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Proprioception: Bilateral inputs first

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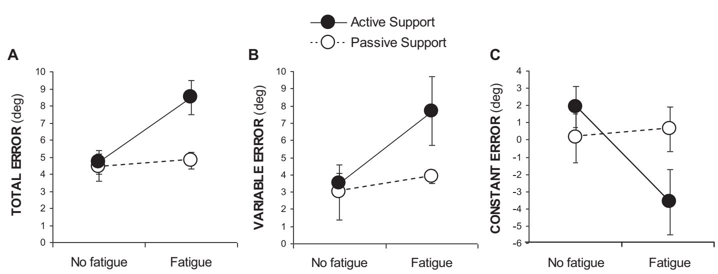
HIGHLIGHTS

- ► Proprioceptive weighting gives priority to bilateral over unilateral inputs.
- ► The fatigue effect is stronger in bilateral muscle contractions.
- ► Effects of muscle fatigue are weaker in passive relative to active joint position sense.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study focused on assessing whether the effects of muscle fatigue on joint position sense are dependent upon the unilateral or bilateral nature of proprioceptive inputs. To this aim, a group of young adults performed an active contralateral concurrent ankle matching task in two conditions of support of the reference limb (active vs. passive) and two conditions of fatigue of the indicator limb (no fatigue vs. fatigue). In the absence of muscle fatigue, results failed to evidence significant difference of matching errors between the active and passive conditions of support. However, in the context of muscle fatigue, increased matching errors were observed in active but not passive condition of support. The deleterious effects of muscle fatigue on joint position sense were therefore dependent upon the laterality of the proprioceptive inputs related to muscle contraction. These results suggested that sensory weighting for proprioception gives priority to inputs available bilaterally over the ones available in a single limb only.

1. Introduction

Proprioception is the perception issued from the central processing of information coming from proprioceptive receptors and motor cortical areas [6]. This perception reports the relative position of body segments in relation to each other and to the environment. The processing of such information in the somato-sensory cortical areas allows perception of body kinematics. More precisely, this perception stems from an afferent component related to information gathered by: (1) muscle spindles which have been assigned a prominent role in proprioception and provide information about muscle stretch [19], (2) Golgi tendon organs especially sensitive to contractile forces [16], (3) skin receptors [9] and (4) joint receptors whose proprioceptive contribution is thought to be minor [25]. Proprioception also stems from efferent signals derived from motor commands of cortical areas involved in planning and executing a motor act. These signals are transmitted to somato-sensory areas involved in processing the resulting sensations.

One of the main methods used to assess proprioception is the contralateral concurrent joint position matching task [5,6]. In this task, a subject's limb is displaced to a reference position. While this reference limb is actively or passively maintained in a reference position, the subject is asked to actively replicate this position with the contralateral limb (i.e., the indicator) on the basis of concurrent

Abbreviations: TE, total error; VE, variable error; CE, constant error; VAS, visual analogue scale.

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proprioceptive information of the two limbs and without visual feedback.

To perceive the position of both limbs when performing the contralateral concurrent matching task, the brain computes the weighted sum of all available information related to this perception [29]. Two possible strategies could then be considered: (1) to weight the proprioceptive inputs (muscle spindles, Golgi tendon organs, skin and joint receptors, efferent signal) regardless of the unilateral or bilateral nature of these inputs or (2) to weight the proprioceptive inputs according to their laterality nature.

No previous study aimed at assessing whether the brain was using one or the other strategy. One possibility to unmask this strategy is to assess the proprioceptive system in the context of muscle fatigue. Most of the previous studies using the contralateral concurrent matching task to assess proprioception showed a deleterious effect of muscle fatigue on joint position sense [2–4,10–13,21,26–28] but some others failed to demonstrate such an effect [7,12,24,27,28]. We suggested that the discrepancy reported in these previous studies using active matching tasks could be related to the active or passive condition of support of the reference limb which are associated to differences in laterality of the proprioceptive information (unilateral vs. bilateral). Indeed, most of the results demonstrating an effect of muscle fatigue were observed when the reference limb was active [2,4,10,11,13,21,27,28]. Conversely, all the results that failed to evidence an effect of muscle fatigue were observed when the reference limb was passive [7,12,24,27,28]. Nevertheless, the only experiments that could be linked to an effect of support on joint position sense in a single sample of participants were performed at the elbow [3,27]. Unfortunately, these latter results did not lead to any conclusion. Indeed, one of these studies did not report any effect of limb support [3] whereas the other one showed an effect of support with greater constant errors after fatigue of the elbow muscles when the reference forearm was active but not when it was passive [27].

