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Research report

Backward and common-onset masking of vibrotactile stimuli

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Abstract

To inform the design of haptic information displays for noisy environments, we investigated two mechanisms for temporal masking of vibrotactile stimuli (backwards and common-onset) using a commodity display. We used a two-channel setup, presenting stimuli to the middle and ring finger of a participant's right hand. The stimuli consisted of 250 Hz sinusoidal waveforms displayed at a fixed amplitude in various combinations of duration (0, 30 or 300 ms) and stimulus onset asynchrony (0 or 30 ms). In anticipation of future embedded applications where signals are deliberately masked but levels cannot be individualized, signals were standardized at conservative (harder to mask) levels. Our results confirm the existence of a statistically significant masking effect for both forms of haptic masking explored, with common-onset exhibiting a significantly larger masking effect than backwards. However, an analysis of confidence in response levels shows no difference between the two successful masking techniques. We discuss mechanisms that could be responsible for these results, which have implications for the design of user interfaces that rely on tactile transmission of information.

Keywords: Tactile; Re-entrant processing; Haptics; Perception

1. Introduction

Take a passing glance at a picture of a snowy field. Your impression is of undulations in the whiteness: shadows, texture, a weathered fence. Then, look at the same picture with a red barn in the middle. Now you see a red barn and a white field: the contrast of the red overwhelms the subtle variations in the white. This is a form of masking in the visual system; the same phenomenon occurs via several mechanisms, including close temporal spacing, in vision and other senses [22].

A common definition for stimulus masking is "the interference of one perceptual stimulus with another causing a decrease or lessening in perceptual effectiveness" [19]. For our purposes, we will consider a stimulus to be masked when interference from another stimulus (differing either in time or location) prevents the recipient from explicitly detecting, identifying or localizing it.

Our own motive for understanding tactile masking is to support perceptual design of an emerging class of user interfaces that convey information through touch, often in multitasking contexts that are filled with distractions. Two perspectives pertain. Sometimes, a designer will wish to avoid inadvertent masking of signals: for example, temporal masking due to "packing" stimuli closely in time in an effort to maximize information transfer [36,10,23]. At other times, the designer might wish to deliberately mask perceivable information-bearing tactile stimuli as a tool to isolate the factors that affect our ability to process tactile patterns sequentially, and their relation to attention and signal detection [24,18,25], or to produce actionable signals that minimize attentional demands.

Our focus is on the latter, and in the study described here we seek practical methods (usable in commodity applications) for masking information-bearing tactile signals.

1.1. Previous work

Our knowledge of tactile single-stimuli perception is exemplified by experiments of Srinivasan, Tan and others which use synthetic stimuli to determine various human capabilities, including pressure, stiffness, position resolution and force magnitude [32,33,36]; while Klatzky et al. have studied texture perception extensively, most recently touching through a stylus [21]. These and other studies lay the foundation upon which we can further explore tactile perception and begin to build a tactile language. However, because of the real-world environment in which this language will be used (full of distractions and

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competing demands on our attention) we also need to understand how tactile signals are masked.

We differentiate the tactile masking studies we will review here along two dimensions: characteristics of the stimulus being masked, and properties of the masking technique itself. These studies typically investigate either stimulus *detection* (a stimulus is perceivable as present or absent) or stimulus *identification* (where the stimulus incorporates some manner of variation in pattern, e.g. spatial layout or rhythm, and is thus capable of delivering information based on its identity). Masking techniques that have been commonly studied include *forward* (masking stimulus precedes target stimulus; attributed to temporal integration), *backward* (masking stimulus follows presentation of target stimulus), and *sandwich* (target stimulus is both preceded and followed by maskers) masking.

Numerous studies have investigated the masking effects of tactile stimuli. Many of these have focused on how masking affects the *detection* of simple vibrotactile stimuli [39,15–17,26]. In these studies, different tracking methods are used to determine detection thresholds for stimuli in the presence of different forms of maskers. Some utilized collocated target and masker stimuli, with the masker being band-limited noise and the target a sinusoidal waveform [16]. Another paradigm utilizes targets and maskers presented at different frequencies, e.g. [39]. These results have provided a foundation for other investigations into masking effects of more complex, information-rich stimuli.

