Human Movement Science 62 (2018) 1–13

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

# Proprioceptive identification of joint position versus kinaesthetic movement reproduction

Francesca Marini*, Martina Ferrantino, Jacopo Zenzeri

*Motor Learning, Assistive and Rehabilitation Robotics Laboratory, Department of Robotics, Brain and Cognitive Sciences, Istituto Italiano di Tecnologia, Genova, Italy*

ARTICLE INFO

*Keywords:*
Wrist movement
Robot aided assessment
Kinaesthesia
Proprioception
Amplitude and position coding
Spatial location

ABSTRACT

Regarding our voluntary control of movement, if identification of joint position, that is independent of the starting condition, is stronger than kinaesthetic movement reproduction, that implies knowledge of the starting position and movement's length for accuracy, is still a matter of debate in motor control theories and neuroscience.

In the present study, we examined the mechanisms that individuals seem to prefer/adopt when they locate spatial positions and code the amplitude of movements.

We implemented a joint position matching task on a wrist robotic device: this task consists in replicating (i.e. matching) a reference joint angle in the absence of vision and the proprioceptive acuity is given by the goodness of such matching.

Two experiments were carried out by implementing two different versions of the task and performed by two groups of 15 healthy participants. In the first experiment, blindfolded subjects were asked to perform matching movements towards a fixed target position, experienced with passive movements that started from different positions and had different lengths. In the second experiment, blindfolded subjects were requested to accurately match target positions that had a different location in space but were passively shown through movements of the same length.

We found a clear evidence for higher performances in terms of accuracy (0.42 ± 0.01 1/°) and precision (0.43 ± 0.01 1/°) in the first experiment, therefore in case of matching positions, rather than in the second where accuracy and precision were lower (0.36 ± 0.011/° and 0.35 ± 0.01 1/° respectively). These results suggested a preference for proprioceptive identification of joint position rather than kinaesthetic movement reproduction.

## 1. Introduction

How humans plan their movements toward a target is a fascinating research topic in biomechanics, movement science and neuroscience. Despite there are many possible ways to move one's hand towards an object, due to the redundancy of our musculoskeletal system, it is now certain that humans tend to move in a specific way (Morasso, 1981). Nonetheless, the theory of the mechanism behind this voluntary motor planning is still under debate. Specifically, two main sensorimotor strategies have been identified (Miall & Wolpert, 1996).

A first perspective claims that the movement is generated after a prior estimation of the relative distance between the limb and the target (Miall & Wolpert, 1996; Morasso, 1981; Wolpert, Ghahramani, & Jordan, 1995), thus entailing a vectorial coding of space

* Corresponding author.
*E-mail address:* francesca.marini@iit.it (F. Marini).

https://doi.org/10.1016/j.humov.2018.08.006
Received 14 March 2018; Received in revised form 15 August 2018; Accepted 22 August 2018
0167-9457/ 

representation, based on the amplitude of the movement to plan (Bock & Eckmiller, 1986; Ghez, Gordon, & Ghilardi, 1995; Meyer, Abrams, Kornblum, Wright, & Smith, 1988). Conversely, it is also thought that the motor system controls limb movements by setting muscle length-tension parameters (Feldman, 1980), so that the final equilibrium point corresponds to the position of the target, whatever the initial position of the limb in space (Bizzi, Polit, & Morass, 1976; Feldman, 1980; Latash & Gottlieb, 1991).

From a simplistic viewpoint we can say that, while the first idea is fully dependent from the knowledge of the initial position of the movement, and therefore its amplitude, the second one unbinds the motor planning to the initial position, claiming that our motor system only needs the final location for a good motor planning. Accordingly, considering point-to-point movement around a single joint, one can then describe the two processes respectively as *amplitude* control and *position* control (Miall, Haggard, & Cole, 2017).

This dichotomy has been mesmerising researchers for more than forty years (Jones, 1972; Marteniuk & Roy, 1972), but only few studies have tried to systematically investigate the problem from different perspectives. Specifically, all the above mentioned studies have considered the movement as an entity generated by the motor system with the contribution of both visual and proprioceptive information.

