators are used to enhance events and increase emotional immersion in a movie by rendering them directly onto the viewer's body. This enables the viewer to, for instance, experience what the main character is experiencing and thus to become more immersed in the movie.

In this paper, we first describe the construction of the jacket continuing with a section on a user test of this jacket to test our ideas that includes excerpts of our findings. Finally conclusions and suggestions for future work are drawn up.

2 BODY–CONFORMING TACTILE JACKET

The main design criteria for the jacket were: ability to stimulate back and front of the human torso and arms, wearable and prepared for wireless operation, battery powered, smooth integration of electronics with fabric (for good aesthetics), good accessibility of electronics, and light weight. The current design consists of 64 actuators distributed uniformly over the jacket resulting in a layout with roughly 15 cm distance between neighboring actuators.

A stretchable fabric has been chosen to create a tight fit. This ensures that the actuators are as close as possible to the human skin to achieve an optimum tactile sensation. The jacket was made in several sizes, for differently sized persons: small, medium, large, and extra large.

Figure 1: Outer lining (left) and jacket turned inside-out showing the inner lining with electronics and wires (right).

2.1 Electronics design

For the actuators we have opted for pancake–shaped excenter rotating–mass (ERM) motors because they are light weight, thin, and inexpensive compared to other offerings. A small disadvantage is that we are limited to vibrotactile stimulation. The main electrical and mechanical characteristics of the motors are listed in Table 1.

For the electronics design it is important to realize that such a vibration motor is an inductive load which means that certain precautions need to be taken to prevent induced voltage peaks when switching off the motor as these voltage peaks might harm the other electronics components in the jacket.

The electronics design is an electrical architecture as shown in Figure 4. The motors are divided into 16 different segments hat each contain 4 motors. Each segment is controlled using a segment driver mounted on a custom–made printed circuit board (PCB).

Table 1: Some electrical and mechanical characteristics of the ERM-motors.

Characteristic	Specification
Operating voltage	2.5~3.5 V_{DC}
Max. Current	90 mA
Coil Resistance	80 Ω_{max}
Mass	0.08 gram
Rotation Speed @ 3 V_{DC}	13000 ± 2500 rpm

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The distribution and ordering of these segments over the body is shown schematically in Figure 3. The driver PCB has five connectors (see Figure 2). The larger ones on the left and the right side (labeled ‘IN’ and ‘OUT’, respectively) are for the jacket internal data and power bus. This bus handles the SPI communication and the power distribution. The connector at the top (labeled ‘Prog’), is used for programming the micro processor and optionally doubles as an extra insertion point for electrical power. The two smaller connectors at the bottom side of the driver segment PCB (labeled ‘1 2’ and ‘3 4’) are the connectors for the motors.

The ERM motors are glued on either of two types of custom made PCB’s. The intermediate type of motor PCB (Figure 2, upper right) has two connectors to relay of electrical power to the terminal motor PCB (Figure 2, lower right). The two types of PCB’s are in PCB design exactly the same but differ in what components are placed and to what pads the motor is soldered. The connections between the motor PCBs and the driver PCB are made with wires.

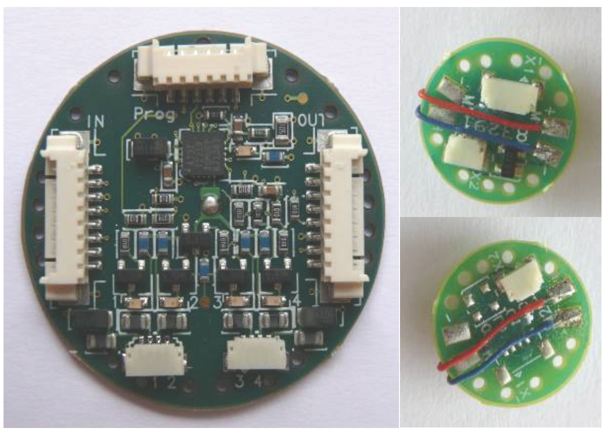

Figure 2. PCB’s of a segment driver and an intermediate (upper right) and terminal motor print. (not visible) are placed on the back of the motor prints.

