Discrimination of the Frequency of Vibration Applied to the Finger at Two Acceleration Magnitudes

Conference Paper · September 2018

2 authors:

Sean R Mills
University of Southampton
4 PUBLICATIONS **0** CITATIONS

SEE PROFILE

Michael J. Griffin
University of Southampton
448 PUBLICATIONS **11,030** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project   Psychophysical diagnosis of impaired touch perception View project

DISCRIMINATION OF THE FREQUENCY OF VIBRATION APPLIED TO THE FINGER AT TWO ACCELERATION MAGNITUDES

Sean R. Mills and Michael J. Griffin
Institute of Sound and Vibration Research
University of Southampton
Southampton, SO17 1BJ
United Kingdom
sean.mills@soton.ac.uk

Abstract

The perception of fine textures is believed to depend on the encoding of high frequency vibration by the Pacinian (PC) channel. However, the rapidly-adapting (RA) channel may also be able to encode the frequency of vibration. The aim of this study was to investigate whether the ability to perceive changes in the frequency of 100-Hz vibration at the finger depends on whether the magnitude of vibration is such that the RA channel also contributes to perception. Vibration magnitudes were identified at which the stimuli can be assumed to activate either the PC channel alone, or both the PC channel and the RA channel. Sixteen participants completed a two-alternative forced-choice task that determined thresholds for the discrimination of changes in frequency at both magnitudes. Frequency discrimination thresholds were significantly greater for the PC channel alone than for the PC channel and the RA channel together. This finding suggests the RA channel plays a key role in frequency discrimination, even at high frequencies often thought to be primarily mediated by the PC channel.

1. Introduction

When we brush our fingers across a surface we perceive it as hard or soft, rough or smooth, grippy or slippy. These sensations depend on systems of mechanoreceptive neurons in the skin that encode the parameters of the complex physical interaction between the surface and the skin. These systems are known as the 'tactile channels' (Gescheider, 1976; Capraro *et al.*, 1979; Gescheider *et al.* 2010). At least four tactile channels exist, mediated by four different kinds of mechanoreceptive neurons in the skin (Johnson, 2001; Gescheider *et al.*, 2010).

The channels behave in different ways to capture information from the physical environment (Johnson and Hsiao, 1992; Johnson, 2001; Saal and Bensmaia, 2014). In the case of fine texture, perception depends on the ability to encode the frequency of the vibration induced in the skin by brushing it across the surface (Hollins *et al.*, 2002; Bensmaia and Hollins, 2003). We can investigate this capacity to encode frequency by asking people to make discriminations between a vibration and a target vibration of a different frequency, and then estimating their Weber fraction – the smallest change in the frequency of vibration they can reliably detect, proportional to the original frequency (i.e., $\Delta f/f$).

Vibration frequency is encoded by Pacinian corpuscles (the PC channel). This is suggested by electrophysiological evidence that the PC channel responds to small changes in skin indentation in a phase-locked way, encoding the frequency of the vibration (Freeman and Johnson, 1982; Bolanowski and Zwislocki, 1984; Horch, 1991). As the magnitude of the vibration increases, a second channel

_____

mediated by Meissner's corpuscles, known as the Rapid-Adapting (RA) channel, is activated. This channel has also been implicated in encoding frequency (Mountcastle and Steinmetz, 1990; Mountcastle et al., 1990; Salinas et al., 2000) and shares the capacity to respond to vibrations in a phase-locked way (Talbot et al., 1968). The purpose of this study was to address whether there is a difference between Weber fractions for frequency in conditions thought to activate the PC channel alone and those that activate both the PC channel and the RA channel.

