Towards Tactile Displays of Spatiotemporal Social Cues

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Abstract. Facial expressions play a dominant role in facilitating social interactions. We endeavor to develop tactile displays to reinstate facial expression modulated communication. The high spatial and temporal dimensionality of facial movements poses a unique challenge when designing tactile encodings of them. A further challenge is developing encodings that are attuned to the perceptual characteristics of our skin. A caveat of using vibrotactile displays is that tactile stimuli have been shown to induce perceptual tactile aftereffects when used on the fingers, arm and face. However, at present, despite the prevalence of waist-worn tactile displays, no such investigations of tactile aftereffects at the waist region exist in the literature, though they are warranted by the unique sensory and perceptual signaling characteristics of this area. Using an adaptation paradigm we investigated the presence of perceptual tactile aftereffects induced by continuous and burst vibrotactile stimuli delivered at the navel, side and spinal regions of the waist. We report evidence that the tactile perception topology of the waist is non-uniform, and specifically that the navel and spine regions are resistant to adaptive after-effects while side regions are more prone to perceptual adaptations to continuous but not burst stimulations. Results of our current investigations highlight the unique set of challenges posed by designing waist-worn tactile displays. These and future perceptual studies can directly inform more realistic and effective implementations of complex high-dimensional spatiotemporal social cues.

Keywords: Perception and Psychophysics, Cognition, Social Tactile Displays.

1 Tactile Encodings of Facial Expressions

1.1 Motivation

Facial expressions carry our emotions and create a stable and intimate link with the people around us. They are an important vehicle of communication and essential to promote social interactions. Reduced vision disrupts the rich dynamic of face-to-face communication and can significantly diminish an individual's quality of life. Sighted individuals typically use facial expressions, nuanced head and postural movements as well as hand gestures to emphasize speaking points, lead the course of conversation and communicate motives or intentions to others. This wealth of social cues is not accessible to visually impaired individuals. Converting facial movements to a format that can be received and understood by those with visual impairment would serve to improve their engagement with others, thereby enhancing their quality of life. At present, few tactile social-assistive aids for presenting facial expressions to the skin exist.

1.2 Salient Facial Features

Our stance is that the design of tactile encodings of facial movements should draw on findings from human facial expression perception literature, which indicate that both static and dynamic aspects of faces are critical for facial expression identification. While the debate is still open with regards to the advantage dynamic versus static information has in expression recognition ([1],[2]), it has been shown that perceptual processes underlying emotional face recognition are tuned to facial motion information [3]. Studies have demonstrated that humans are sensitive to the temporal interactions of dynamic facial features in the unfolding of facial expressions (e.g. the eye and mouth regions moving together during a smile) [4] and that dynamic features help discriminate among morphologically similar expressions [5]. Facial movement can be decomposed into rigid head movements and intrinsic facial feature movements and it has been shown that processes encoding facial expressions are tuned differently to these different facial movement sources [6]. The key takeaway is the high spatial and temporal dimensionality of facial movements, which needs to be considered when designing tactile encodings of them.

A significant challenge in designing tactile displays of facial expressions is developing encodings that are attuned to the perceptual characteristics of our skin. Our tactile sensory system has a reduced frequency bandwidth, when compared to our visual system [7], reduced sensitivity for temporal, intensity and frequency discrimination and overall reduced capacity for information transfer ([7],[8]). This dictates that we need to reduce from the dimensionality of facial information while still preserving aspects that are important for expression discrimination. To do so, it is advantageous to include as many dimensions of the signal as possible while limiting the number of variables along each dimension [9]. This has been recently demonstrated in the literature for speech-to-tactile encoding on the arm, in which phonemic information was mapped to the amplitude, frequency, waveform, duration, location, numerosity and movement of tactile patterns [17].

In summary, the challenges of facial tactile encodings is to determine a subset of static and dynamic facial features to saliently and discriminatively represent facial movements, and to design multidimensional tactile mappings, which allow for a representation of the span of facial expressions.

2 Characterizing perceptual tactile aftereffects on the waist

We maintain that the design of realistic tactile displays that encode facial movements in several dimensions including amplitude, frequency, numerosity and duration, necessitates an investigation of the tactile perceptual qualities of the target region on which the display will be worn, and their characteristics as a function of all the dimensions along which we intend to encode information. Only then can we guarantee tactile display efficacy in which designed tactile patterns are perceived as intended. A caveat of using vibrotactile displays is that tactile stimuli have been shown to induce perceptual tactile aftereffects when used on the fingers [10], hand [11], arm [12], and the face [13]. Tactile dimensions susceptible to adaptation, including distance frequency, amplitude, and perceived extent of passive motion [11]. These effects manifest as a perceptual shift in the localization of stimuli after delivery of a prolonged adaptive stimulus at a neighboring location.

Vibrotactile wearables have been designed to be worn on different body locations (e.g. on the fingers, arm, the head, the back and on the waist). A particular benefit of waist-worn tactile displays is that they take advantage of the fact that the abdomen plays an important role in ego-location and provides a stable frame of reference for spatial orientation awareness relative to objects in the environment. At present, despite the development of waist-worn tactile displays, no investigations of tactile aftereffects at the waist exist in the literature. Adaptations in this region are worth exploring, particularly because tactile aftereffect findings from other body regions do not necessarily translate to the waist due to the unique sensory and perceptual signaling characteristics of the waist region. Signals triggered by tactile stimulation at the waist terminate in both brain hemispheres, due to the presence of ipsilateral and bilateral as well as dorsal and frontal cells on the waist periphery [14]. To this end, we have conducted a series of psychophysics experiments to investigate the presence of tactile aftereffects at various locations around the waist, namely the navel, the side and the spinal regions ([15], [16]).

Using an adaptation paradigm, we investigated tactile localization after adaptation to prolonged continuous vibrotactile stimuli delivered at the navel (cardinal north), side (cardinal east) and ordinal regions of the waist, both individually and simultaneously. We report statistically significant evidence that tactile perception at the waist is spatially non-uniformly distributed [15], and specifically that the navel and spine regions are resistant to adaptive aftereffects while ordinal regions are more prone to perceptual adaptations to continuous but not burst stimulations at cardinal east ($N=8$, $p<0.001$, Cohen's $d=2.07$) [16]. When continuous stimulations are simultaneously delivered at cardinal north and east, no statistically significant perceptual shifts occur. The absence of aftereffects for burst [15] and simultaneous spatially distributed stimulations [16] suggests that perceptual but also higher-level attentional mechanisms could be involved in the relative localization of stimuli. Furthermore, the ability to relatively localize stimulations along the waist seems to be contingent on the simultaneous presence of reference stimulations at the navel and side, and proposes the joint role of these locations as defining axes of a local frame of reference for haptic spatial localization along the waist. An open question that remains with regards to the impact of location tactile aftereffects on the waist is whether they occur when adapting and testing at regions away from the navel and cardinal positions.

Findings from our current investigations highlight the unique set of challenges posed by designing waist-worn tactile displays and have strong implications on their design as spatial invariance is not guaranteed and the perception of delivered patterns are a function of location. Further features of tactile aftereffects on the waist that remain to be investigated are whether frequency or amplitude dependent aftereffects may occur, as has been shown for other regions of the body[11]. Results of present and future studies are relevant to the development of tactile encodings involving simultaneous multisite stimulation, which allow for encoding of more complex, higher-dimensional patterns as a function of design parameters such as location, amplitude, numerosity and frequency. These perceptual studies can directly inform more realistic and effective implementations of spatiotemporal social cues.

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