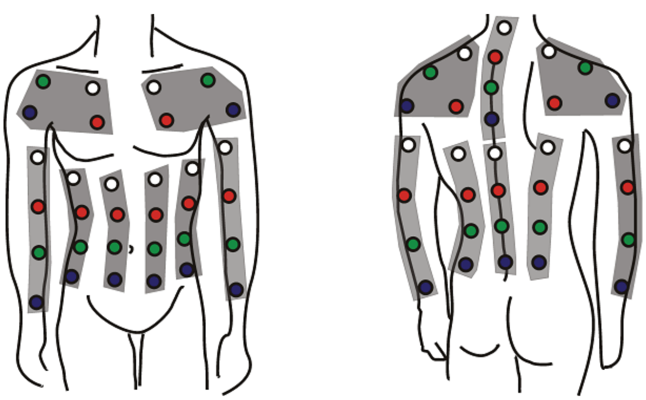

Figure 3: Human torso with distribution of vibrotactile actuators. The actuators are represented by the colored circles and are grouped into 16 segments each containing four actuators. Inside the segments the actuators are ordered as white, red, green, and blue.

The driver segments are daisy chained to form a serial bus that starts and terminates at a custom–made interface PCB. This PCB combines the SPI-bus from the external USB-to-SPI interface with the power supply line from the two AA batteries.

The electronics design enables a good distribution of the electrical current to the motors without too much cabling. In our design the wires can handle a maximum of two amperes. Reducing the number of driver segments would increase the power requirements for the electrical components. Increasing the number of drivers segments would lead to more cabling and hence a heavier and more failure–prone jacket.

With rechargeable batteries that deliver 2500 mAh each, the jacket has an operational lifetime of 1.5 hours when continuously driving 20 motors at the same time.

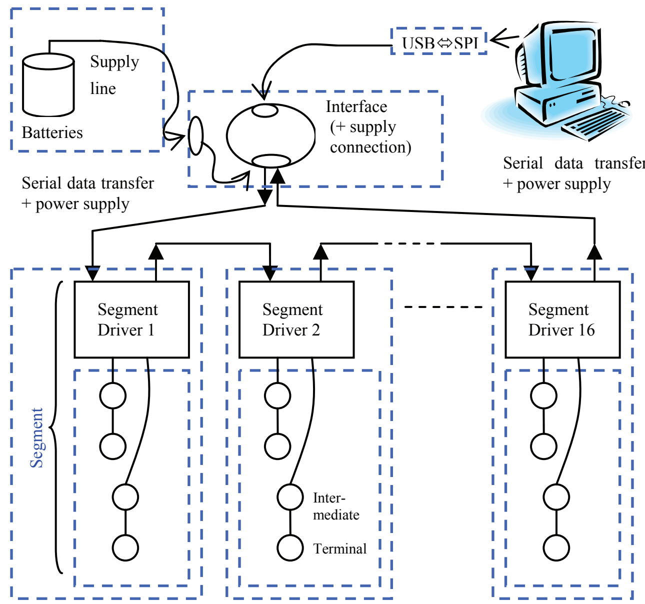

Figure 4. Schematic overview of the electrical layout of the jacket. The serial chaining of segment drivers highlights the modularity of the design.

2.2 Textile integration

The jacket consists of two layers: an outer lining and an inner lining. The electronics were attached to the inner lining and then covered by the outer lining for protection and aesthetics. At the bottom side of the torso and at the end of the sleeves the linings were not sewn together for easy access to the electronic components. All PCBs have holes placed along the outer perimeter so that the PCB can be sewn easily onto textile. The photograph on the right of Figure 1 shows the shirt inside-out, exposing the PCBs and wires.

The thin white wires connect the motors and the slightly thicker red wires connect the driver PCBs. The wiring from the segments 1 and 16 to the interface PCB is partially done with a ribbon cable, also visible in the figure. The batteries are kept in a holder which is sewn into the vest. The total weight of one jacket, including electronics and batteries, is approximately 700 grams.

2.3 Software interface

The actuators in the jacket are controlled from a PC using a LabVIEW™ (National Instruments, Austin, TX, USA) software interface that was developed in–house. The LabVIEW application allows us to generate tactile stimuli on various levels of granularity.

First, we create different types of shapes, relating to PWM settings, that are sent to the motors. Shapes define the vibration intensity over time and are the building blocks for patterns. Patterns specify at what point in time a particular motor has to render the given shape. Patterns thus define the distribution of vibrations over the torso. Finally, these patterns are played back on the jacket at predetermined times or these patterns can be triggered by external events.