There have been few studies of the discrimination of vibrotactile frequency (e.g., Roberts, 1932; Mowbray and Gebhard, 1957; Goff, 1967; Franzén and Nordmark, 1975; Rothenberg et al., 1977; Horch, 1991; Sinclair and Burton, 1996; Tommerdahl et al., 2005; Mahns et al., 2006; Deco, Scarano, and Soto-Faraco, 2007; Kuroki et al., 2013). These studies do not address the question of how the recruitment of the RA channel affects Weber fractions. Most researchers have used stimuli with 'sensation levels' (SL; levels greater than the observer's absolute threshold) of between 16 and 35 dB. These levels are likely to activate all the tactile channels, and the findings may vary because of variability in individual absolute thresholds within each channel. In this study, the acceleration of the vibration, rather than the perceptual intensity, was controlled across target and comparison stimuli, and participants were instructed to identify an unspecified difference between the reference and target stimuli (an 'odd one out').

It was hypothesized that Weber fractions for vibrotactile frequency would be smaller at an acceleration thought to activate both the RA and the PC channels than at an acceleration activating the PC channel alone. There are two ways in which the recruitment of a second channel may improve Weber fractions: 1) the recruitment of a more sensitive channel supersedes, or replaces, the less sensitive channel or, 2) the recruitment of a second channel is additive, and always improves discrimination, regardless of which of the two is more sensitive.

2. Methods

2.1. Participants

Sixteen participants were recruited from the staff and students at the University of Southampton (11 male and 5 female, with an average age of 27 years [SD = 5.45]). On a screening questionnaire, the participants reported that they had no problems with their touch perception, and that they had not been exposed to vibration or taken medication that may have affected their sense of touch.

2.2. Apparatus

Vibration stimuli were delivered with an *HVLab* Tactile Vibrometer (VTT) having a circular 10-mm diameter contactor to which the subjects applied the distal phalanx of their left middle finger. A rigid surround, with a 1-mm gap to the contactor, was used to limit the spread of surface waves. The output of the VTT was calibrated using a Brüel and Kjaer calibration exciter (type 4294). A constant downward force of 2 N was maintained on the surround using feedback from a force sensor. Pink noise was played to the participants over circumaural headphones at 75 dB to mask any auditory cues to the frequency of vibration. Visual cues to the timing of the presentation of the stimuli were shown on a computer monitor, and responses were made by clicking a mouse. All stimuli were controlled with custom Matlab

software, and monitored by the experimenter. Testing took place in a temperature-controlled room (21 ±1°C). The participants sat on one side of an opaque screen so that they could not see the experimenter or the control equipment.

2.3. Procedure

Participants completed a single two-alternative forced choice (2AFC) task for the discrimination of vibrotactile frequency differences at two magnitudes: 1) a PC targeting condition, and 2) a PC + RA targeting condition. The experiment also included frequency discrimination trials on another contactor, and the measurement of absolute thresholds, but these data are not reported here.

A single trial of the task consisted of three intervals. The first interval was always the presentation of a 'reference' stimulus. The second and third intervals contained a 'target' stimulus, and a repeat of the reference stimulus in a randomised order. For both conditions, the 'reference' stimulus was a vibration of 100 Hz, and the 'target' was a vibration of the same acceleration magnitude as the reference but a different frequency. The conditions were randomly interleaved within the session.

Visual cues were presented on the computer monitor for each stimulus interval. One, two, and then three white boxes appeared across the screen in front of the subject as each interval occurred. When all the stimuli had been presented, the two boxes representing the intervals in which a 'target' may have been presented turned orange. Participants then indicated which interval was most likely to contain the 'target' with a left or right mouse click. Feedback was provided by the box turning green (correct) or red (incorrect).

The stimulus to be presented in each trial type followed a 3-down 1-up method of limits staircase, with the staircases evolving in parallel. The two frequency difference staircases had the initial frequency of the 'target' as 110 Hz (i.e., 100 Hz plus 10%), with the step size starting at 30% and decreasing in size by 5% with each reversal. The difference limen was taken as the average of the 5th reversal through to the 10th reversal. This method converges on the 79.4% correct level of performance.

Experimental trials were completed in blocks of 20, each lasting around 2 minutes. Between each block, a break of at least 1 minute was enforced, during which participants rested their finger and removed their headphones. This was to limit any effect of temporary threshold shift (TTS) from exposure to vibration, and to reduce any fatigue. Participants completed a supervised training block at the start of the experiment to ensure that they had understood the instructions and maintained the correct contact with the vibrator.

