An instance of tactile suppression: Active exploration impairs tactile sensitivity for the direction of lateral movement

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ABSTRACT

The phenomenon of a reduction in tactile sensitivity during voluntarily executed body movement we call "tactile suppression". This is in analogy to saccadic suppression where the visual sensitivity is reduced during voluntarily executed eye movements [1]. Here we investigate tactile suppression using an integrated tactile/kinesthetic display – consisting of a tactile shear force device [2] mounted on a hyper redundant haptic display (ViSHaRD10 [3]). To quantify the tactile suppression effect we measured subject's motion-direction discrimination performance for tactile stimuli moving laterally on the index finger under various active and passive exploration conditions. In the baseline condition ("static") only tactile stimuli were provided using the shear-force device while the arm was held still. In the "active" condition subjects had to discriminate the direction of tactile motion while actively executing arm movements at the same time. Finally, in the "passive" condition the kinesthetic device passively moved the subjects' arm, while the subject was performing the discrimination task. Compared to the "still" condition results indicate a significant decrease of tactile sensibility during active movements whereas passive movements seem to have a minor effect on tactile discrimination performance.

Keywords: Tactile suppression, psychophysics, shear force, kinesthetic, tactile movement perception

1 INTRODUCTION

The effect that the visual sensitivity for motion is reduced during active eye movements is often called saccadic suppression [1]. Tactile suppression, which may be seen as analog to saccadic suppression, refers to the phenomenon whereby tactile stimulation during self-produced body movement is felt less intensely than that produced by an external event. A well-known version of this effect is that you can't tickle yourself or at least the sensation of self-tickling is less powerful [4]. One proposed explanation for tactile suppression is that self-produced movements and their sensory consequences can be predicted precisely [5]. This precision in prediction is said to attenuate the sensory effects of movement and hence, serve to prevent an overwhelming amount of sensory input during normal activity. However, the exact mechanisms by which proprioceptive information interact with tactile perception remains to be an open question. Here we investigate the interplay between tactile and kinesthetic information for the perception of tactile motion on the index finger. Specifically we ask whether performance for the discrimination of direction of a moving tactile stimulus is affected by passive or active arm movements. With this experiment we want to discriminate between two hypotheses:

1) Sensitivity reduction: Tactile suppression during active movement exceeds that during passive movement because the active component is necessary to elicit the active reduction in sensitivity – i.e., the suppression effect. If tactile sensitivity is generally reduced during the arm movement this should be direction independent.

2) Predictability of arm movement: Tactile sensitivity during active movement exceeds that during passive movement. This may be because arm movements in general are an additional source of noise and therefore make discrimination performance worse when the arm is in motion as compared to when it is still. However, active motion is more predictable then passive motion and therefore in the "active" condition there is less added noise than in the "passive" condition. If prediction plays a role during tactile suppression of tactile motion perception we may further predict that the suppression effect is direction selective for the movement direction of the arm.

2 METHODS

2.1 Participants

Twelve right-handed, Participants (seven male, five female) participated for pay. Ten of them were naïve to the purpose of the experiment; the remaining two were authors (MPV, MF). Their age ranged from 19 to 35 years (average 26 years). None of them reported previous injuries or impairment of tactile sensibility of the finger tip.

2.2 Apparatus and Stimuli

For our kinesthetic/tactile experiments we mounted a shear force device (SFD [2]), which can produce lateral motion of a pin in any direction of the x/y plane (amplitude ±1 mm), on a kinesthetic robot arm (ViSHaRD10 [3]). The kinesthetic robot arm was used to control the human arm movement and to provide haptic feedback when necessary. Movement of the kinesthetic robot arm was limited to 1 DOF (for a detailed description see Deliverable D4.3, http://www.touch-hapsys.org).

Participants sat comfortably on a bar stool which was height adjustable in front of the kinesthetic/tactile setup. Their left hand was attached with adhesive tape to the cover plate of the SFD in order to avoid unintentional hand movements during the experiment and to maintain the index finger still and without additional force during all the experimental conditions. Thus, accidental skin stretch on the finger tip was reduced to a minimum. The distal phalanx of the left index finger was not supported by the device's cover plate (Fig. 1).

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To ensure full skin stretch and to avoid translational cues, the metal pin which induced the skin stretch was glued with a minimal amount of cyanoacrylate to the tip of the index finger. Sight of the index finger was retarded by cardboard built blinds. The lateral surfaces of the SFD were covered with cardboard to prevent sight on the mechanics and thus to avoid additional hints for the direction of the moving pin.