2.3.1 Shapes

Shapes have a 10 ms resolution that is determined by the hardware constraints; Their duration is in principle unlimited. The shape amplitude at each 10 ms step is a value in a range of 25 steps. This amplitude is translated into a PWM output that is sent to the motors. The shape can be any arbitrary waveform as long as all values are positive. Examples of basic shapes are a sine squared wave or an offset square wave.

2.3.2 Patterns

With the shapes we can build tactile patterns using a custom–made pattern editor (see Figure 5). A tactile pattern determines for each actuator the timing(s) to start a shape. An example of a pattern is a sine–squared shape running from the left wrist over the shoulders and neck to the right wrist.

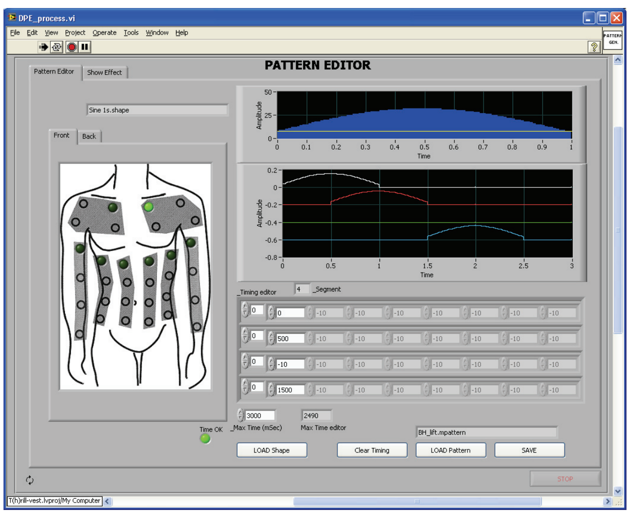

Figure 5: Pattern editor. For each motor a time, at which the motor is fired with the given shape, can be entered.

3 USER TEST

We base our hypotheses that tactile stimulation can help to increase (emotional) immersion into a movie on the premise that distinct emotions are accompanied by distinct bodily reactions. We then presume that triggering a similar bodily reaction could possibly elicit an emotion. In other words, if a consumer is watching a movie designed (by the director) to elicit fear, s/he will experience particular bodily reactions like goose bumps or shivers down the spine. With the tactile jacket, these reactions are mimicked to try to facilitate and increase the emotional immersion in the movie.

A user test evaluated whether the tactile patterns indeed helped viewers to become more immersed in a movie. To measure efficacy of the patterns, we used three questionnaires (employing Likert–type scales) and took measurements of physiological signals that are known to be related to emotion [2].

We invited 14 participants to view 7 video clips in two variations: without tactile stimuli (also called actuation absent) and with tactile stimuli (called actuation present). We expected to see stronger responses on questionnaire data and physiological measurements for the clips containing the tactile patterns. In the questionnaires this would be reflected as higher scores for the clips with the patterns as compared to the (same) clip without emotion patterns. We expected a similar increase for the physiological signals: for instance, higher skin conductivity, more skin–conductivity responses, or an increase in heart rate.

3.1 Method

3.1.1 Participants

Fourteen volunteers (age range 24 to 58 years; 4 female participants) took part in the experiment. They received € 5,– for their time and effort. Participants were requested to wear thin, short–sleeved t–shirts over which they could wear a snugly fitting size of the tactile jacket.

3.1.2 Stimuli and materials

Because we were interested in emotional immersion, we selected seven movie clips that had had been validated as eliciting a single (to the extent possible) emotion [4]. The emotions that we selected were love, enjoyment, fear, sadness, anger, anxiety, and happiness. The respective clips were extracted from the movies Braveheart, When Harry met Sally, Jurassic Park III, The lion king, My bodyguard, Silence of the lambs, and a Tom & Jerry cartoon. Each clip was presented twice: once without (actuation absent) and once with tactile patterns (actuation present).

For creating the tactile patterns, we relied on a two–track strategy. First, from an earlier study, we gleaned a number of typical touch behaviors from human–to–human emotional touch communication. Secondly, we created a number of patterns based on common wisdoms and sayings, like ‘having butterflies in your stomach’ for love or ‘a shiver down your spine’ for fear and anxiety. These two sets of patterns were complemented by more abstract patterns that were aimed at achieving a suggestion following events in a movie clip. For instance, in the lion king clip, a comforting arm around a shoulder is suggested with suitably designed pattern.

3.1.3 Design & data acquisition

We used a pseudo–randomized design in which we intermixed clips without and with tactile patterns. The pseudo randomization was such that for each clip, it was first presented without tactile patterns and on the second viewing with tactile patterns. This design was chosen to, at least, have an equivalent viewing order for each clip, because available testing time was constrained.