2.4. Stimuli

To determine the magnitudes of the stimuli in the two conditions, the sensitivity of the RA and PC channels was estimated based on tuning curves derived from previous research on vibrotactile thresholds (Verrillo, 1963; Bolanowski and Verrillo, 1982; Gescheider *et al.*, 1985; Verrillo and Bolanowski, 1986; Bolanowski *et al.*, 1988). Channel sensitivity varies systematically as a function of frequency and contactor size, among other factors. To estimate the sensitivity of the two channels in the conditions chosen for this experiment, the detection thresholds of 8 participants (5 male and 3 female, with an average age of 25 [$SD = 2.05$]) were measured at 125 Hz with the same 10-mm diameter

contactor as in the main experiment, using the von Békésy method of limits as defined in ISO 13091-1:2001. The mean absolute threshold at 125 Hz was found to be 0.22 ms^{-2} r.m.s (standard error of the mean [SE] = 0.06). This value was used to estimate channel sensitivity across a broader frequency range when using a 10-mm contactor, by multiplying the historical tuning curves such that that they intersect with this experimentally determined threshold (this process is detailed in Mills and Griffin, 2017). Stimuli were then chosen for the 1-channel and 2-channel conditions to have magnitudes of double the expected absolute acceleration threshold for the relevant channel, in order to activate one or two target channels. All vibration stimuli therefore had an acceleration magnitude of either 0.31 ms^{-2} r.m.s. or 2.52 ms^{-2} r.m.s., and consisted of 1-second sinusoidal vibrations with a 0.05-second taper at either end. The 'reference' stimuli always had a frequency of 100 Hz. The 'target' stimuli were identical to the 'reference' stimuli except for their frequency, which was higher than the reference (never exceeding 250 Hz). Figure 1 shows estimates of tuning curves for PC and RA channels, and the chosen stimulus magnitudes for 1-channel and predicted 2-channel activation.
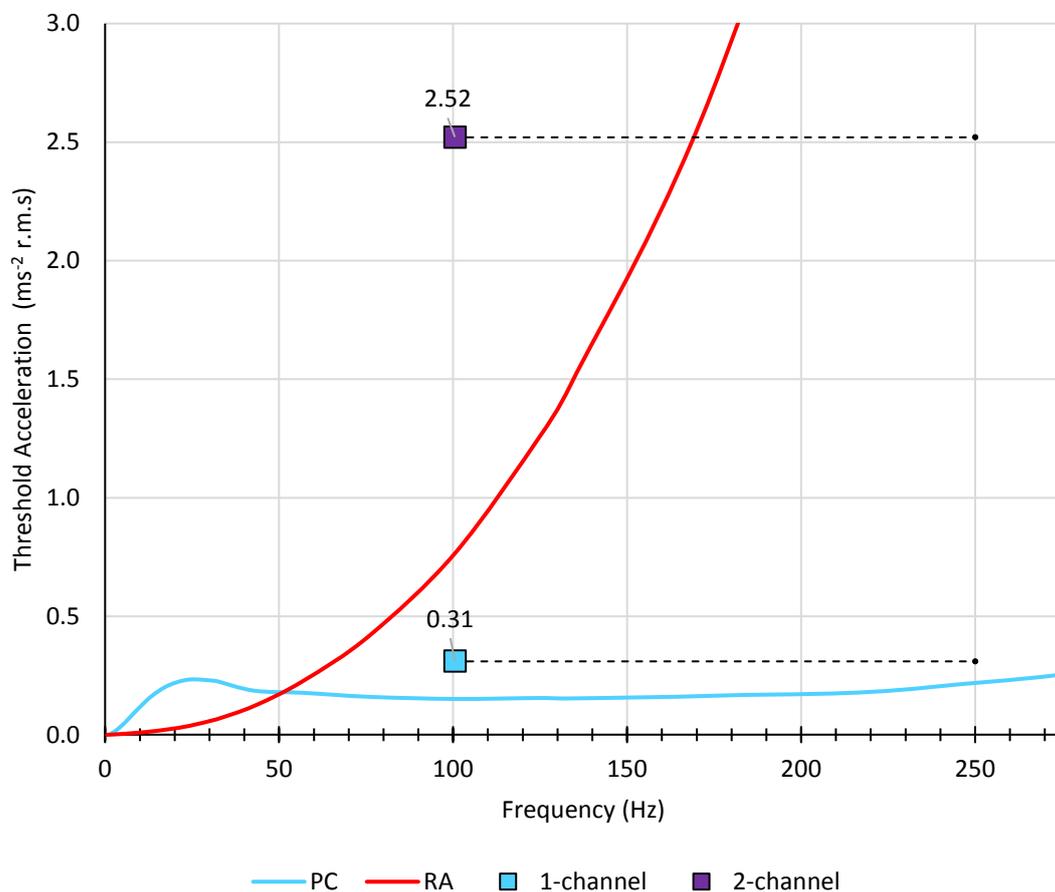