Auditorily, white noise was presented via earphones to mask the sound, which was produced by the servo motors driving the pins of the SFD. Two IBM-compatible PCs (one for the tactile and one for the kinesthetic device) controlled the stimulus presentation, data collection and the movement of the SFD in space, using custom programmed applications.

The stimulus consisted of a stroke of the pin of the SFD. A single stroke consisted of a tactile motion in forward and backward direction of one metal pin starting from a center position of the SFD. The amplitude of the pin movement was 1mm in length for each direction with a velocity of 10 $mm*s^{-1}$. Stroke directions are defined by their radial deflection according to Figure 2. Subject's task was to discriminate the motion direction of two successively presented strokes on the finger pad and they had to report whether the second stroke was rotated clockwise or counterclockwise relative to the first stroke. A custom made input device consisting of a rotary switch was used for the subjects to intuitively enter their responses. If participants perceived the second stroke displaced in clockwise direction relative to the first stroke they were instructed to turn the rotary switch in a clockwise direction and vice versa.

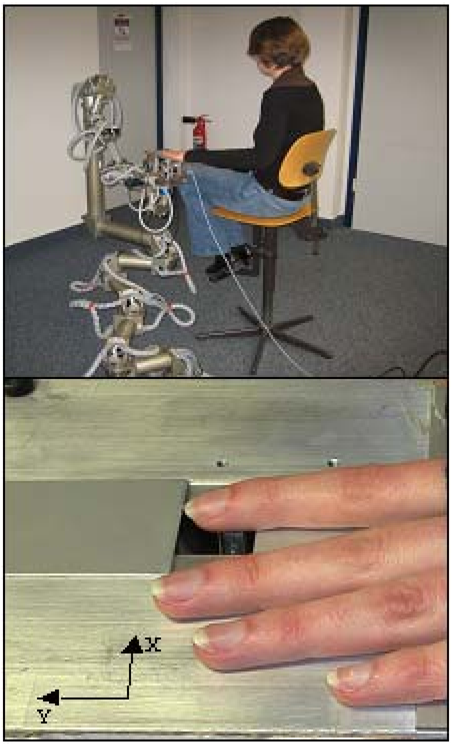

Figure 1: The upper panel shows a participant in front of the tactile/kinaesthetic device performing the experiment. Lower panel shows participant's hand on the cover plate of the SFD. The metal pin underneath the distal phalanx of the index finger is glued to the skin. For demonstrational purposes the cardboard build blinds were removed in this image and the hand was not fixated with adhesive tape.

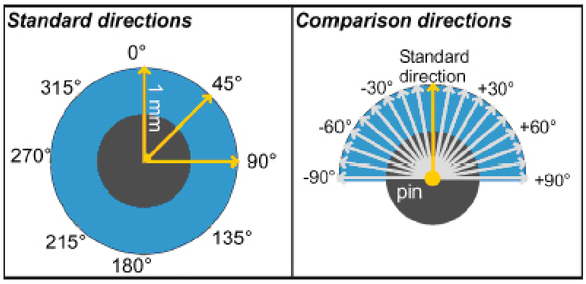

Figure 2: Possible directions of the standard and the comparison stimuli. The left panel of the figure shows the three standard directions (yellow arrows); the right panel shows the possible comparison directions (grey arrows) relative to the standard directions (yellow arrow).

2.3 Design and Procedure

Stroke directions consisted of three standard orientations, i.e., 0° (towards the finger tip) 45° and 90°. Each standard orientation was paired with a set of 19 comparison strokes ranging from ±90° around the standard direction in steps of 10° (Fig. 2). An 84%-discrimination threshold was measured for every standard direction using the method of constant stimuli in a two-interval forced-choice paradigm. The discrimination task was performed in three experimental conditions, which were "static", "active" and "passive". Each of the three experimental conditions comprised twelve repetitions of each standard and its 19 comparison strokes (the order of the intervals in which the pairs of strokes were presented was randomized) resulting in 684 trials overall. All the trials were presented in three blocks of 228 trials each. Each block lasted for about 20 minutes. Between each block there was a 5 minute break. So collecting data for one condition lasted a bit more then an hour per subject. All three conditions were tested for all subjects on different days. The order of blocks (i.e., static, passive, active) was randomized. The entire experiment was divided into three experimental days each consisting of 684 trials.

