

THE CONTRIBUTION OF PROPRIOCEPTION AND TOUCH TO THE PERCEPTION OF WEAK FORCES: PRELIMINARY RESULTS

Gabriel Baud-Bovy^{1,2}, Elia Gatti¹

¹*Faculty of Psychology, San Raffaele Vita-Salute University, Milan*

²*Italian Institute of Technology, Genoa, Italy*

gabriel.baud-bovy@hsr.it

Abstract

The general objective of this study was to test the contribution of touch to identifying the direction of a weak force (0.08 N) transmitted by a hand-held object. In the first experiment, we found that the performance did not vary when participants held the object with a distal or a proximal grasp. This negative result suggests that cutaneous receptor types that are unequally distributed between the phalanges involved in the two grasps played a limited role in this task. In a second experiment, we found that an ischemic block of the hand led to a marked decrease in performance. This observation suggests that signals originating in the hand provide important information about the direction of the force though it is difficult to know whether these signals have a cutaneous or proprioceptive origin since the block also affected the intrinsic muscles of the hand.

Both afferent and efferent signals contribute to force perception (reviews in Jones, 1986; Gandevia, 1996; Proske & Gandevia, 2009). In a previous study, we measured the minimum amount of force transmitted by a hand-held object needed to identify its direction (Baud-Bovy & Gatti, 2010). To focus on the properties of the proprioceptive system and minimize the contribution of touch in these experiments, the subjects maintained a firm grasp that insured that the mechanoreceptors would be strongly activated by the grip force, which was completely unrelated to the force that the participants needed to perceive. Still, it is possible that the small lateral force transmitted by the hand-held object might be encoded by the SA-I, FA-I and SA-II afferents in the volar aspects of the fingertips (Birznieks et al., 2001) and by the SA-II receptors near the borders of the nails (Birznieks et al., 2009).

The general objective of this study was therefore to test the contribution of touch in this task. In the first experiment, the participants grasped the object transmitting the force using either a distal grasp or a more proximal grasp. We hypothesized that the performance would be better with the distal grasp if mechanoreceptors played a role because the density of mechanoreceptors is largest at the fingertips (Johansson & Vallbo, 1979). The proximal grasp in particular did not stimulate the SA-II receptors near the borders of the nails. In the second experiment, we used an ischemic block at the wrist to block afferences from the hand.

Method

Experimental setup and procedure. The experimental setup consisted of an impedance-controlled 3-DOF haptic device (Omega, Force Dimension) equipped with a small 6-DOF force torque transducer (Nano-17, ATI Technologies) mounted between a custom-made nacelle and the spherical handle (diameter 1.5 cm) grasped by the subject (Fig. 1A). Thanks to the force sensor that measured the interaction force and controlled the stimulus intensity, the force was rendered with good accuracy and precision (root mean square error < 1.5 gr).

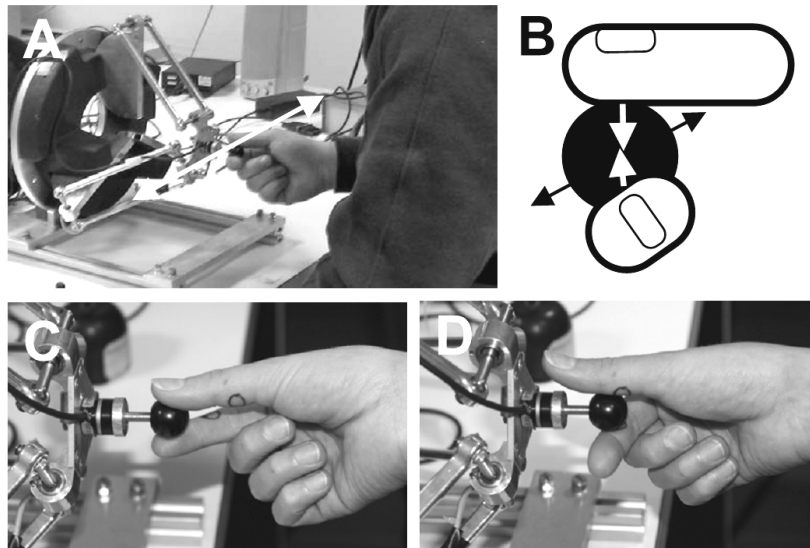


Fig. 1. A: Experimental setup. The white arrow indicates the direction of the force and movement. B: Schematic representation of the grip forces (white arrows) and stimulus (black arrows). C and D: Distal and proximal grasps used in the first experiment.

