Muscular exercise improves knee position sense in humans

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Abstract

To determine how position sense depends on the functional state of the receptors involved, we assessed the accuracy of knee position sense before and after a moderate exercise on a cycle ergometer. Measurements were done on 32 healthy subjects with four protocols combining two tasks (intramodal: using the contralateral leg, and crossmodal: using a scheme of a leg on a screen) and two ways of positioning (active and passive). Results showed an improved position sense after exercise with the intramodal protocol combined with active positioning of the reference leg. Whatever the mechanisms involved, enhanced motor performances after exercise can be due not only to improved mechanical properties of the muscles but also to better kinesthetic sensibility.

Keywords: Kinesthesia; Position sense; Exercise; Muscles; Knee; Proprioception

Position sense is generally defined as the ability to assess respective limb’s position without the assistance of vision. Position sense is governed by central and peripheral mechanisms mainly muscular receptors, and also tendinous, articular, and cutaneous receptors. The respective roles of these various sources of afferent information have been debated, but it is now recognized that muscular receptors have the most important part in the elaboration of limb position sense [9]. This role of muscular receptors indicates that modifying the functional state of the muscles can affect the precision of position sense.

Studies have shown that kinesthetic sensibility is decreased by fatigue [14,16] and increased by long term physical practice [2–4]. Muscular exercise also improves general motor capabilities but its action on the sensory systems has not been studied. The aim of our study was to determine how physical exercise may lead to changes in perception of limb position, i.e. changes in accuracy of position sense. Our hypothesis was that the accuracy of position sense would be all the better as the muscles worked under better conditions and that this increase in accuracy could be partly responsible for the increase in motor capabilities. Such an increase may be due to a better proprioceptive feedback (for instance [6]) but may also act indirectly by leading to a better motor imagery. We know indeed that motor imagery is important for motor representation and action (review in [8]) and that mental practice, i.e. imagining movements, facilitates performance [5]. Moreover, as stated by Mitchell [12] ‘motor imagery seems dependent on cross-modal matches between kinesthesia and vision… rather than on kinesthesia alone’. This is the reason why we distinguished intramodal evaluations, which are purely kinesthetic, from more cognitive ones, which include vision and need information transfer between a sensory modality (kinesthetic) to another one (visual). Normative data obtained through these two kinds of protocols have been published [15]. In addition, we studied positioning of the reference leg under both passive and active conditions. Indeed, position sense is better if the reference leg is positioned by the subjects themselves [13], so exercise could then entail more or less marked effects according to the positioning mode. In each case, we compared recordings before and after a moderate exercise on a cycle ergometer. Measurements were done at the knee joint.

Participants were all healthy university students without any neurological, muscular, or orthopedic disorder that could interfere with the results. These 32 subjects included 15 women and 17 men aged on average 24 years (±1.6). None of them practiced any sport activity on a regular basis. Twenty-eight among the 32 subjects used their right legs preferentially.

The subjects were comfortably seated and could not see
their legs. The task consisted of matching the position adopted actively or passively by one leg with the contralateral leg (intramodal task) or with a visual display of the lower limb segments on a screen (crossmodal task). Two factors were thus analyzed. The first was the mode of positioning, active or passive. Active means subjects had to place their right leg in a position of their choice exploring the widest articular range (from full extension to full flexion). Passive means the experimenter moved the subject’s leg. The second factor was the number of sensory modalities involved in the evaluation. Intramodal means the evaluation was done by only the kinesthetic modality. This task was called KK for Kinesthesia-Kinesthesia. In this task seven subjects used a passive positioning mode (KKp) and ten, an active one (KKa). In the crossmodal evaluation, two sensory modalities were involved: Kinesthesia and Vision. In this task, called KV, the subjects had to modify the knee angle shown on the screen until it corresponded to the angle of their own leg. Eight subjects used a passive positioning mode (KVp) and seven, an active one (KVa). We used the apparatus shown on Fig. 1.

Exercise consisted of pedaling during 10 min on a cycle ergometer. Our objective was to obtain warm-up without any fatigue, so the subjects had to pedal at their own sustained and regular rhythm without any imposed cadence. Only the leg whose position was to be evaluated (reference leg) was used for pedaling. To get the subject used to the task, some preliminary trials were done in the same conditions as the definitive recordings. These definitive recordings contained two series of 15 measurements for each subject, one before exercise and one immediately after. Fifteen is a large enough number for statistical analyses and a larger number, which requires a longer recording time, could have induced fatigue effects.

The principle underlying the measurement of the knee angle was to convert flexion and extension movements into resistance variations. According to the task, one or both legs were equipped with a goniometer comprising one potentiometer and two articulated splints fastened to the legs in such a way that the axis of the potentiometer corresponded to the axis of the knee joint. A computer was used to record the angles and to compare them with reference values. Precision of goniometers was about one degree. Errors of the participants’ estimations were calculated through the absolute values of the differences between the real angles and the estimated ones.

To determine how the amplitude of errors varied through a series, we systematically did correlation analyses between error amplitude and serial rank of the recordings. Global accuracy of evaluations was calculated by comparing, for each protocol, the 15 measurements before exercise and the 15 after exercise. Comparisons were performed by Student’s t-test when the conditions for using parametric tests were fulfilled, or by Mann–Whitney U-test or Wilcoxon test in the other cases. In all cases, results were considered significant when associated probability was lower than or equal to 0.05.