"Static" condition: A typical trial in the "static" condition was started by the participant turning the rotary switch of the input device. After a 2 s pause the sequential presentation of both pin-strokes (lasting 200 ms each) started. The two strokes were separated by a 500 ms pause, so there was no transient motion between the presentations of the two intervals apparent. Participants had to judge whether the second stroke was displaced in clockwise or counterclockwise direction relative to the first. After entering their response the next trial was initiated automatically (Fig. 3).

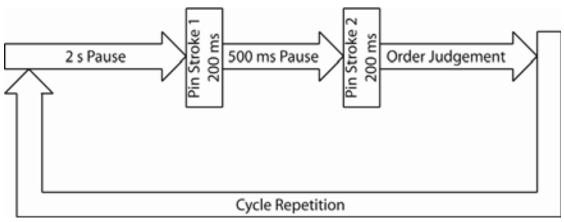

Figure 3: Flow-chart of a trial in the "static" condition. Both pin strokes followed a predefined trajectory in either the same or a different direction.

"Active" condition: In the "active" condition participants had to perform an active arm movement in addition to the direction discrimination task described above. For that purpose the SFD which was mounted on ViSHaRD10 had to be brought in its starting position which was close to the chest of the participant.

At this position, which was 35 cm in front of the midpoint of ViSHaRD10's work-space, white noise initiated via the earphones which was the auditory signal to start the trial. Participants then were instructed to push the SFD with a constant velocity (ranging from 0.2 and 0.3 $m*s^{-1}$) in a forward direction. The achievement of an adequate velocity within 25 cm from the starting position on was essential to trigger the output of the tactile pin strokes. If subjects produced a velocity that was not in this velocity range no stroke was initiated and subjects had to restart the trial. The output of the pin strokes was equal to the procedure in the "static" condition. After entering their judgment using the input device participants had to pull the SFD back to the starting position and the next trial was initiated (Fig. 4).

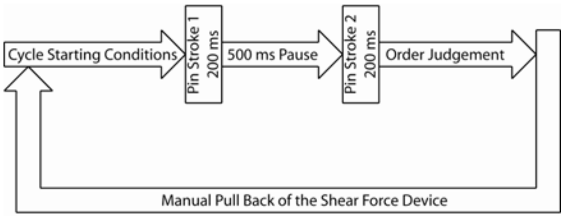

Figure 4: Flow-chart of a trial in the "active" condition. Both pin strokes followed a predefined trajectory in either the same or a different direction.

"Passive" condition: The "passive" condition comprised the same task as in the "active" condition; however the observer's arm-movement was passively guided by the kinesthetic robot arm. That is, ViSHaRD10 produced a force to passively move the participant's arm in a forward and backward direction. There was a maximum limit on the force that ViSHaRD10 could produce. The tactile strokes were generated after accelerating the subjects arm to a velocity of 0.3 $m*s^{-1}$ at the position 8 and 19 cm after the starting position resulting in the same stroke output duration as in the other conditions (Fig. 5). If subjects did not reach this velocity criterion in the given limits no stroke was elicited. This however actually never happened which is indicating that subjects did not actively hold or push the ViSHaRD10 robot arm.

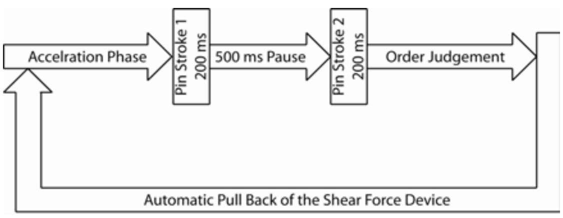

Figure 5: Flow-chart of a trial in the "passive" condition. Both pin strokes followed a predefined trajectory in either the same or a different direction.

3 DATA ANALYSIS

To analyze that data we plotted for each comparison stimulus the proportion of trials in which the comparison stroke was perceived as more clockwise compared to the standard stroke. From these plots individual discrimination thresholds were determined by fitting psychometric functions in form of cumulative Gaussians. For the fitting procedure we used the Maximum Likelihood approach build into the psignifit toolbox for Matlab [6, 7]. Thereby the 84% discrimination threshold was estimated for each subject in each condition and for each standard stimulus resulting in 9 thresholds per subject. The threshold was the only free fitting parameter, that is, the 50% point was fixed to the standard direction.