We employed a dual–computer setup for the experiment [5]. One computer used the custom–made LabVIEW interface for controlling the presentation of the tactile stimuli as well as the movie clips. Starting times of each emotion pattern were established manually for each movie clip.

The other computer recorded the physiological measurements that it received via a Bluetooth connection to a NeXus-10 recorder (Mind Media). We measured blood–volume pulse (BVP) via a finger–attached photoplethysmograph, respiration via a chest belt (RSP), and skin conductivity (SCL) using two finger electrodes. All sensors were default Nexus sensors and Biotrace+ was used as recording software. We used a sea–life movie clip as background for recording a baseline measurement of the physiological state at rest (no or neutral emotional state); at the end of this clip all motors in the vest were sequentially fired once to allow the participant to get used to the feeling.

After viewing each clip, participants had to fill in two questionnaires and had to score the emotions that they experienced on a predetermined list of emotions taken from [6]. The questionnaires that we employed were the self–assessment manikin (SAM; Lang, 1985) and a questionnaire that was developed in–house to measure experience and immersion [8,9]. The SAM questionnaire consisted of two graphically displayed items asking for self–reported valence (positivity/negativity) and self–reported arousal on a 5–point scale. The immersion questionnaire comprised 13 items that are scored on a 5–point scale. Although his workstation was in another corner, the experimenter had to remain present throughout the experiment because it could not be run fully automated. The entire experiment took around 90 minutes to complete.

4 Results

We used a combined effort of *R* [10] and *Matlab*® (2007, MathWorks, Natick, MA, USA) to read in and combine all data for one participant into a convenient data structure. *Matlab* particularly was used to compute the derived measurement of heart rate (HR) from the BVP, respiration rate (RSPR) from RSP and skin–conductivity responses (SCR) from SCL (using the SCRGAUGE algorithm [11]). We created four data series of physiological measurements: mean skin conductivity level, frequency of skin conductivity responses (i.e., amount of skin responses per second), mean heart rate, and mean respiration rate.

Unfortunately, due to equipment failure, the data of one participant was lost, so for 13 participants and each movie clip, we computed means of the physiological data using *R.* The means were computed over the entire duration of the clips. We also computed a mean and standard deviation for all physiological data points over the duration of the entire session. The latter means and standard deviations were used to compute intra–participant normalized *z*–scores for the experimental video clips relative to their averages over the entire duration of the experiment.

For each participant we thus computed 266 data points (7 clips x 2 viewings x (2 responses of the self–assessment manikin + 13 responses of the immersion questionnaire + 4 physiological measurements)) that we used as input for a multivariate repeated–measures ANOVA using SPSS 15 (SPSS Inc, Chicago, IL, USA). We incorporated two within–subjects factors into the analysis design: Clip (7) x Actuation (2). We did not include gender into the analysis because of the rather unbalanced numbers.

4.1 Manipulation check

To assess whether the intended emotions in the movie clips were indeed experienced as such by the participants, we carried out an informal manipulation check. For each movie clip, we computed average scores for all items on the list of emotions [6] that participants had to score and created bar plots of the resulting averages.

Visual inspection of these graphs showed that all clips evoked the intended emotions in the participants. Overall, the intended emotions were scored higher than the other listed emotions. Only for My bodyguard, the scores were more mixed: although all negative emotions scored higher than the positive ones, the difference in scores was not very large. We also observed that the When Harry met Sally clip scored relatively high on embarrassment.

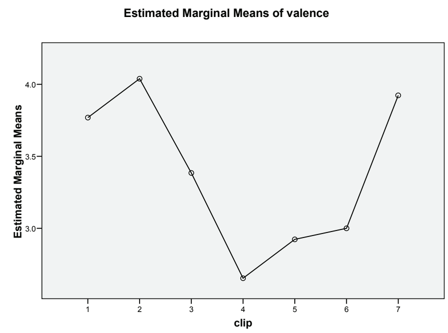

Figure 6. Self–reported valence (*y*–axis; on a scale of 1–5) for all clips (*x*–axis) confirms manipulation check. Clips are numbered and ordered from left to right as: Braveheart, When Harry met Sally, Jurassic park III, The lion king, My bodyguard, Silence of the lambs, and Tom & Jerry. The *y*–axis displays self–reported valence from the SAM questionnaire.