Participants grasped the spherical handle with their right hand and held a button box with their left hand. The elbow joint was flexed at 90° and aligned with the center of the workspace. After a familiarization period, participants were blindfolded and a double face tape was put on the handle to insure that participants would not release the handle during the experiment. Each trial started with the device bringing the subject's hand to the center of the workspace. Haptic guidance was obtained by progressively increasing the stiffness of an elastic force field (max stiffness = 1000 N/m). The stiffness was then progressively released to zero to avoid discontinuity with the following 3.0 s long loading phase where the force magnitude increased up to the desired level. Then, the force remained constant until the end of the trial. A more detailed description of the setup and of the trial structure can be found in Baud-Bovy and Gatti (2010).

The grasp experiment. Five university students (2 males) aged between 17 and 21 years participated to this experiment. The experiment was divided into two sessions. Participants held the device with a *distal grasp* involving the distal phalanges of the thumb and index finger in one session (Fig. 1C), and with a *proximal grasp* involving the middle phalanges of the same fingers in the other session (Fig. 1D). The grasp order was counterbalanced across participants. Each session included six blocks of 15 trials. At each trial, one of three possible forces (-0.08 N, 0 N and 0.08N) was presented and the task consisted in identifying the direction of the force. Each force was presented five times in a random order within a block. The participant responded by pushing the left button for a force direction perceived as oriented toward the left and the right button in the opposite case (forced choice).

The experimenter used a staircase procedure to measure the tactile sensitivity of the distal and proximal phalanges of the thumb and index finger of each participant with Semmes & Williams monofilaments (SWM), also called von Frey hairs. To start, the experimenter touched the skin three times with the weakest hair (SWM=1.65). If zero or only one contact was perceived, the following applications were conducted with the next thicker hair. If two or three contacts were perceived, the following applications were conducted with a weaker hair. The procedure ended after at least 6 reversals. The threshold was defined as the mean of the last four reversal points.

The Ischemic Block Experiment. The authors (43 years and 23 years), and one female graduate student (25 years) participated in the experiment. All participants repeated the experiment at least three times on different days. Each experiment included a control session without the ischemic block followed by a session with the ischemic block. Both sessions included a *static condition* where the participants were instructed to keep their hand immobile and a *dynamic condition*, where they were free to move the end-effector to feel the force better before giving the response. Each 20 minutes long session comprised two blocks of 10 trials in each condition, yielding a total of 40 trials. At each trial, a weak force was presented (± 0.06 N for the first repetition and ± 0.07 N for second and third repetitions of the experiment by S1, ± 0.08 N for S2 and S3) and the task was to identify its direction. The force direction was randomized within each block and the condition alternated between blocks. Participants held the device between the thumb and index finger of their right hand (Fig. 1A) and used their left hand to respond with a button box.

For the ischemic block sessions, a pediatric cuff was applied to the participant's wrist and inflated 100 mmHg above the systolic pressure. Tactile sensitivity of the thumb and index finger pads were monitored with von Frey hairs until it was completely lost, which took approximately 20-25 minutes. Tactile loss was accompanied by a loss of perception about the finger position, and a partial loss of the motor function. A small rubber band around the thumb and index finger prevented an accidental loss of the handle in this condition. The cuff was removed at the end experiment and about 15 minutes were needed to regain an almost normal tactile sensitivity.