Researchers have also begun to study temporal and spatial masking effects on *identification* of different types of tactual stimulation *patterns* (intended to carry detectable information beyond presence/absence) delivered to various areas of the body, e.g. [5,35]. These investigate the effects of stimulus masking on different vibration patterns presented through an array of tactile displays, and used to convey meanings in a similar fashion to the raised dots used on an electronic Braille display.

Aligned with the goal of the experiment reported here, some recent studies using relatively complex stimuli, representing either temporal and spatial patterns have reported several different forms of masking which can occur for the sense of touch [2,28,29,21,35,34]. Of particular relevance is a series of experiments by Tan et al. which targeted temporal masking properties of complex patterns *designed for information transfer* [35]. In this study, stimuli were delivered to the left index finger of three participants who were asked to identify target signals masked by forward, backward, and sandwiched paradigms with stimulus onset asynchronies (SOA) of up to ± 640 ms. The SOA is the temporal interval between the onsets of two stimuli. Seven perceptually distinct stimuli composed of one, two or three spectral components (2–4, 30 and 300 Hz) were constructed at each of two signal durations (125 or 250 ms). The masking stimuli were selected from the same stimulus set as the target stimuli. Results show a masking effect (average 70% of correct responses, with performance increasing with SOA) for the different types of masking. For these complex stimuli, participants often confused characteristics of the masker with those of the target; and there was considerable variation in individual performance.

Craig performed a series of experiments investigating the ability of participants to localize a tactile pattern presented at one of several locations on their left index finger, in the presence of a second tactile masking pattern [4]. The target stimulus, generated on a 6×24 array of stimulators, was presented either by itself or in the presence of an extraneous stimulus (masker) that either preceded (200–0 ms SOA) or followed (0–200 ms SOA) the target. The masking stimuli were identical in form to the target stimuli. The localizability of the target was affected by the SOA between the target and masker with masking being strongest (68% correct responses) when the masker followed the stimulus at relatively short SOA's (0–30 ms). In another study [6], Craig and Quian found that the identification of a spatial target pattern presented to one finger may be interfered with by the presentation of a second pattern to either the same or a second finger in both forward and backwards masking paradigms.

Evans observed the strongest masking effects at target durations under 100 ms [11]. Both Tan et al. [35] and Craig and Evans [5] found that degree of masking was influenced by the complexity of the stimuli employed; participants were able to identify simpler spatial patterns more accurately. Tan used long complex stimuli and longer SOA's (>125 ms) in order to accommodate low-frequency spectral content, and observed lower and less consistent masking effects. However, Tan's study also showed that percent correct scores were highest with the simplest target patterns (those that contained one spectral component).

Di Lollo and Enns have shown an application of another form of masking for visual stimuli, called *common-onset* or *object substitution* masking [8], where the masking stimulus is presented simultaneously with a clearly visible target stimulus but the surrounding masker remains after the target stimulus has been removed. In vision, this form of masking can be considered to be the result of two separate masking mechanisms: *camouflage masking* (or noise masking) which refers to a degradation in the representation of a target stimulus through the addition of noise from the mask, and *interruption masking* (backward masking (BWM)) which occurs when the mask appears before the target has been fully processed and represents a competition for higher level processes involved in object recognition. The term *object substitution* is used to describe the latter category because the mask appears to do more than interrupt the perceptual process and instead seems to become the new focus of object recognition mechanisms.

Di Lollo and Enns offer a theory of how common-onset masking (COM) works for vision [7,9]: they suggest that object substitution occurs whenever there is a mismatch between the re-entrant visual representation (in their experiments, the participant's representation of the target) and the ongoing lower-level activity produced by current sensory input (the persistent masker). In the case of tactile stimuli applied to two fingers, the re-entrant representation theory would play out as follows. Initially, two signals (one from each stimulus) are sent through the nervous system to the homunculus in the somatosensory cortex, where a representation of the skin and other senses is stored. The prefrontal cortex, responsible for consciousness, requests a re-entrant confirmation of one of the response hypotheses (finger 1, 2 or both) from the homunculus. By this time, the stimulation