



THE INFLUENCE OF TACTILE FEEDBACK ON HAND MOVEMENT ACCURACY

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ABSTRACT

Purpose. This study aimed at measuring the reaction of the hand when tactile feedback was impaired in upper extremity motor performance in order to empirically evaluate how precision was affected during visually controlled hand and arm movement. **Methods.** 26 right-handed young male adults were tested with the use of a line tracking task by means of Schuhfried's Vienna Test System. Tactile feedback during line tracking task was impaired by the use of different gloves: a surgical latex glove, a rubber glove and a thick work glove made of soft animal leather. **Results.** The results found a strong relationship between hand movement accuracy and the degree of tactile impairment; no significant relationship was found between tactile impairment and movement speed. Limiting tactile feedback was found to influence motor task accuracy during local wrist movements (using only the carpal and palm joints), while tasks that allowed global movement (both wrist and forearm) were found to have accuracy influenced only when tactile feedback was highly impaired (line tracking with the thick leather glove). **Conclusions.** The results have indicated that the role of tactile feedback on accuracy during visually-guided precision movement is far greater than previously reported.

Key words: tactile feedback, movement precision, motor control

Introduction

Precision is the ability to make highly controlled movement adjustments to improve a preconceived aim, particularly in tasks that demand a high degree of coordination [1, 2]. Movement accuracy, speed and variability are important aspects of motor coordination and influence the quality of controlled movement. The different cause/effect relationships of these parameters determine the speed and precision level of a given motor action [3]. Movement accuracy has been reported to be crucial in accomplishing tasks by the majority of voluntary motor actions [1]. Whether a movement can be precisely controlled is decided by the accuracy of the control mechanisms that are involved in a corrective feedback loop: sensory input, central processing capacity, timing and motor output [2, 4]. The entire process of integrating information from multiple inputs is responsible for both anticipatory and on-line motor control, and this integration process is assumed to be the basis of movement adaptability [5]. Sensory information from cutaneous, proprioceptive and visual afferents is essential for skilled movements of the upper extremities (grasping, reaching for an object, etc.). Visual feedback of the hand contributes to the on-line control of reaching throughout the full extent of movement, even during relatively fast upper extremity actions [6]. Previous findings found evidences that vision and proprioception contribute differently to kinematic planning

and solving inverse dynamics [7]. Visual feedback control might steer the hand to maintain a predetermined visual path, making corrective adjustments, while sensory feedback seems to indicate the position of the hand and its deviations from a desired trajectory [8]. Previous studies on adaptation assume that the motor system does attempt to maintain preferred kinematic trajectories, such as straight-line paths [9, 10]. Although information on the position of the hand is available from both visual and non-visual sources, the role of vision has been also considerably emphasized in some studies [1, 11]. It has been suggested that sensory feedback from vision influences both motion and position in the initial as well as final phase of hand movement [8]. The role of other sensory information on the speed and accuracy of visually constrained movements is still not well documented, as well as the relationships between different sensory inputs during precise hand movement. Although the tactile feedback mechanisms involved in the on-line control of hand movements are still not clear, some experiments indicated their important role in the successful transmission of precise information on velocity [12]. Tactile information has been shown to play an essential role in the regulation of grasping force [13]. Experiments on the influence of cutaneous feedback on hand grip have shown intact sensory feedback to be crucial for predictive grip force regulation [14]. A complete elimination of tactile feedback by local digital anesthesia produced severe deficiencies in the control of the grip force in object manipulation tasks [15, 16]. However, there is still no clear information on the relationship of sensory-motor coordination and a partial lack of the

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tactile information from fingers during manipulative actions requiring speed and accuracy. An interesting study by Romano et al. has shown a prolonged reaction time in the absence of sufficient tactile feedback [17], and another study has pointed to unnecessarily high grip force of an object's surface due to low levels of tactile input [18].