The main analysis corroborated these observations. The analysis showed a main effect of Clip on self–reported valence [$F(6,72) = 6.920$, $p = .000$] from the Self–Assessment Manikin (SAM) questionnaire. The positively intended clips of Braveheart, When Harry met Sally, and Tom & Jerry indeed resulted in very high (i.e., positive) valence whereas The lion king, My bodyguard, and Silence of the lambs scored low with Jurassic Park in between (see Figure 6).

Based on these observations, we decided to include all clips in the main analysis. Because the factor of Actuation is of primary interest for the present purpose, we focus on this factor in the presentation of the results.

4.2 Questionnaire data

For the immersion questionnaire, we extracted six out of thirteen items from the experience questionnaire as relevant for the present paper. The items are listed in Table 2; the table also shows the differences in average scores for viewing the clips without and with tactile patterns.

The repeated–measures ANOVA showed that the scores on items 7, 8, and 12 were significantly higher when the tactile patterns were present than when they were not (p's < 0.05).

There were no significant interactions of Clip and Actuation, indicating that the increased scores that we obtained applied to all clips that we showed to the participants.

4.3 Physiological data

We observed a significant difference of Actuation in skin–conductivity level (SCL; $p < .05$) with (the normalized) average levels in the condition without patterns being approximately the same as the overall level of the entire experimental session, and the average level in the viewing with tactile patterns being 0.3 (normalized) unit higher.

For some of the physiological measurements we found an interaction(s) between Clip and Actuation that indicated that between clips differences existed regarding the effect of Actuation on a particular physiological measurement. Specifically, we observed significant interactions for SCL and for heart rate (HR; both p's < 0.05).

Table 2. List of relevant questions from the immersion questionnaire [8,9] with average scores (on a 5–point scale) for the actuation absent and actuation present conditions. * indicates significantly different from actuation absent at $p < 0.05$.

Item	Question	Absent	Present
4	I felt myself drawn in.	3.12	3.32
6	I enjoyed myself.	3.52	3.54
7	My experience was intense.	2.68	3.04*
8	I had a sense of being in the movie scenes.	2.32	2.67*
11	I responded emotionally.	3.08	3.04
12	I felt that all my senses were stimulated at the same time.	2.03	2.59*

If we look at the upper panel in Figure 7, we see that for each clip average SCL for viewing with tactile patterns follows the measurements while viewing without actuation, but that for clips 3, 5, and 6, SCL increases more with actuation present. Paired t–tests showed that the observed differences were significant for My bodyguard (clip #5; p = .003), marginally significant for Silence of the Lambs (#6; p = 0.07), and non–significant for Jurassic park III (#3). These clips all elicit negatively valenced emotions.

The bottom panel of Figure 7 shows that for When Harry met Sally and Jurassic Park III HR increases with actuation present but (visually) decreases for all other clips. For Silence of the lambs (clip #6), the difference is significant (p = 0.005) and the effect is marginally significant for The lion king (#4; p = 0.069) and Tom & Jerry (#7; p = 0.06).

4.4 Comparison to affect–neutral baseline

To be able to assess meaning to the findings presented in the previous section, we carried out another ANOVA that included the physiological data gathered while participants were viewing the affect–neutral sea–life clip. We could not include this clip in the main analysis because no questionnaire data were gathered for this clip.

In general terms, the ANOVA showed that skin–conductivity level was significantly higher for the experimental clips than for the affect–neutral clip (see Figure 8). For the other physiological measurements we observed (for the baseline) increased scores for the part of the affect–neutral clip containing tactile patterns. However, compared to skin–conductivity level findings, there was not such an obvious overall difference between the affect–neutral and the experimental clips.

4.5 Summary and discussion

Our main topic of interest, for this user test, was whether the addition of tactile patterns would make the viewer of a movie clip become more immersed in that clip. So the main factor of interest was Actuation, that is, viewing a movie clip with tactile patterns present.

For Actuation we found higher scores (with actuation present) for three interesting items from the immersion questionnaire. Particularly the significant effect of Actuation on “My experience was intense” and the nearly significant effect on “I had a sense of being in the movie scenes” (#7 and #8, respectively) provide evidence that the tactile patterns allowed viewers to become more immersed in a movie clip.