4 RESULTS

In figure 6 we plot the results for mean discrimination performance for the three conditions. Mean thresholds (for stroke direction) ranged in the "static" condition from 30.9° to 40.6°, in the "passive" condition from 50.2° to 60.8° and in the "active" condition from 58.5° to 69.2° (Figure 6).

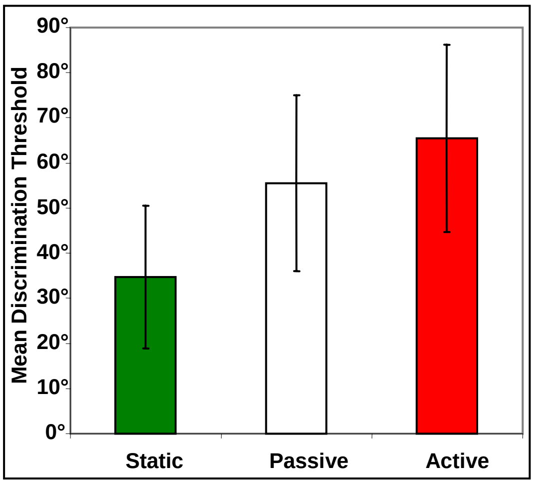

Figure 6: The diagram depicts the mean discrimination threshold of each experimental condition. The difference between "static" and "active" as well as "static" and "passive" condition is significant. Error bars depict the standard deviation.

Figure 7 depicts the mean thresholds of the three experimental conditions and the three standard directions. For a statistical analysis individual thresholds were entered into a 3x3 ANOVA with the factors Condition (static, passive, active), and Direction (0°, 45°, 90°). The main factor of Condition was significant. F=16.9, p<0.001. A subsequent t-test showed that there is a significant difference between the "static" and "passive" and between the "active" and "static" condition.

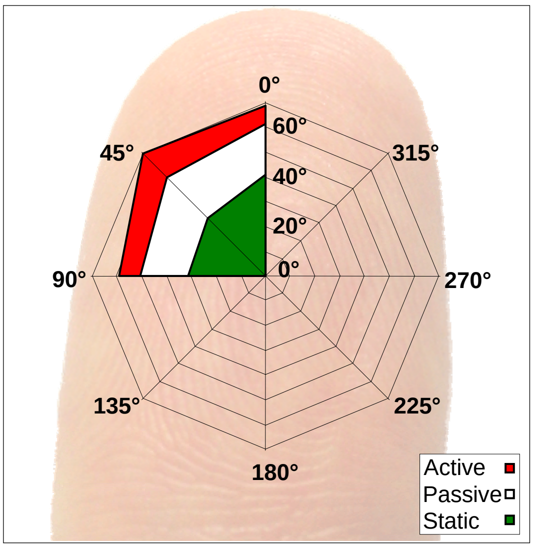

Figure 7: The diagram depicts the 84%- discrimination thresholds in the coordinates of the finger-tip (projected on the palm of the finger): 0° threshold in forward direction 90° threshold for a standard stroke to the left with 45° as an intermediate value. Thresholds are averages across participants.

There is no anisotropy for direction in any of the three conditions. That is, performance is equally worse with arm movement, independent of whether the stroke direction is inline with the direction of arm movement or not.

5 DISCUSSION

In the introduction we described two general hypotheses which we intended to distinguish: 1) Active movement itself is necessary for the suppressing effect, resulting in a general decrease in tactile sensibility. With this tactile suppression in the "active" condition is predicted to have exceeded that in the "passive" condition. 2) On the other hand we were arguing that tactile suppression in the "passive" condition might exceed tactile suppression in the "active" condition since a movement, which is executed passively is less predictable for the central nervous system. If prediction plays a role, the sensory consequences of self-produced movements could be canceled by the prediction and therefore tactile information should be less noisy, which would result in a lower threshold in the "active" condition.

As we have shown arm experimentally movement has a substantial effect on tactile discrimination. Tactile discrimination performance is worst if the arm is moved actively. It is best when the arm is held still. And we find an intermediate value if the arm of the observer is passively moved. Furthermore, no anisotropy for the direction of tactile discrimination was found. Therefore, our results are clearly only consistent with hypothesis 1 meaning that there is a general degradation of tactile sensibility when the arm is moved actively by the observer and there is no selectivity in direction for the reduction in sensitivity. Suppression of tactile sensation may play an important functional role, namely filtering out behaviorally unimportant tactile stimuli.