Because repetition of assessments could have lead to a learning effect or a fatigue effect, we first analyzed the evolution of error amplitude as a function of the serial rank of the evaluation. Among the 64 series, only six showed a significant positive correlation corresponding to a slight decrease in accuracy (one series for KVa, KVp, KKa and three for KKp). No significant negative correlation was found in any series of recordings. Thus the serial rank of the measurement has no global incidence on the accuracy of position sense.

Fig. 2 shows the influence of exercise for each protocol; mean errors for all subjects are reported.

For the KK task in passive positioning, the mean errors for all seven subjects (absolute values of difference between real angles and estimated angles) were compared before and after exercise.
after exercise in each recording series (Fig. 2, KKp). Statistical analysis (paired t-test) showed that the global mean before exercise (5.6±2.3°) did not differ from the one after exercise (5.4±2.3°). Thus, for this protocol, the exercise did not globally improve the knee position accuracy. Among these seven subjects, a significant decrease in errors (P = 0.019) was found for only one subject (7.6° before and 3.8° after exercise). For active positioning (ten participants), paired t-test showed a significant (P = 0.03) decrease in errors after the exercise, from 6.8±3° to 4.7±2.3° (Fig. 2; KKa). The analysis of the individual results showed an improved estimation for seven subjects among the ten, and a significantly increased accuracy for five of them. Subjects performing better after exercise were those showing the worst results before exercise. Indeed there was a significant positive correlation (r = 0.68, P = 0.028) between the gain of accuracy due to exercise and the amplitude of initial errors.

The second task analyzed was the crossmodal KV task. For passive positioning, global results (Fig. 2, KVp) for the eight subjects show that the mean difference in the accuracy of assessment did not differ significantly before (9.8±2°) and after exercise (7.8±2.1°); the associated probability was P = 0.35. Individual results show that among these eight subjects, only one significantly improved accuracy after exercise. For active positioning of the reference leg, the global means of the seven subjects did not significantly differ after exercise (8.0±3.2°) and before exercise (7.8±3.8°). None of the seven subjects presented significant changes in accuracy after exercise.

Thus the accuracy of knee position sense was improved after a moderate muscular exercise. This improvement was observed in the case of intramodal evaluation (KK) and only with active positioning of the reference leg. Before considering how these improvements can be explained, we will discuss the influence of the serial rank.

If we had observed better performances at the end of the series of recordings, such an improvement could have been due to learning effects linked with habituation to the task or the apparatus, in spite of the systematic preliminary trials. Indeed rehearsal by itself can in some cases lead to improved performances [11]. Conversely, accuracy could have decreased, because of fatigue effects, either physical (in particular for protocols with active positioning) or attentional. Yet, we observed no significant decrease in error amplitude and observed a significant increase at the end of recording series in only six among 64. This means that, as already observed [4], there is no learning effect and globally no appearance of fatigue when the number of recordings increases. Furthermore, this absence of performance variations within the series suggests that rehearsal does not induce changes in error amplitudes from one series to the next one. Thus, the results obtained, when significant, were not due to fatigue or learning effects.

Also, the largest increases in accuracy after exercise were those of the subjects with the worst performances before. It seems that the subjects with accurate assessments before exercise had already reached their maximal performances, which could not be further improved.

The recordings were made by using the right leg as the reference leg whatever the lower limb preference of the subjects (four among 32 used preferentially the left leg). This difference among the subjects cannot affect the validity of the results as the comparisons were done before and after exercise always for the same (right) leg.

That improved accuracy was not observed in the KV task (crossmodal evaluation of the position) means that exercise does not affect much the central processes. In fact, this task requires information processing much more complex (crossmodal transfer from Kinesthesia to Vision) than that of the intramodal KK task, for which an increase in accuracy was observed after exercise. Indeed crossmodal transfer increases error amplitudes [4,15]. The improvements observed in the KK task with an active positioning could exist in the crossmodal protocol but they would be masked by the largest errors occurring in this condition. Whatever its cause, this lack of improvement of accuracy in the crossmodal kinesthetic-visual task shows that any improvement of general motor performance due to a better position sense cannot be brought by enhancing motor imagery in the way hypothesized in the introduction.

The other factor playing an important role is how the reference leg is positioned, i.e. actively or passively. That active positioning was required for improved accuracy shows that exercise brings about changes on processes that are better represented in active than in passive mode. Such processes may be either peripheral or central. The peripheral receptors providing information to the central nervous system and differently involved in active and passive modes are essentially the tendinous and neuromuscular ones. Several factors linked with exercise may affect these receptors: better visco-elastic properties of muscular tissue, enhanced oxygenation, and increased body temperature because of vasodilatation [1]. Such effects may improve the functioning of the receptors involved and thus the kinesthetic sensibility. For cutaneous receptors, increased temperature decreases the thresholds and thereby improves tactile sensibility [7]. The effects of exercise may also be explained by central factors and particularly those concerning the motor command. Indeed the muscular response to a given command probably differs after exercise; it could be affected by a modification of either corollary discharges, likely involved in position sense [10], or fusimotor commands and then spindle sensitivity.

Our results show that position sense is improved after a moderate muscular exercise. This enhancement was observed with a kinesthetic evaluation mode and an active positioning of the reference leg. These original data therefore show that moderate exercise, which clearly improves muscle performances, can also act on the sensory systems by improving kinesthesia. The well known improvement of motor performances after exercise could then be due not
only to improvement of mechanical properties of muscular tissue but also to better kinesthetic sensibility.