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Exploring Tactile Amplitude Discrimination Ability at Varying Frequencies for Young Adults

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Introduction: Historically, many studies of both amplitude and frequency tactile discrimination were conducted under the assumption that perceived intensity of vibro-tactile stimuli needed to be controlled across trials for accurate results. This resulted in amplitude or frequency adjustments to control for “intensity” depending on what variable (amplitude or frequency) was being changed (Hollins & Roy, 1996). For example, if a frequency discrimination task was being conducted and frequency was being changed, the amplitude of the stimulus would also be altered based on the change in frequency to control for perceived intensity. The goal of this study was to test the “intensity” assumption and to determine if frequency level had an impact on tactile amplitude discrimination performance.

Methods: The experiment was conducted using a Brain Gauge (BG), which uses two adjacent tactile stimulators for dicrimination tasks. Participants completed four trials of amplitude discrimination conducted at 10, 20, 30, and 40 Hz respectively as this range is physiologically relevant as well as had the fastest adaptation within rapidly adapting (RA) neurons (Fernandez et al., 2011, Tommerdahl, et al, 2010, Purves et al., 2001).

Results: There is no statistically significant difference ($p > 0.27$) found for the amplitude discrimination tested at 20, 30 and 40 Hz. Amplitude discrimination was significantly worse ($p < 0.05$) at 10 Hz than at the higher frequencies.

Discussion: Our results suggest that the perceived intensity of stimuli, due to changes in frequency in the 20 to 40 Hz range, does not affect amplitude discrimination performance. This challenges the historical understanding that different frequencies had different perceived intensities which therefore needed to be accounted for by adjusting the amplitude (Hollins & Roy, 1996).

Introduction

Despite numerous technological advancements, the diagnosis of many common neurological disorders remains challenging. Current diagnostic equipment is often bulky, expensive, and produces high-dimensional data which is difficult to interpret (Siuly et al., 2016)[4]. Rather than imaging techniques, like MRI and EEG, sensory testing is an emerging modality for non-invasive neurological assessment. One such sensory testing paradigm is tactile stimulation, and changes in tactile sensory performance are associated presence of several disorders, such as ADHD, Autism, Epilepsy, and CRPS, with the potential of being a low-cost and portable [5-7].

One common tactile sensation test is amplitude discrimination, which assesses an individual’s ability to distinguish between the intensity (i.e., magnitude of skin deformation) of different stimuli, which are often sine wave pulses against the skin, which are transduced by mechanoreceptors [8]. Performance at differentiating between the amplitude of two simultaneous stimuli at different locations on the body is believed to be, in part, governed by lateral inhibition in the primary somatosensory cortex [9,10]. Tactile amplitude discrimination tasks often occur at a fixed frequency, but mechanoreceptors sensitivity and adaptation performance varies at different frequencies [3,11,12]. The common frequency at which amplitude discrimination tests were conducted at was 25Hz or the “flutter” stimulation [13]. It is largely unknown how amplitude discrimination performance varies at different tactile stimulation frequencies. However, to our knowledge, amplitude discrimination performance has yet to be assessed at different frequencies.

Thus, the purpose of this experiment was to assess amplitude discrimination capacity at various frequencies. The frequencies which are most distinguishable by human RA somatosensory neurons are 10-40 Hz [2,3]. Also, 10-40 Hz is representative of the physiological relevant range of frequencies [1]. For these reasons, this frequency range may therefore exhibit the largest, if any, changes in amplitude discrimination between frequencies. By using tactile stimulation technology, it is possible to explore how different stimulation frequencies can impact one’s ability to distinguish between different amplitudes using vibrations and the somatosensory cortex.

Methods

The study was conducted on 46 young adult individuals (21.2 years ± 0.6 years, 21M/25F). For the test battery that was programmed into the brain gauge for testing, amplitude discrimination trials were conducted at ascending frequencies. The test frequencies were chosen due to RA neurons adapting optimally to stimuli within the range of 10 - 40 Hz [3]. Amplitude discrimination trials proceeded in the following order for each test subject (Table 1):

Trial	Frequency (Hz)
1	10
2	20
3	30
4	40

Table 1. *Frequency Levels for Amplitude Discrimination Trials*

The amplitude discrimination tests were conducted using a vibrotactile stimulator (Brain Gauge (BG); Cortical Metrics, Chapel Hill, NC, USA) which uses two adjacent finger vibratory stimulators. The stimulators were used to interface with the second and third digit shown below (Fig. 1):