Figure 1. Stimuli for the 1-channel and 2-channel conditions. Solid lines show the estimated tuning curves for a 10-mm diameter contactor, based on historic tuning curves (Verrillo, 1963; Bolanowski and Verrillo, 1982; Gescheider *et al.*, 1985; Verrillo and Bolanowski, 1986; Bolanowski *et al.*, 1988). Markers show the frequency and magnitude of the two 'reference' stimuli used for frequency discrimination. Dashed lines indicate the acceleration magnitudes and the possible range of frequencies of the 'target' stimuli.

3. Results

A paired samples t-test was conducted to investigate differences in Weber fractions for frequency in conditions expected to excite the PC channel alone (target stimuli with a magnitude of 0.31 ms^{-2} r.m.s.) and conditions expected to excite both the PC channel and the RA channel (target stimuli with a magnitude of 2.52 ms^{-2} r.m.s.). Weber fractions were significantly lower in the 2-channel condition at the greater vibration magnitude than in the 1-channel condition at the lower magnitude ($t(14) = 5.97$, $p < 0.001$, $d = 1.78$). The average difference between the frequency that could be discriminated from the 100 Hz reference in the two conditions was 34 Hz ($SE = 5.6$), reducing from 165 Hz in the 1-channel condition to 131 Hz in the 2-channel condition. These results are shown in Figure 2.
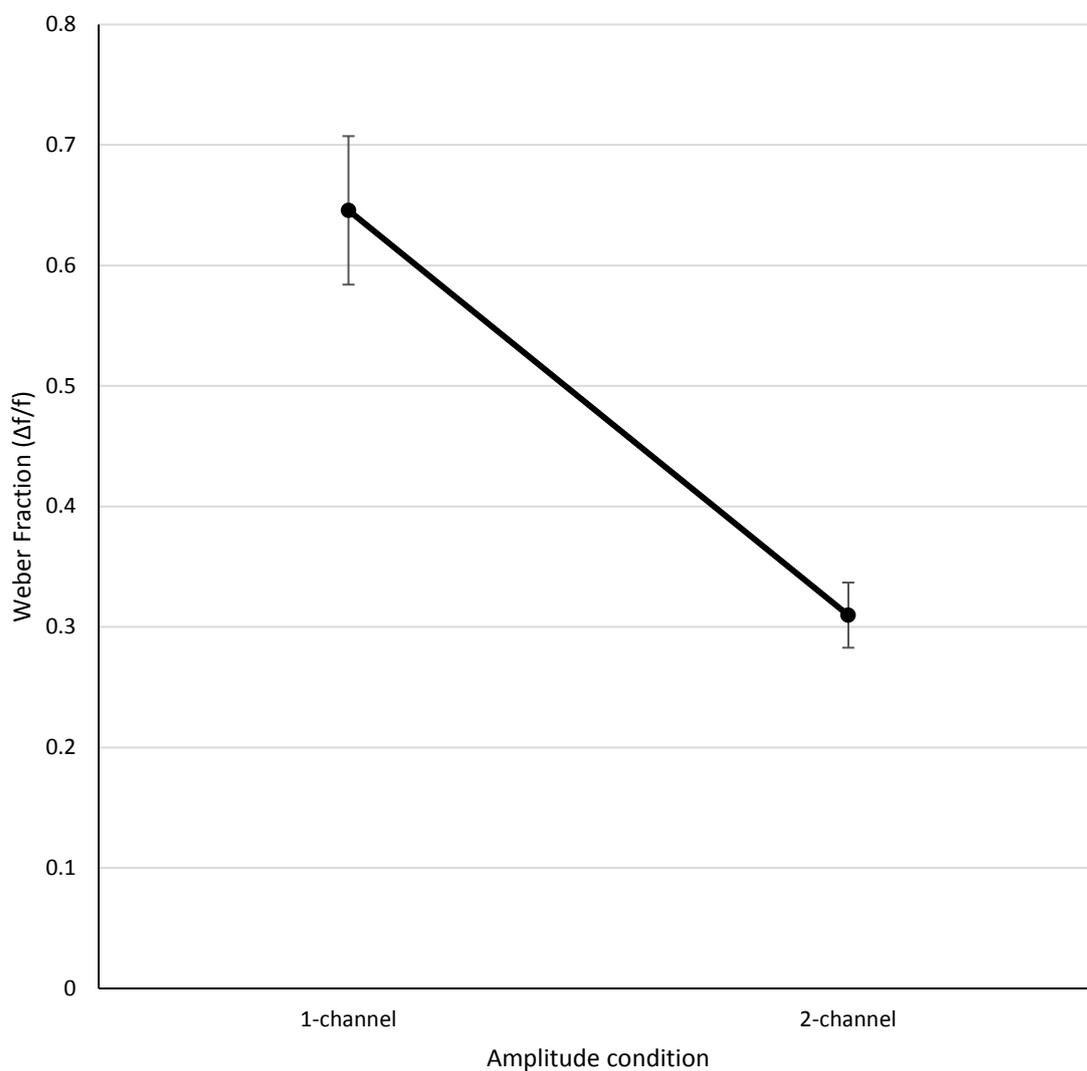