In the present study we measured the response of the hand to tactile feedback impairment during upper extremity motor performance in order to evaluate the contributions of tactile feedback during the on-line control of visually controlled hand movements. One common example when tactile information is limited is when using gloves; therefore, in this experiment we used three different kinds of gloves to analyze what tactile effect they have on movement speed and accuracy. The results are expected to highlight the role of sensory input from tactile receptors on hand movements requiring precision.

Material and methods

A group of 26 right-handed young male adults aged 22.4 ± 2.7 years took part in the experiment in accordance to the guidelines from the Bioethical Board of the Academy of Physical Education in Katowice, Poland. All participants provided informed consent but were kept unaware of the true purpose of the experiment. The level of psychomotor performance was evaluated by the use of selected tests from a computer-aided psychological diagnosis system, the Vienna Test System (VST, Schuhfried, Austria). A motor-performance test battery (the Motorische Leistungsserie, MLS) from VST was used to measure the speed and accuracy of hand and arm movement. The MLS is a battery of tests providing a detailed examination of fine motor abilities (Fig. 1). The apparatus consists of a $300 \times 300 \times 15$ mm work panel covered with holes, grooves and contact surfaces. A special pen is attached to each (left and right) edge



Figure 1. The MLS device from VST



Figure 2. The shape of the VTS full length tracking task – hand/arm performance from the left to the right side



Figure 3. The shape of the VTS short tracking task – hand performance from the left to the right side

of the work panel. In this experiment, hand and arm movement precision was analyzed by the use of a unilateral line tracking task with the right pen (for the right, dominant hand). The task was to track an outlined groove with the pen as quickly and accurately as possible – without any contact with the groove's outer walls. Contact with the wall was recorded as a performance error. The speed and the accuracy of hand/arm performance were measured by the following variables: the time to complete the task, the time of the errors and the number of errors. Only the dominant (right) hand of each participant was tested.

The experimental design included two variants of the outlined task. In the first variant, each participant was seated comfortably at the work panel. The tested arm was free to move in any direction (no elbow support was provided) in order to complete the line tracking task. The entire length of the tracking groove was used in this tracking task (Fig. 2). In the second variant, each participant was also seated comfortably at the work panel, but arm movement was restricted by stabilizing the elbow and forearm on the table. In such conditions only radial movements – by the carpal and palm joints – were allowed to be used to complete the tracking task. The length of the tracking groove was shortened to adjust for the use of the restraints (Fig. 3) as well as to allow for a comparison of both line tracking variants (a short track and a long track) by differentiating the influence of tactile feedback on movement speed and precision during local and more global upper extremity movements.

Both variants of the test were performed by the participants four times, each time with different situations

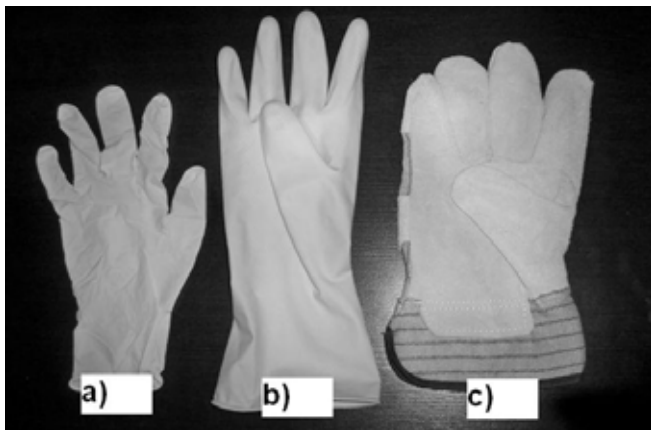


Figure 4. Gloves used in the experiment:
 a) chirurgical latex glove, b) rubber glove,
 c) thick work glove made of soft animal leather