In agreement with our results Blakemore et al. [5] claimed based on experimental finding that self-produced tactile stimuli are perceived less intensely than tactile stimuli that are generated by an external source. Blakemore proposes a major role of the Cerebellum in predicting the sensory consequences of self-induced movements. The prediction can be taken into account to attenuate sensory information in the somatosensory cortex. This phenomenon described by Blakemore et al. shows participants acting on their own body (as during self tickling) and the observed suppression of self-generated tactile stimuli is located on one's own body. It is unclear however whether it is a general shut down of the tactile sensitivity in the region of the body where one touches oneself. For such a general shut down only a temporal prediction of when exactly I will touch myself is needed. Alternatively the reduction in sensitivity could also include the exact spatial properties of one person touching itself and it is the temporal/spatial properties of the tactile stimulation on the body that is predicted and suppressed.

In contrast to Blakemore we used externally generated, not self-generated tactile stimuli. Therefore, only the temporal aspects of the stimulation during active arm movement could have been predicted by the subject, but not the spatial aspects. If the perceptual system used temporal/spatial prediction for tactile suppression we should have observed an anisotropy in the direction of the arm movement, which should not have been present in the "still" condition. This is because when naturally exploring a texture a tactile stroke occurs in the same direction on the finger, as is the direction of the arm movement. We find no anisotropy and therefore conclude that tactile suppression is only based on temporal prediction and a general, spatial independent shut down of the tactile sensitivity.

Our results seem to be in line with the findings of Seki et al. [8]. Via neurophysiologic experiments they observed evidence for presynaptic inhibition, which suppresses cutaneous input to the spinal cord during voluntary movements in primates. The major sources of this inhibition are expected to be caused by descending central commands and peripheral inputs from afferent fibers, that is, input from other cutaneous areas, muscle spindle and tendon organ afferents [9, 10, 11, 12]. Furthermore, observations that suppression of afferent information during active movement precedes electromyographic onset, provide a hint for the dominant role of descending motor commands in generating presynaptic inhibition of afferent input [8]. While peripheral input is present in both - the "active" and "passive" condition - the descending central command is only present in the "active" condition, which explains the higher suppression of cutaneous input (i.e., higher threshold) in the "active" versus the "passive" condition.

One may argue that the decrease in sensitivity during arm movement (whether "passive" or "active") may not be coming from actively reducing the tactile sensitivity, but may come from adding noise to the system and therefore making the discrimination process more difficult. Such an additional noise may be the result of muscle signals disturbing the tactile information or of a different distribution of attentional resources during active or passive movement. Even though we cannot exclude this hypothesis at the moment, it seems unlikely that the cause of the increased thresholds is of attentional nature, because we used highly trained subjects. Furthermore, if additional noise was the reason for the increased thresholds, this additional noise source must be substantial as the thresholds increased almost by a factor of 2. One way of distinguishing between these two possibilities, i.e., actively reducing sensitivity vs. additional noise sources, may be to investigate the timing of the suppression effect. From the saccadic suppression literature we know that saccadic suppression can be observed already slightly before the actual eye movement is initiated [1] indicating active suppression. We will use the same strategy investigating discrimination performance just before the actual arm movement in further studies of tactile suppression.

Comparing our results with that found earlier we can make the following observations: In contrast to the results of Drewing et al. [2] who found an anisotropy in the discrimination thresholds with stroke direction our results do not suggest such a difference in discrimination performance. However, in agreement with our findings Keyson and Houtsma [13] also showed that discrimination thresholds seem to have equal levels for pin strokes in forward and sideward directions. There were two main differences between our study and that of Drewing et al. that might explain these different findings. The first is that we glued the subjects' finger to the metal pin in order to isolate perceptual cues to shear stroke and thereby excluding any cues resulting from the slip of the pin. The second difference is that participants in Drewing et al. were asked to lift the finger after the forward stroke of the metal pin to prevent them from feeling the backward stroke. Since the finger was glued to the pin in our study this was not possible. A stroke here contained always a forward and backward motion of the pin away from the center position, indication some direction, and back to the center. Feeling the forward and backward movement of a single stroke provides participants with additional information.