Results

The Grasp Experiment

The force actually displayed by the device was -0.075 ± 0.013 N, 0.002 ± 0.012 N and 0.008 ± 0.012 N for the -0.08 , 0 and 0.08 N stimuli respectively (mean \pm standard deviation). In other words, it did not differ by more than 0.5 ± 1.3 g from the desired value. The percentage of trials where the direction of the 0.08 N stimuli was correctly identified was 68 ± 7 % for the proximal grasp, and 73 ± 12 % for the distal grasp. A paired t test indicated that this difference was not statistically significant ($t_4 = 1.1859$, $p = 0.301$). The average percentage of correct responses ranged from 57 % to 81 % depending on the subject (grand average: $70.5 \pm 9.8\%$). When the force was null, the percentage of rightward responses remained within the 95% binomial interval of confidence (i.e., 37-63 % for $N=60$ with $p=0.5$) for all but one subject (grand average: $53 \pm 14.3\%$).

A 2-way full-factorial repeated-measure ANOVA did not reveal any difference of tactile sensitivity between the phalanges of either finger or between the thumb and index finger ($p > 0.5$). The grand average threshold measured with von Frey hairs was 0.07 ± 0.02 g (all participants and phalanges pooled together).

The Ischemic block experiment

We found a marked decrease of the performances during the ischemic block sessions (see Figure 2). For all subjects, the performance under anesthesia did not differ significantly from chance level as it lied within the corresponding 90% binomial confidence interval (i.e., 30-70% for $N=20$, $p=0.5$). For the first subject, the difference was statistically significant between the two control and two anesthesia sessions (Tukey HSD, $P < 0.05$). The absence of an effect between the static and dynamic conditions in the control session was unexpected but this participant - the most expert one - reported being able to perceive the build-up of the

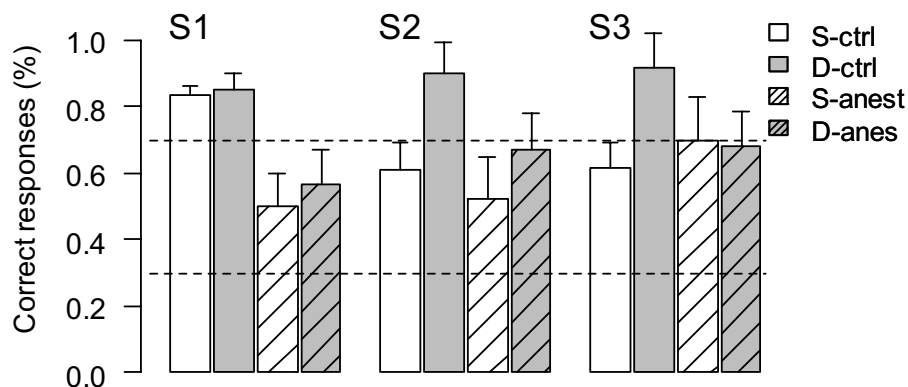


Fig. 2. Proportion of correct responses for each subject in the ischemic block experiment. The vertical bars denote the standard deviations and the horizontal lines mark the limits of the 90% binomial interval of confidence

force during the loading phase. For the second and third participants, the proportion of correct responses decreased markedly in the static condition of the control session, an observation that reflects the main finding of a previous study (Baud-Bovy & Gatti, 2010). For these two subjects, the performance in the dynamic condition of the control session was statistically different from the performance in all other conditions (Tukey HSD, $p < 0.05$).

Discussion

Changing the grasp did not affect the performance in the first experiment. This result suggests that the SA-II receptors near the borders of the nails did not contribute to the performance in this task. With respect to the mechanoreceptors located on the volar aspects of the phalanges, the evidence is less conclusive. First, it should be noted that the density difference between proximal and distal phalanges is most marked for FA-I (or RA) receptors (Johansson & Vallbo, 1979). The absence of effect suggests that these receptors did not provide relevant information in this task. The absence of effect does not however exclude a contribution of SA-I and SA-II receptors, which are more equally distributed across phalanges. Second, it is noteworthy that we did not find any difference when testing the tactile sensitivity of the distal and proximal phalanges with von Frey hairs. It might be possible that callouses on participant's fingertips might have somewhat compensated for the lesser density of mechanoreceptors in the more proximal phalanges. In any case, the lack of a significant tactile sensitivity different between the two phalanges suggest that the amount tactile inputs originating from the volar aspects of the finger did not vary between the two grasps, which invalidates in part the rationale for this experiment.