of tactile perception: using their bare hand or wearing a chirurgical latex glove, a rubber glove or a thicker work glove made of soft animal leather (Fig. 4). To eliminate the impact of learned strategies (motor learning) on subsequent tests, the participants were randomly divided into two groups of 13 individuals; the first subject in the first group started the tests with his bare hand while the other group started testing with a glove. The full length tracking task was performed first by all participants. The trials were performed with two-minute pauses in order to eliminate the effects of fatigue. The total amount of errors (how many times the participant touched the walls of the groove with the pen) during the line-tracking tasks as well as the total time of error (the length of time being outside of the groove) were recorded as indicators of movement precision. The obtained data were analyzed with standard descriptive statistics methods. Chosen procedures enabled to describe the normality of the distribution of data obtained in the experiment. One-way analysis of variance (ANOVA) for repeated measures was used to determine the influence of tactile feedback on hand/arm movement accuracy. The chosen level of significance was fixed at $p \leq 0.05$. Fisher's Least Significance Difference (LSD) method during post-hoc testing was also used for a more detailed analysis of the differences among the movement parameters. All statistics were calculated with Statistica ver. 9.1 software by Statsoft (USA).

Results

When subjected to variance analysis ($p \leq 0.05$), the results indicated that limited tactile perception influenced accuracy when performing the full length tracking task. Significant differences in accuracy, measured by the number of errors, were found among the various tactile impairment trials. The largest amount of errors were made when the subject was burdened with the largest degree of tactile impairment (the thick work glove, see Fig. 5). A significant relationship was also found

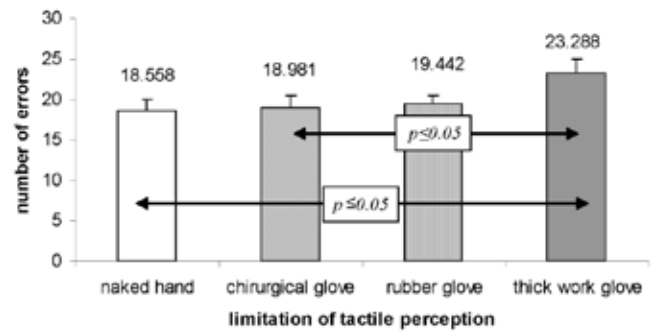


Figure 5. The influence of tactile feedback impairment on the number of errors in the full length tracking task (error bars show standard error)

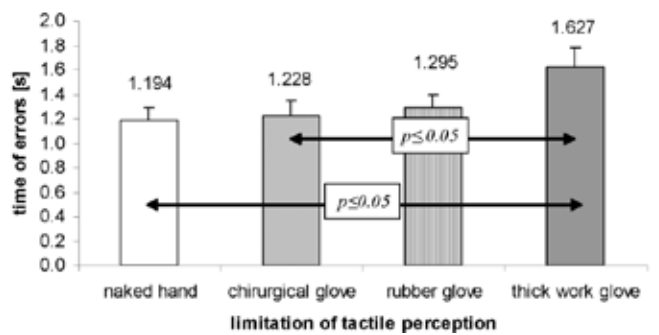


Figure 6. The influence of tactile feedback impairment on the time of error in the full length tracking task (error bars show standard error)

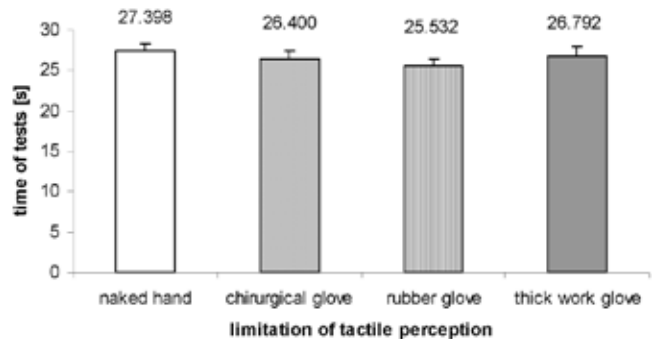


Figure 7. The influence of tactile feedback impairment on the time of the test in full length tracking task (error bars show standard error)

between tactile impairment and the time of error. In the full length tracking task, the total time of error was more prolonged when participants wore the thick work glove (Fig. 6). No significant differences were found in the time it took to complete the task in relation to the degree of tactile impairment (Fig. 7).