The present study proposed to test whether the effects of muscle fatigue on joint position sense were dependent upon the unilateral or bilateral nature of the proprioceptive inputs. To this aim, participants performed a contralateral concurrent ankle matching task in two conditions of support of the reference limb (active vs. passive) and two conditions of fatigue of the indicator limb (fatigue vs. no fatigue). It was hypothesized that (1) laterality of the available proprioceptive information (unilateral vs. bilateral) would have no significant effect on ankle joint position sense in the absence of muscle fatigue of the indicator limb but that (2) addition of muscle fatigue would reveal a sensory weighting strategy based on the laterality nature of the inputs.

2. Materials and methods

2.1. Participants

Fourteen young healthy adults (age: 22 ± 2 years; weight: 54 ± 2 kg; height: 162 ± 8 cm; mean ± SD) participated in the study. Leg dominance was an inclusion criterion. To identify the dominant leg, participants were asked their preference for kicking a ball towards a target [18]. All participants indicated their right leg as their dominant leg. All participants gave written informed consent before undertaking the experiment which was conformed to the declaration of Helsinki (1964).

2.2. Apparatus and materials

Joint position sense performance was measured with an apparatus and a setup previously described [5,6]. To explain it briefly, participants were seated barefoot with the feet secured onto two rotating lightweight paddles. Two precision linear potentiometers attached to each paddle provided analogue voltage signals which were converted into angular displacements proportional to ankle angles. Participants held a switch in the dominant hand to record the trial.

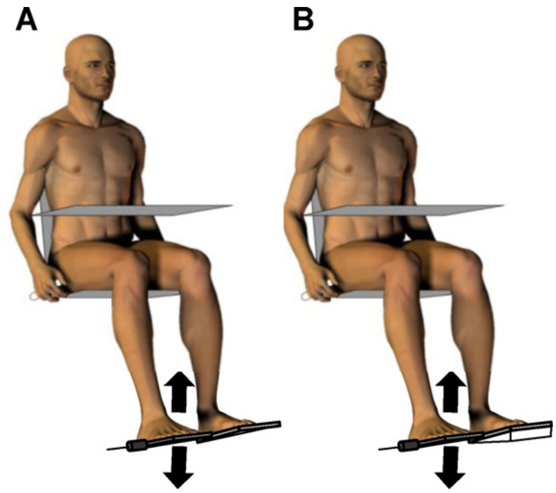

Fig. 1. Setup for the contralateral concurrent ankle joint position matching task in active (A) and passive (B) conditions of support of the reference. Black arrows stand for the possible motion of the indicator foot.

2.3. Procedure

To assess the ankle joint position sense, participants performed a contralateral concurrent matching task. Before each condition of this matching task, both ankles were conditioned with a voluntary contraction of ankle plantarflexors and dorsiflexors to control for muscle history effects [14]. For this conditioning, participants placed both feet between the floor and a fixed horizontal block and were asked to push downwards onto the floor for 2 s with an half-maximal contraction, to relax for 2 s and to push upwards onto the block for 2 s. Participants were then asked to relax their lower limbs. The initial feet position was $40 \pm 0.1^\circ$ under horizontal. Next, one experimenter positioned the reference foot at a $10 \pm 0.1^\circ$ position above horizontal, corresponding approximately to a 10° plantarflexion target position. This reference position was chosen to minimize the potential proprioceptive feedbacks issued from skin and joint receptors [8]. A verbal "ready" command alerting participants of the trial's beginning came immediately after the positioning of the reference limb. After a 2 s delay and the verbal command "go", the participants had to actively estimate the reference position with the indicator foot at a self-paced speed. Participants were instructed to indicate that they had reached a satisfactory matching by pressing the switch registering the performance. After each trial, the indicator foot returned to the initial position whereas the reference foot remained in position for the five trials of the considered condition. Reference and indicator feet were the non-dominant and dominant, respectively. This procedure was performed in two conditions of support and two conditions of fatigue of the indicator limb (active + no fatigue; active + fatigue; passive + no fatigue; passive + fatigue). In the condition of active support (Fig. 1A), the reference ankle was actively maintained in position by the participant. In the condition of passive support (Fig. 1B), the reference ankle was passively maintained on a block and participants were instructed to maintain this foot relaxed throughout the duration of the trial. To ensure that participants remained relaxed during and after positioning of their reference ankle, a physical therapist experimenter continuously