In the second experiment, we found that performance deteriorated markedly during the ischemic block sessions. While the intention was to suppress tactile sensitivity, this technique also led to a loss of proprioception and motor function, which can be related to the effect of ischemia on intrinsic muscles. The observed decrease of performance reflects the importance played by the distal aspects of the hand without allowing one to precisely pinpoint which one contributed most. More selective techniques such as a nerve block might be needed to isolate, for example, the contribution of cutaneous finger afferents (e.g., Augurelle et al., 2003). The increase of performance observed when moving the arm in the control sessions confirms the results of the previous study, where we found the identification threshold for the direction of force was about 10 g (0.1 N) in the static condition and about 5 g (0.05 N) in the dynamic condition (Baud-Bovy & Gatti, 2010). Unfortunately, the results of this experiment did not allow us to ascertain the origin of the performance increase during movement in the

control condition. However, it is noteworthy that this performance increase must reflect an increased sensitivity of our sensory apparatus because the force remained constant during movement. In other words, such an improvement cannot be explained by an external factor such as the presence of additional inertial cues (see Brodie & Ross, 1985, for other possible explanations). It is also unlikely that this improvement reflects a property of the tactile inputs because other studies have found a decrease of tactile sensitivity during movement, the so-called tactile suppression phenomenon (Milne et al., 1988; Vitello et al., 2006).

Acknowledgements

We thank the Dr. Paolo Marchettini from the Pain Center of the San Raffaele Hospital for his help with this research and Eleonora Bartoli who helped with the collection of the data and volunteered to participate to the second experiment. This research was sponsored by the IIT Network Research Molecular Neuroscience Unit of San Raffaele Foundation, Milan, Italy.

References

- Augurelle A.-S., Smith, A. M., Lejeune T., Thonnard J.-L. (2003) Importance of Cutaneous Feedback in Maintaining a Secure Grip During Manipulation of Hand-Held Objects. *The Journal of Neurophysiology*, 89: 665–671.
- Baud-Bovy, G., Gatti, E. (2010) Hand-Held Object Force Direction Identification Thresholds at Rest and during Movement. In A. Kappers, J. van Erp, W. Bergmann Tiest, and F. van der Helm (Eds.), *Haptics: Generating and Perceiving Tangible Sensations, Lecture Notes in Computer Science, Volume 6192*. Springer Berlin / Heidelberg, pp. 231-236.
- Birznieks, I., Jenmalm, P., Goodwin, A. W., Johansson, R. S. (2001) Encoding of direction of fingertip forces by human tactile afferents. *Journal of Neuroscience*, 21:8222–8237.
- Birznieks, I., Macefield, V. G., Westling, G., Johansson, R. S. (2009) Slowly Adapting Mechano-receptors in the Border of Human Fingernail Encode Fingertip Forces. *The Journal of Neuroscience*, 29, 9370–9379.
- Brodie, E. E., Ross, E. H. (1985) Jiggling a Lifted Weight Does Aid Discrimination. *The American Journal of Psychology*, 98, 3, 469-471.
- Gandevia, S. C. (1996) Kinaesthesia: roles for afferent signals and motor commands. In L.B. Rowell and J. T. Sheperd (Eds.), *Handbook of physiology, section 12*. New-York: Oxford University Press, pp. 128-172.
- Johansson, R. S., Vallbo A. B. (1979) Tactile sensibility in the human hand: relative and absolute densities of four types of mechanoreceptive units in glabrous skin. *Journal of Physiology (London)*, 286:283-300
- Jones, L. (1986) Perception of Force and Weight: Theory and Research. *Psychological Bulletin*, 100, 29-42.
- Milne, R. J., Aniss A. M., Kay N. E., Gandevia, S. C. (1988) Reduction in perceived intensity of cutaneous stimuli during movement: a quantitative study. *Experimental Brain Research*, 70, 569-576.
- Proske, U., Gandevia, S. C. (2009) The kinaesthetic senses. *Journal of Physiology (London)*, 587(17):4139-4146.
- Vitello, M. P., Ernst, M. O., Fritschi, M. (2006) An instance of tactile suppression: Active exploration impairs tactile sensitivity for the direction of lateral movement. *Proceedings of the EuroHaptics 2006 International Conference*, pp. 351-355.