When the short line tracking task was performed (with a stabilized arm and elbow), the results also indicated an evident influence of tactile perception impairment on the quality of motor performance ($p < 0.001$). Similar to the full length tracking task, no differences in the time of task completion were found among the various degrees of tactile impairment ($p > 0.05$). In the short tracking task, significant differences in movement accuracy were recorded by the number of errors

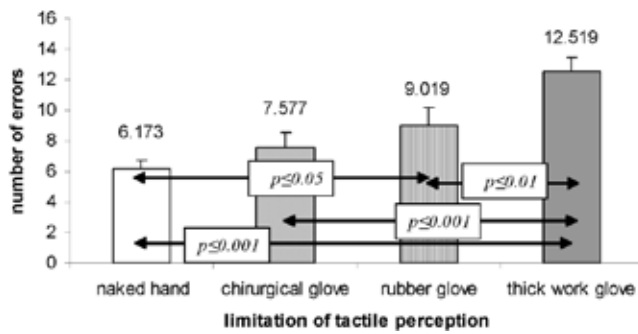


Figure 8. The influence of tactile feedback impairment on the number of errors in the short tracking task (error bars show standard error)

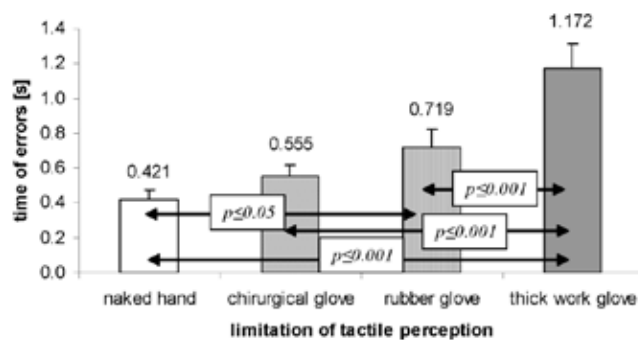


Figure 9. The influence of tactile feedback impairment on the time of errors in the short tracking task (error bars show standard error)

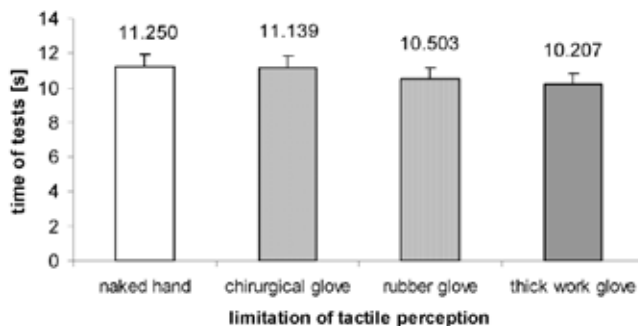


Figure 10. The influence of tactile feedback impairment on the time of the test in the short tracking task (error bars show standard error)

and the time of error not only when using the work glove, the bare hand or surgical glove, but also between the bare hand and rubber glove, and between the rubber glove and the thick work glove (Figs. 8–10).