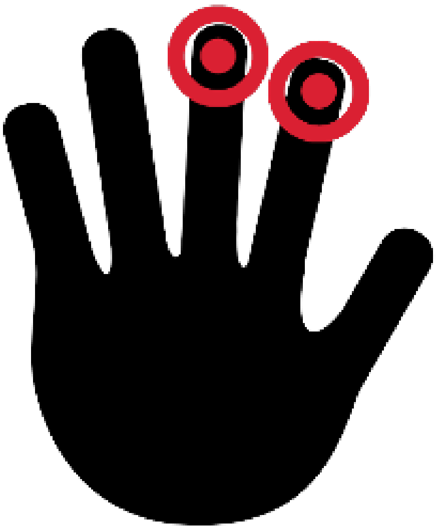

Figure 1. *Locations of Tactile Stimulation for Experiment*

The two stimulators can be independently adjusted for amplitude and frequency of stimuli, however for this experiment only the amplitude was different between the two stimulators. Each frequency trial that was conducted was a set of 20 amplitude discrimination tests, in which the participant was instructed to press down on the stimulator that was producing the most intense vibration correlating with a higher amplitude. A tracking algorithm was used to determine each subject's just noticeable difference (JND) in stimulation amplitude [14], with a variable test stimulus and an unchanging standard stimulus of 200 µm. The test stimulus begins at 400 µm, and increases or decreases by 20 µm if the participant identifies the larger stimulus correctly or incorrectly, respectively. Amplitude discrimination performance is quantified by the difference limen (µm), which is calculated by averaging the difference in amplitude between the test and standard stimuli over the last five test iterations.

For analysis of the amplitude discrimination data collected, differences in amplitude discrimination score were assessed for statistical significance using two-way pairwise t-tests (▯ < 0.05).

Results

Amplitude discrimination performance was worst (i.e., highest difference limen) during 10 Hz stimulation, and was significantly worse than the 20 Hz ($p = 0.013$), 30 Hz ($p < 0.001$), and 40 Hz ($p = 0.022$) stimulation conditions (Fig. 2). Amplitude discrimination performance was not significantly different ($0.27 < p < 0.86$) between the 20, 30, or 40 Hz stimulation conditions.

Additionally, the difference in level of stimulation between fingers was tracked for each participant across each of the 20 amplitude discrimination test iterations within a trial. Each iteration for its respective frequency was averaged across all participants, producing "tracking curves" for each frequency trial (Fig. 3). A tracking curve is a graph showing the progression of the difference in stimulus level between the two stimulators as the trial progresses, approaching the JND.