Our insight is that restraining the visual feedback and forcing the subject relying only on proprioceptive information could fill the existing knowledge gaps, tipping the balance between the two theories.

The sensory stream responsible for the unconscious perception of body movements and spatial awareness is called proprioception (McCloskey et al., 1978), and it originates from mechanoreceptors within muscles, tendons, and skin, giving rise to kinaesthesia and the sense of joint position (Gandevia, Refshauge, & Collins, 2002). While the sense of joint position is the proprioceptive process which underlies the interpretation of body segments' location in space, kinaesthesia is the ability to sense the motion of a joint. Although there is clear evidence for both joint position sense and kinaesthesia to play a crucial role in all the processes related to motor control and learning (Smyth & Mason, 1998), yet, literature about the mechanisms underlying these processes is still sparse (Ostry, Darainy, Mattar, Wong, & Gribble, 2010), such as no clear understanding of principles giving rise to proprioceptive perception have been achieved. Specifically, what it is worth to investigate is the balance between amplitude and position control during proprioceptive matching, which could be revealed by a predominant preference for either proprioceptive *identification of joint position* or *kinaesthetic movement reproduction*.

Only recently, motor control principles, in proprioceptive matching have been investigated with the purpose of ascertain the predominant strategy between the *amplitude* control strategy and the *position* control strategy, and explore the balance between the two, in both heathy participants (Chieffi, Conson, & Carlomagno, 2004; van der Graaff, Brenner, & Smeets, 2017) and a deafferented subject (Miall et al., 2017).

Yet, up to date, no common understanding has been reached and the balance between these two extremes of control remains uncertain. Therefore, in light of these recent papers, with the aim to fill this knowledge gap, we have lately started to investigate human wrist proprioception through a robotic interface, able to provide quantitative, objective and reliable measurements (Marini, Squeri, Morasso, Konczak, & Masia, 2016). The use of a robotic device, with high resolution sensors and high precision actuators, allowed to reach a high level of repeatability and accuracy in measuring subjects' performance. In a preliminary work (Marini, Squeri, Morasso, & Masia, 2016) we found evidences supporting preference for amplitude coding of target positions in proprioceptive tasks, but the random shift in positions from trial to trial in this study, hindered a comprehensive analysis.

We now aim to extend this corpus of work, examining which mechanisms individuals seem to prefer/adopt when they locate spatial positions and code the amplitude of movements, with attention at controlling the different variables contributing to the proprioceptive information (i.e the execution speed Chieffi et al., 2004), possibly affecting the results. Specifically, the main goal of the present study was to investigate whether the proprioceptive acuity in perceiving final positions and in perceiving movement's length is similar, or if conversely, in one of the two cases the proprioceptive system provides a better perception.

Two different versions of a robot-based joint position matching task were implemented on a haptic device and performed by two groups of 15 healthy participants. In the proposed task, individuals were requested to replicate a reference joint angle in the absence of vision; the proprioceptive acuity was given by the goodness of the matching.

The first experiment aimed to test proprioceptive *joint position identification* (*JPI*) (position control strategy), and consisted in matching movements in the absence of vision, towards a fixed target position, experienced with passive movements that started from different positions and had different lengths. In the second experiment, blindfolded subjects were requested to accurately match target positions that had different locations in space but were passively shown trough movements of same length, to test ability in *kinaesthetic movement reproduction* (KMR) (*amplitude control strategy*). Different spatial conditions were presented, to correlate the phenomenon to the amount of the shift or displacement involved.

## 2. Methods

### *2.1. Participants*

Thirty right-handed subjects (mean age 28.3 ± 4.1 years, 13 females, 17 males), with no history of neuromuscular disorders and naïve to the task, were randomly divided in two groups (each of 15 subjects) and participated to the study. Handedness of all participants was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971) and the study was approved by ethics committee of the regional health authority, Azienda Sanitaria Locale Genovese (ASL) N.3 (Protocol number 311REG2014 approved on 09/12/2015). Experiments were carried out at the Motor Learning, Assistive and Rehabilitation Robotics Lab of the Istituto Italiano di Tecnologia (Genoa, Italy). Each subject signed a consent form that conforms to these guidelines, according to ethics committee