Figure 2. Mean vibrotactile frequency difference limens in conditions targeting the PC channel alone (0.31 ms^{-2} r.m.s.) and the PC and RA channels together (2.52 ms^{-2} r.m.s.) expressed as Weber fractions (just detectable changes in frequency / 100 Hz). Error bars give the standard error of the mean.

4. Discussion

In this study, Weber fractions for the perception of changes in vibrotactile frequency were found to be smaller in magnitude conditions thought to activate both the PC and RA channels than in conditions activating the PC channel alone. This is consistent with the belief that both of these channels are capable of encoding vibration frequency, and that highly discriminative touch depends on information from more than one channel in the tactile system.

Psychophysical investigations of touch perception have been largely dependent on absolute thresholds – the least amplitude of vibration that can be detected reliably. This approach has been effective at identifying the selectivity of the individual channels, and attributing the activation of particular channels to discrete functions (Johnson, 2001). The results of this experiment suggest that frequency is likely to be coded in both the PC channel and the RA channel. As the number of recruited channels changes, the ability to discriminate vibration frequency at the finger also changes. This could be understood either as the takeover of the PC channel by the RA channel, which is more capable at frequency discrimination, or as the integration of two informative channels to provide a more accurate percept.

The finding has implications for the diagnosis of impaired tactile perception, which currently depends on absolute thresholds for the perception of vibration to identify the sensitivity of the PC and RA channels. This appears to be a useful part of a suite of diagnostic tools for identifying the sensorineural components of hand-arm vibration syndrome (e.g., Ye and Griffin, 2017). In day-to-day discriminative touch, however, the PC and RA channels are likely to be encoding the temporal properties of stimuli, rather than simply the presence or absence of vibration. More informative diagnostic tools would reflect changes not just in the absolute thresholds, but in the sensory processing that underlies feeling the texture of a surface or the manipulation and control of hand-held tools.