However, the pseudo–randomized design that we were forced to use due to time pressure does limit the weight that we can attach to our findings. Because the viewing with tactile patterns (actuation present) was always the second time that participants saw a clip, it can be that the differences that we observed are mainly due to the repeated viewing rather than due to the actuation. It is difficult to disentangle these two explanations because at present we cannot reference to a ground truth for the types and patterns in physiological signals that uniquely pair to particular emotions. Nor do we have data available from a better balanced design in which, at least, actuation is also present in the first viewing and absent in the second viewing.

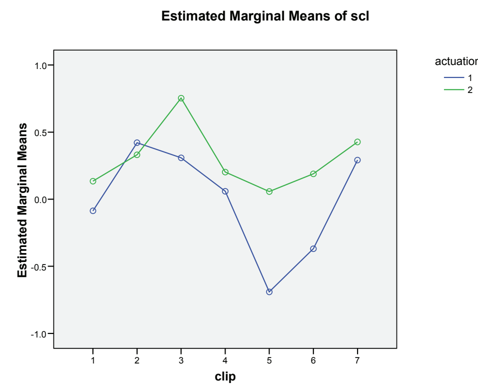

Figure 7. For all clips the effect of Actuation on skin–conductivity level (left panel) and heart rate (right panel). The darker line is for actuation absent; the lighter line is for actuation present. For the order of the clips see Figure 6. On the y–axis the normalized physiological measurements.

5 CONCLUSION

We have created a hardware platform employing vibrotactile actuators and carried out a user test to investigate whether this platform allows us to reliably enhance emotional immersion. In the user test participants had to view seven movie clips two times: the first time without using the actuators and the second time with actuators. We investigated whether the actuation resulted in increased emotional experiences and in improved immersion in the video clip.

The user test shows that the tactile jackets are sufficiently robust to hold up to the rigors of lab testing. We had many degrees of freedom to create tactile patterns that simulate emotional bodily reactions, because the jacket effectively projects tactile effects on the entire upper torso and back and front of the arms. The data that we gathered in the user test show promising effects that indicate that actuation has the intended effects on emotional immersion.

The discussion of the results has highlighted a number of directions that we can take for future studies to investigate the effect on immersion during movie viewing of vibrotactile stimulation via a body–conforming wearable jacket. One route that we envision is a more detailed investigation of the effects of the individual tactile patterns. To accomplish such a study we are currently developing a mechanism to be able to lock the onset and offset of a pattern to a subset of samples from all physiological measurements using time stamping.

Another approach that we consider interesting is a more continuous measure, for instance, of self–reported valence. To this end, we have developed a hardware device that implements a visual–analog scale. With this 'slider box', participants can continuously indicate the valence of their emotions or any other item from a questionnaire that can be translated into a VAS item.

To summarize, the idea that tactile patterns can help to become more immersed was not disproven. We base this conclusion on the statistical analyses that we have reported in the present paper as well as on reactions of over 150 visitors who experienced our jacket during an internal research exhibition.

6 Acknowledgments

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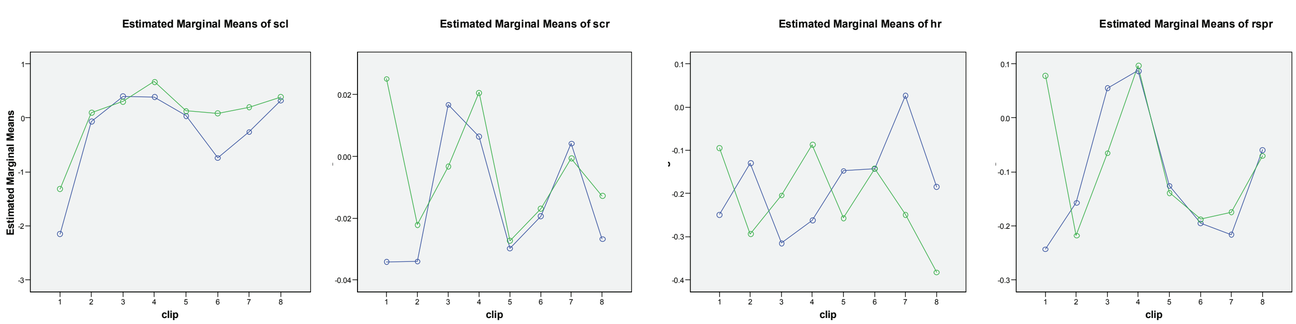

Figure 8. For all clips an overview of the physiological measurements (from top to bottom, SCL, SCR, HR, and RSPR) that includes the affect–neutral baseline measurement (clip number 1) for the condition with actuation absent (dark line) and actuation present (lighter line).