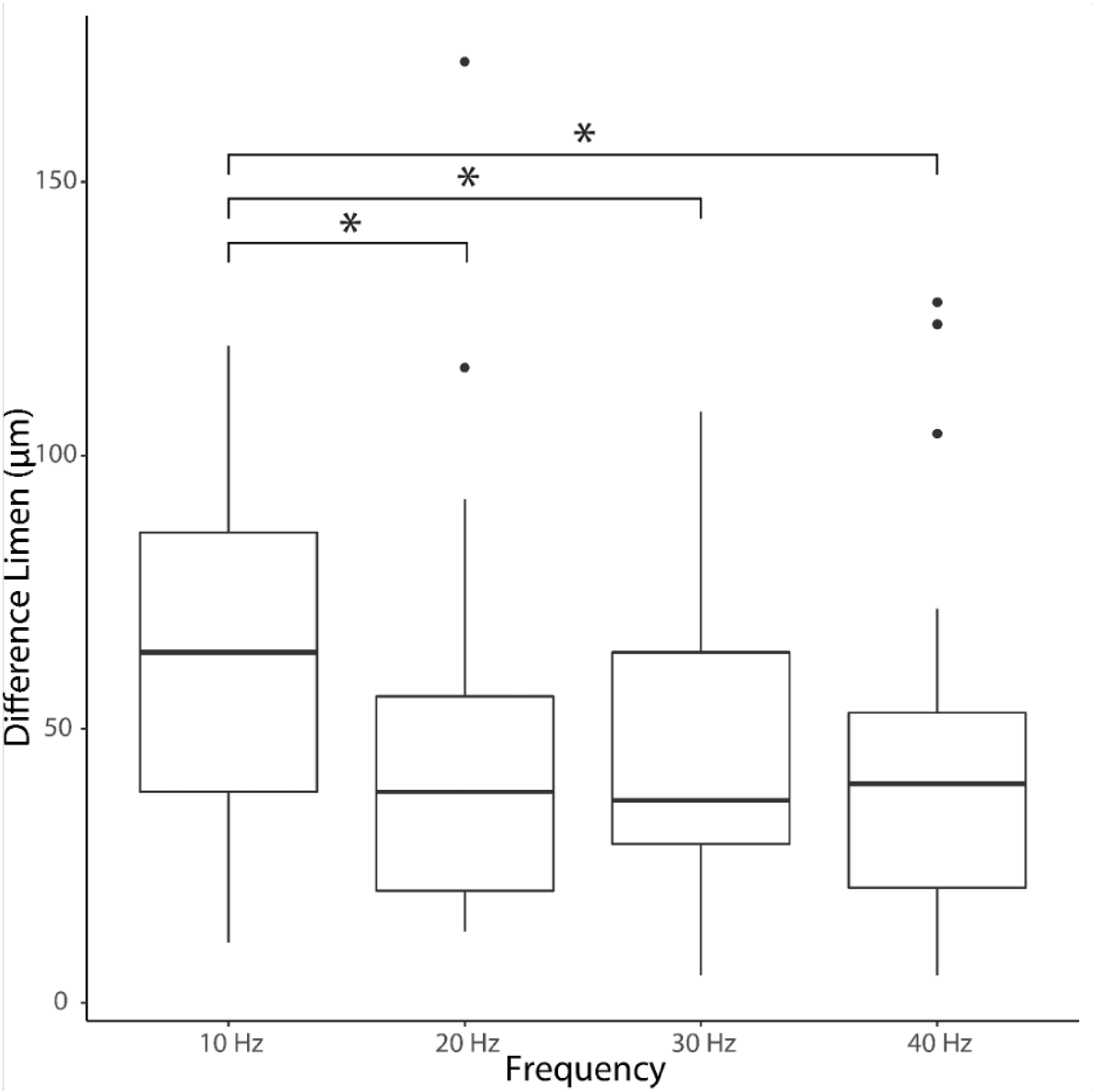

Figure 2. *Tactile amplitude discrimination performance during flutter stimulation at 10, 20, 30, and 40 Hz.* * indicates statistically significant ($p < 0.05$) pairwise differences.