The results of this experiment go some way to explaining the highly varied frequency discrimination thresholds observed in previous studies. Those studies that used higher magnitude stimuli may have resulted in smaller Weber fractions for vibrotactile frequency because they recruited both the RA channel and the PC channel. Previous research has found difference limens for the perception of changes in frequency from 100 Hz as disparate as 3 Hz with a reported sensation level (SL) of 30 dB (Franzén and Nordmark, 1975), 21 Hz with 12 dB SL stimuli (Mahns *et al.*, 2006), and 118 Hz with 6 dB SL stimuli (Kuroki *et al.*, 2013) . Differences in experimental design, contact area, and training may have influenced the previously reported thresholds, but it is likely that the stimulus magnitude was also a key factor influencing the large differences in vibrotactile frequency discrimination.

5. Conclusions

The discrimination of changes in the frequency of vibration applied to the finger is greater when both the RA channel and the PC channel are activated than when only the PC channel is activated. This suggests that supra-threshold touch is supported by the joint action of the tactile channels, each with a different capacity to encode vibrotactile frequency. The findings emphasize the importance of the choice and control of the magnitude of vibration in psychophysical investigations of frequency discrimination, and have implications for psychophysical methods used in the diagnosis of impaired tactile perception.

6. References

Bensmaïa SJ and Hollins M (2003) The vibrations of texture. Somatosensory and Motor Research, 20(1), 33–43.

Bolanowski SJ and Verrillo RT (1982) Temperature and criterion effects in a somatosensory subsystem: a neurophysiological and psychophysical study. Journal of Neurophysiology, 48(3), 836–855.

Bolanowski SJ and Zwislocki JJ (1984) Intensity and frequency characteristics of pacinian corpuscles. I. Action potentials. Journal of Neurophysiology, 51(4), 793–811.

Bolanowski SJ, Gescheider GA, Verrillo RT and Checkosky CM (1988) Four channels mediate the mechanical aspects of touch. The Journal of the Acoustical Society of America, 84(5), 1680–1694.

Capraro AJ, Verrillo RT, and Zwislocki JJ (1979) Psychophysical evidence for a triplex system of cutaneous mechanoreception. Sensory Processes.

Deco G, Scarano L and Soto-Faraco S (2007) Weber's law in decision making: integrating behavioral data in humans with a neurophysiological model. The Journal of Neuroscience, 27(42), 11192–11200.

Franzén O and Nordmark J (1975) Vibrotactile frequency discrimination. Perception and Psychophysics, 17(5), 480–484.

Freeman AW and Johnson KO (1982) Cutaneous mechanoreceptors in macaque monkey: temporal discharge patterns evoked by vibration, and a receptor model. The Journal of Physiology, 323(1), 21–41.

Gescheider GA (1976) Evidence in support of the duplex theory of mechanoreception. Sensory Processes.

Gescheider GA, Sklar BF, Van Doren CL, and Verrillo RT (1985) Vibrotactile forward masking: psychophysical evidence for a triplex theory of cutaneous mechanoreception. The Journal of the Acoustical Society of America, 78(2), 534–543.

Gescheider GA, Wright JH and Verrillo RT (2010) Information-Processing Channels in the Tactile Sensory System: A Psychophysical and Physiological Analysis. Psychology Press.

Goff GD (1967) Differential discrimination of frequency of cutaneous mechanical vibration. Journal of Experimental Psychology, 74(2p1), 294.

Hollins M, Bensmaïa, SJ and Roy EA (2002) Vibrotaction and texture perception. Behavioural Brain Research, 135(1–2), 51–56.

Horch K (1991) Coding of vibrotactile stimulus frequency by Pacinian corpuscle afferents. The Journal of the Acoustical Society of America, 89(6), 2827–2836.