Discussion

The results of this study only partially corroborated previous findings on the relationship of tactile feedback and motor coordination. It was previously suggested that during precise movement when information from many different sensory sources is involved, the role of visual feedback is of particular importance [4, 11, 19]. It was also stated that minimum variance integration is an important component of sensorimotor processing

[20]. Our results have indicated that limiting tactile information negatively influences movement quality, where a decline in accuracy is coupled to a rise in the degree of tactile impairment, even despite full visual control of the movement. The relationship between tactile feedback and performance accuracy was clearly visible during localized hand movements, even when the fingers are minorly impaired. In the short tracking task, the differences among the results of different tactile conditions were much greater than in the full length tracking version – movements that engage longer kinematic chains (hand/forearm/arm movements). The relationship between tactile feedback and final accuracy were significant only when the hand had a high degree of tactile impairment. These results seem to indicate a more pronounced role of tactile information during localized hand performance (fine movements) in comparison to more global arm movements, which incorporate more muscles and joints. In some previous studies, tactile feedback improved movement accuracy and control during tactile precision-grip tasks [21]. These results seem to highlight the special importance of tactile receptors in the on-line control of fine movement. It is possible that in gross motor tasks the lack of feedback from tactile receptors may be compensated by other sensory inputs (vision, proprioception of the joints and muscles, etc.) to process the corrective mechanisms involved in the closed-loop control [4]. Taking into consideration that visual information takes longer to process in the voluntary feedback loop than in the kinesthetic loop [22], it seems quite logical that individuals would use non-visual sources of information on movement accuracy in the short tracking line task. It was previously proven that in time-restricted movements there is a trade-off between the time allotted to gather visual information, action planning and motor execution [23]. Our results support these findings and suggest tactile information plays a special role in the motor accuracy of hand movement.

Previous studies have indicated that tactile perception is crucial for optimal speed and movement accuracy when a visual cue of movement is not available. In such conditions, a host of tactile receptor information can allow an individual to maintain an optimal movement speed without losing a high level of accuracy [24]. In visually controlled tasks, the role of vision was previously suggested as critical in both movement speed and accuracy. Feedback information from the visual sensory system was assumed to dominate over information from the other senses during the process of sensory integration. Vision was assumed to be crucial in the reduction of movement error [3, 4]. Our results have suggested on-line, afferent feedback from tactile receptors in the control of movement accuracy plays an important role despite full visual control of hand movement. However, we found no such effect on movement speed. Saunders and Knill [8] reported that visual

cues of both hand movement trajectory and hand position influence all phases of movement only in specific conditions, such as when there is a lack of other sensory inputs and when vision is the only sensory contributor for precision performance (this experiment was conducted in virtual reality). Experiments on total visual impairment and full vision found that an activation of the visual cortex could occur in situations of no visual control not only in blind but also sighted participants when learning a fine motor task [6, 19, 25]. These and other results confirm that in human motor control, many sources of sensory information may be simultaneously involved while control processes can dynamically adapt to task conditions. Position estimates, used in movement vector planning, were suggested to rely mostly on visual input, whereas estimates used to compute joint-based motor command relied more on proprioceptive signals [7]. This suggests that when estimating the arm's position, the brain selects different combinations of sensory inputs. However, our results on the length of the test contradict the results of Kinoshita [18], who reported differences in the time of the task in relation to the material of the gloves that were used.

The main limitations of this study were the laterality of the limbs when performing the task as well as an asymmetry of the results, caused by the fact that the tasks were performed only with the dominant hand. Another aspect to consider would be the type of glove and material used, the weight of the glove or the degree in how it adheres to the hand. Another interesting research issue related to the relationship of tactile feedback and movement precision is what problems they pose in terms of motor learning. Another research aspect not analyzed in this study were individual differentiations – this issue aspect requires research on different sample population, such as athletes from different sports. It seems, therefore, that the research question analyzed in this study warrants further research.

Conclusion

In conclusion, our results have indicated that the role of tactile feedback in the accuracy of hand movement may be far greater than previously believed and is worth further research in variable tasks conditions. Limitations of tactile feedback seem to influence movement accuracy while no effect was found on movement speed. This suggests that the time control of movement execution probably relies on sensory inputs other than tactile ones and/or on the sensory integration process. However, our experiment proved that in visually controlled tasks the role of tactile information is important in performing accurate, aimed hand movements.

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