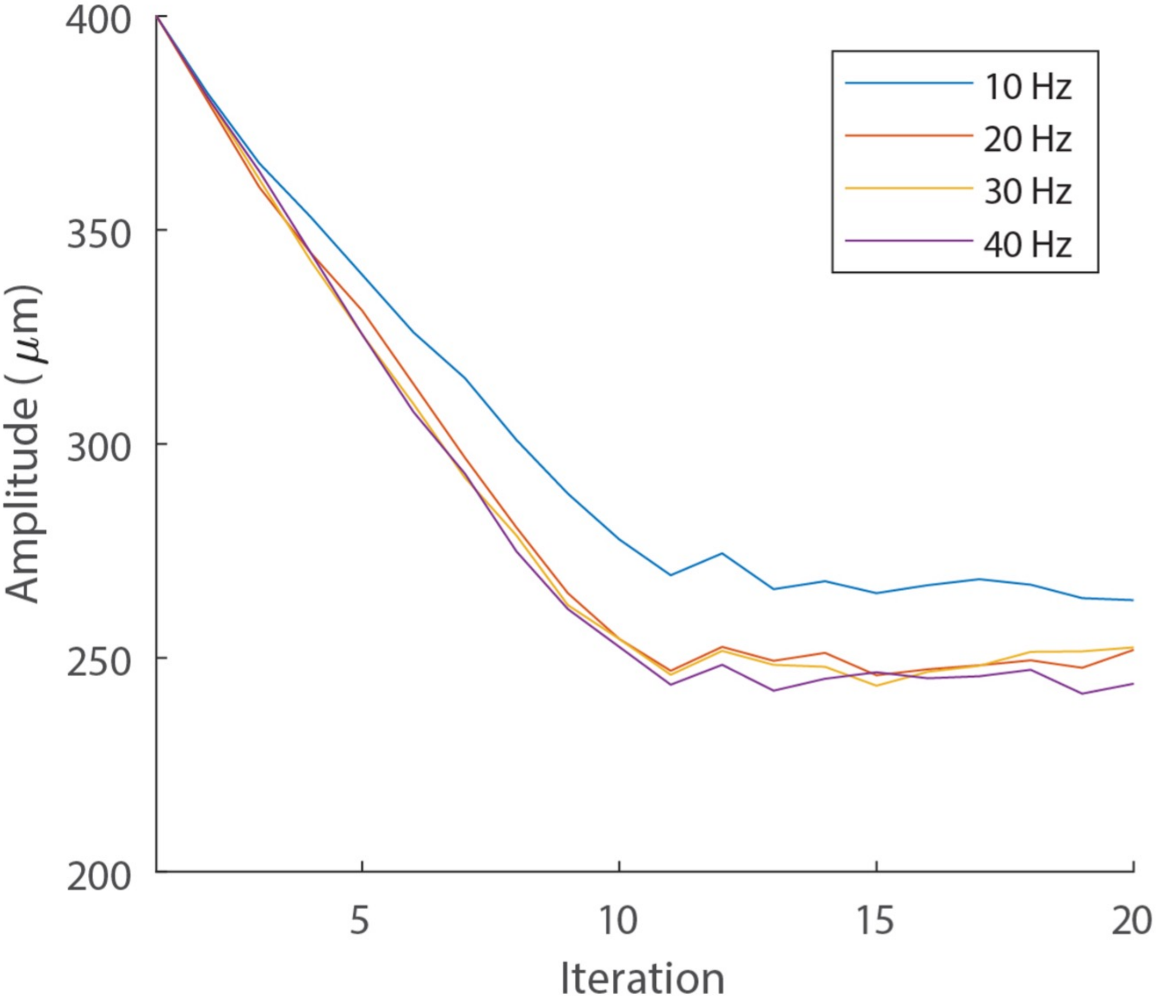

Figure 3. *Tactile amplitude discrimination tracking curves averaged for all subjects.* Test stimulus amplitude begins at 400 µm and decreases or increases by 20 µm in response to correct or incorrect identification of the larger stimulus by subjects.

Freqeuncy For Amplitude Discrimination				
10Hz	20Hz	30Hz	40Hz	
Difference Limen (µm)	65.5	50.5	51.9	43.3

Table 2. *Amplitude discrimination performance at different frequencies.* Lower difference limen is indicative of greater amplitude discrimination performance.

Discussion

The current research aimed to investigate the role of vibrotactile stimulation frequency on amplitude discrimination performance. Across the four frequency conditions (10, 20, 30, and 40 Hz), only amplitude discrimination at 10 Hz was significantly different than the rest.

Historically, researchers have operated on the assumption that vibrotactile stimulus frequency and amplitude jointly contribute to perceived intensity. For this reason, experimental protocols involving increases in vibratory frequency were offset with corresponding decreases in stimulus amplitude, or vice versa [8]. Our findings cast doubt on this assumption. When tested at a single frequency, amplitude discrimination performance has been demonstrated to vary proportionally with stimulus amplitude (i.e. intensity), in accordance with Weber's law [15]. If increased stimulus frequency were to contribute to a greater perceived intensity, we would expect to see that absolute amplitude discrimination performance would worsen at higher frequencies, as performance intensity increases. Our findings suggest the opposite, with improved absolute amplitude discrimination performance at high frequencies (Fig 2).

The findings from this study suggest that higher frequencies have limited effect on amplitude discrimination performance. Thus, it appears that amplitude discrimination tasks and frequency discrimination tasks utilize different features of information processing. Together, these findings contribute to a growing body of evidence to suggest that vibrotactile stimulus frequency and amplitude contribute to perceived intensity via different mechanisms.

An area of expansion in looking into the combination of amplitude and frequency variation for tactile discrimination would be to add a confounding variable into the respective discriminiation test. A frequency confound could be introduced into an amplitude discrimination battery, this would manifest as an amplitude discrimination test using the BG where the two tactile stimulators vibrate at slightly different frequencies. Conversely, an amplitude confound could be introduced into a frequency discrimination test where the two tactile stimulators of the BG vibrate at slightly different amplitudes. This would give further insight into the relationship between the combination of frequency and amplitude level of tactile stimuli and the ability for stimuli discrimination.

Author Contributions

Experimental Design: *CF, MF, JF*

Abstract: *MF, JF*

Introduction: *CF, MF, JF*

Methods: *CF, MF, JF*

Results: *CF*

Discussion: *CF, MF, JF*

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