International Organization for Standardization (2001) Mechanical vibration -- Vibrotactile perception thresholds for the assessment of nerve dysfunction -- Part 1: Methods of measurement at the fingertips. ISO 13091-1:2001

Johnson KO (2001) The roles and functions of cutaneous mechanoreceptors. Current Opinion in Neurobiology, 11(4), 455–461.

Johnson KO and Hsiao SS (1992) Neural mechanisms of tactual form and texture perception. Annual Review of Neuroscience, 15(1), 227–250.

Kuroki S, Watanabe J and Nishida S (2013) Contribution of within-and cross-channel information to vibrotactile frequency discrimination. Brain Research, 1529, 46–55.

Mahns DA, Perkins NM, Sahai V, Robinson L and Rowe MJ (2006) Vibrotactile frequency discrimination in human hairy skin. Journal of Neurophysiology, 95(3), 1442–1450.

Mills SR and Griffin MJ (2017) The touch perception puzzle: a basis for choosing stimulus parameters in vibrotactile psychophysics. Presented at the 52nd UK Human Response to Vibration Conference and Workshop, Shrivenham, Cranfield University, Cranfield Defence and Security, UK Defence Academy.

Morioka M and Griffin MJ (2002) Dependence of vibrotactile thresholds on the psychophysical measurement method. International Archives of Occupational and Environmental Health, 75(1–2), 78–84.

Mountcastle VB and Steinmetz MA (1990) Cortical neuronal periodicities and frequency discrimination in the sense of flutter. In Cold Spring Harbor symposia on quantitative biology (Vol. 55, pp. 861–872). Cold Spring Harbor Laboratory Press.

Mountcastle VB, Steinmetz MA and Romo R (1990) Frequency discrimination in the sense of flutter: psychophysical measurements correlated with postcentral events in behaving monkeys. The Journal of Neuroscience, 10(9), 3032–3044.

Mowbray GH and Gebhard JW (1957) Sensitivity of the skin to changes in the rate of intermittent mechanical stimuli. Science, 125, 1297-1298.

Roberts WH (1932) A two-dimensional analysis of the discrimination of differences in the frequency of vibrations by means of the sense of touch. Journal of the Franklin Institute, 213(3), 283–311.

Rothenberg M, Verrillo RT, Zahorian SA, Brachman ML and Bolanowski SJ (1977) Vibrotactile frequency for encoding a speech parameter. The Journal of the Acoustical Society of America, 62(4), 1003–1012.

Saal HP and Bensmaia SJ (2014) Touch is a team effort: interplay of submodalities in cutaneous sensibility. Trends in Neurosciences, 37(12), 689–697.

Salinas E, Hernández A, Zainos A and Romo R. (2000) Periodicity and Firing Rate As Candidate Neural Codes for the Frequency of Vibrotactile Stimuli. Journal of Neuroscience, 20(14), 5503–5515.

Sinclair RJ and Burton H (1996) Discrimination of vibrotactile frequencies in a delayed pair comparison task. Perception and Psychophysics, 58(5), 680–692.

Talbot WH, Darian-Smith I, Kornhuber HH and Mountcastle VB (1968) The sense of flutter-vibration: comparison of the human capacity with response patterns of mechanoreceptive afferents from the monkey hand. Journal of Neurophysiology, 31(2), 301–334.

Tommerdahl M, Hester KD, Felix ER, Hollins M, Favorov OV, Quibrera PM and Whitsel BL (2005). Human vibrotactile frequency discriminative capacity after adaptation to 25 Hz or 200 Hz stimulation. Brain Research, 1057(1), 1–9.

Verrillo RT (1963). Effect of contactor area on the vibrotactile threshold. The Journal of the Acoustical Society of America, 35(12), 1962–1966.

Verrillo RT and Bolanowski SJ (1986) The effects of skin temperature on the psychophysical responses to vibration on glabrous and hairy skin. The Journal of the Acoustical Society of America, 80(2), 528–532.

Ye Y and Griffin MJ (2017). Assessment of thermotactile and vibrotactile thresholds for detecting sensorineural components of the hand-arm vibration syndrome (HAVS). International Archives of Occupational and Environmental Health, 1–11.