6 CONCLUSION

The purpose of this study was to shed light on the phenomenon of tactile suppression and the better characterize the interplay of tactile and kinesthetic perception. Therefore, we here investigated discrimination performance for the direction of lateral motion on the finger-tip using three experimental conditions manipulating the role of the arm movement. These conditions were “static”, where the arm was held still, “active” where the observer actively produced an arm movement, and “passive” where the observers’ arm was moved by the robot device.

In general we considered the existence of two hypotheses. The first hypothesis suggests a general decrease of tactile sensibility when the suppression is caused by the active movement itself, that is, by descending motor commands which cause an inhibition of ascending tactile information. This would result in a better performance in the “passive” compared to the “active” condition. The second hypothesis proposes the involvement of prediction. Here, an active arm movement and it’s sensory consequences would be predictable and could be canceled which would result in less noisy tactile information and thus resulting in a better performance in the “active” condition compared to the “passive” condition.

We showed that there is a decrease in tactile sensibility for direction discrimination during active arm movement relative to the condition where there was no arm movement while performing the discrimination task. That is, participants performed a tactile discrimination task best when no arm movement was required (“static” condition) compared to the “active” condition were their performance was worst. Only the change of discrimination threshold in the “static” versus the “active” condition reached significance. The loss of tactile sensibility appears to be independent from the movement direction of the stimulating metal pin. Results indicate that self-performed arm-movements decrease tactile sensibility significantly whereas the effect of externally generated arm-movements on the performance level seems to be lower even if the difference is not significant.

In summary in agreement with hypothesis 1 we found that participant’s performance in a tactile discrimination task drops significantly when they had to move their arm compared to a experimental condition were no movement was required during the discrimination task. It seems to be mainly dependent on the active movement itself since the decrease in the discrimination performance was less during a passively performed movement, were the arm movement was generated by a robot arm.

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REFERENCES

[1] J. Ross, M. C. Morrone, M. E. Goldberg and D. C. Burr, Changes in visual perception at the time of saccades. *Trends in Neurosciences,* 24(2):113-121, February 2001.

[2] K. Drewing, M. Fritschi, R. Zopf, M. Ernst and M. Buss, First evaluation of a novel tactile display exerting shear force via lateral displacement. *ACM Transactions on Applied Perception*, 2(2):118-131, April 2005.

[3] M. Ueberle, N. Mock and M.Buss, ViSHaRD10, a Novel Hyper-Redundant Haptic Interface, *Proceedings of the 12th International Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems*, 58-65, March 2004.

[4] S.-J. Blakemore, D. Wolpert and C. Frith, Why can't you tickle yourself?, *Neuroreport*, 11(11):R11-R16, August 2000.

[5] S.-J. Blakemore, D. Wolpert and C. Frith, Central cancellation of self-produced tickle sensation, *Nature Neuroscience*, 1**:**635-640, 1998.

[6] F. A. Wichmann, AND N. J. HILL, The psychometric function: I. Fitting, sampling, and goodness of fit. *Perception and Psychophysics* 63, 1293-1313. 2001a.

[7] F. A. Wichmann, AND N. J. HILL, The psychometric function: II. Bootstrap-based confidence intervals and sampling. *Perception and Psychophysics* 63, 1314-1329. 2001b

[8] K. Seki, S.I. Perlmutter, E.E. Fetz, Sensory input to primate spinal cord is presynaptically inhibited during voluntary movement, *Nat Neurosc,i* 6(12):1309-1316, December 2003.

[9] P. Rudomin and R.F. Schmidt, Presynaptic inhibition in the vertebrate spinal cord revisited, *Exp. Brain Res,* 129:1-37, October 1999.

[10] E. Jankowska, U. Slawinska and I. Hammer, Differential presynaptic inhibition of actions of group II afferents in di- and polysynaptic pathways to feline motoneurones, *J. Physiol.,* 542:287-299, May 2002.

[11] W. Janing, R. F. Schmidt and M. Zimmermann, Two specific feedback pathways to the central afferent terminals of phasic and tonic mechanoreceptors, *Exp. Brain res.*, 6:116-129, July 1968.

[12] J. C. Eccles, R. F. Schmidt and W. D. Willis, Depolarization of the central terminals of cutaneous afferent fibers, *J. Neurophysiol.,* 26:646-661, 1963.

[13] D.V. Keyson, A.J. Houtsma, Directional sensitivity to a tactile point stimulus moving across the fingerpad, *Percept Psychophys*, 57(5):738-744, July 1995.