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Changes in constraint of proximal segments effects time to task failure and activity of proximal muscles in knee position-control tasks

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HIGHLIGHTS

- When maintaining the position of a segment against an external load, the time until the position cannot be maintained (time to task failure; TTF) is greater if potential for movement of the more proximal limb segments is restricted with supports.
- Shorter TTF in tasks with less proximal segment constraint is associated with greater activity of the prime mover muscle as well as antagonist muscles, and muscles of more proximal segments.
- Manipulations of the amount of imposed limb constraint may partly explain the differences in TTF that have been reported in studies of muscle contractions, which differ in load type (muscle contractions to a target force vs. muscle contractions to control a limb position).

ABSTRACT

Objective: Maintenance of a limb position against external load (position-control) fails earlier (time to task failure: TTF) than maintenance of identical force against rigid restraint (force-control). Although possibly explained by physiological differences between contractions, we investigated whether less constraint of movements in other planes and proximal segments (commonly less in position-control tasks) shortens TTF.
Methods: Seventeen adults (32 ± 7 years) contracted knee extensor muscles to task failure in a position-control task, with and without constraint of motion in other planes and proximal segments, and a force-control task with constraints. Electromyography of knee extensors, their antagonist and hip muscles was recorded with force/position.
Results: TTF was shorter for position-control without (161 ± 55 s) than with constraint (184 ± 51 s). Despite identical constraint, TTF was shorter in position- than force-control (216 ± 56 s). Muscle activity and position variability at failure was greater without constraint.
Conclusion: Constraint of motion of proximal segments and other planes increases position-control TTF with less muscle activity and variability. As TTF differed between force- and position-control, despite equivalent constraint, other factors contribute to shorter position-control TTF.
Significance: Results clarify that differences in the TTF between position- and force-control tasks are partly explained by unmatched restriction of motion in other planes and proximal segments.

1. Introduction

Despite similar force, the time for which an individual can maintain a target force (time to task failure: TTF) is longer when exerting a constant submaximal force against a rigid restraint (force-control) than when maintaining the position of the segment (position-control) while loaded with a mass that applies a force equivalent to that exerted in the force-control task (Baudry et al., 2009b; Enoka and Duchateau, 2008; Hunter et al., 2002, 2008; Klass et al., 2008; Maluf et al., 2005; Rudroff et al., 2007a,b, 2010b). This is consistently observed in limbs (but not trunk muscles where the opposite is observed (Thomas et al., 2011)) with few exceptions that are generally explained by differences in limb posture (Rudroff et al., 2007a,b). Physiological differences between tasks have been proposed to explain the variations in the rate at which neural and muscular processes are impaired in force- and position-control tasks. Examples include task-dependent differences in motor unit recruitment (e.g. slower discharge rate, greater

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discharge rate variability, a greater number of active units during position-control (Mottram et al., 2005)) and increased muscle spindle sensitivity in position-control (Akazawa et al., 1983; Baudry et al., 2009a; Maluf et al., 2005).

An additional factor that may contribute to differences in TTF between the force- and position-control tasks that have been tested in earlier experiments is the possibility that these tasks may differ in the amount of activity required of muscles other than those generating the target force (i.e. antagonist muscles and muscles of more proximal segments). This may be a limiting factor in the ability to sustain the task despite the equivalent external force exerted by the muscle performing the target task (prime mover/agonist muscle). Several observations from earlier work provide evidence that this could explain the differences in position- and force-control tasks reported previously. First, TTF in position-control tasks appears increased if the movement of the target joint is restricted to one plane of movement, thus reducing the need for additional muscle activity to adjust out-of-plane motions (Bojsen-Møller et al., 2010; Yoon et al., 2009). Second, position-control tasks can involve greater activation of antagonist muscles than matched force-control tasks (e.g. greater gastrocnemius activity during ankle dorsi flexion (Hunter et al., 2008)). Third, TTF is shorter in a position- than force-control task when the forearm is in a horizontal position and there is a greater increase in shoulder muscle activity in the position-control task, but not in similar tasks performed with a vertical forearm position and no difference in the increase in shoulder muscle activity (Rudroff et al., 2007a). Fourth, performance of an upper limb pushing task has been linked to failure of proximal trunk muscles rather than arm muscles (Le Bozec and Bouisset, 2004). Fifth, shorter TTF in position-control tasks is often reported for conditions where there is also less restriction of motion in other planes or motion of more proximal segments than in force-control tasks as a result of differences in external support between tasks (Rudroff et al., 2011, 2010b) and this would be likely to lead to greater demand on antagonist and proximal muscles.

In order to determine whether differences in TTF between position- and force-control tasks are explained by physiological characteristics between contraction types or alternatively by variations in activity of muscles other than those performing the target task it is necessary to systematically vary activity of these other muscles, within a single task-type. This can be achieved by comparison of TTF between two variants of a position-control task; one with constraints to restrict motion of the proximal segments and one without (which would be expected to induce greater activity of antagonist and muscles of more proximal segments, i.e. auxiliary muscles), and by comparison of TTF between force- and position-control tasks with identical proximal constraints.

If differences in auxiliary muscle activity explain the shorter TTF in position- than force-control tasks we hypothesised that TTF would be shorter in a position-control task with less constraint than an otherwise identical position-control task, and TTF would not differ between position- and force-control tasks if constraint is identical. This study tested these hypotheses using a knee extension task with electromyographic (EMG) recordings of activity of the muscle performing the task (knee extensors), as well as that of an antagonist muscles, and muscles of the hip to confirm the effect of differences of constraint on these muscles.

2. Materials and methods

2.1. Participants

Seventeen healthy adult participants (32 ± 7 years, 9 men and 8 women) volunteered for this study. All procedures conformed to the Declaration of Helsinki, and the study was approved by the Institutional Medical Research Ethics Committee. Informed consent was obtained from all participants.

2.2. Procedure

Participants attended three sessions, each separated by at least 24 h. During each session participants performed one randomly assigned contraction to task failure. Participants lay comfortably on their back on a firm padded treatment table, with the left leg resting extended and the right leg supported behind the thigh (~15 cm from knee joint) by a vertical support so that the participant's hip was flexed to 90° (Fig. 1A–C).

At the beginning of the first session maximum knee extension force was measured during performance of maximum voluntary contractions (MVC) of the knee extensor muscles. Support straps were firmly secured from the table around the participant's pelvis and upper thigh (Fig. 1C). Knee extension force was measured with a strain gauge (Futek, model L2350, 300lb) attached via an adjustable cable to the table and participant's right leg, 30 cm from the lateral knee joint line (Fig. 1C). Participants were instructed and verbally encouraged, to gradually increase their isometric knee extension force to maximum over 3 s, hold for 3 s, and then return to rest. MVCs were performed a minimum of three times, separated by at least 120 s to ensure adequate recovery. MVCs were repeated until the two largest forces differed by <5%. The MVC was determined as the maximum knee extension force produced during any of these contractions and 20% of that force was used as the force target in all of the position- and force-control tasks.

For the position-control tasks participants were required to maintain constant knee angle while supporting a load (matched to 20% MVC) applied to the lower leg until the position could no longer be maintained (i.e. knee angle deviated by >5°). Knee joint angle was measured with an electronic inclinometer (Schaevitz, Accustar) attached ~10 cm distal to the lateral knee joint line. Over the testing sessions, two position-control trials were completed, one with and one without constraint of motion in other planes and of proximal segments. In the constrained condition (position-constrained: PC, Fig. 1B) a 5 cm wide strap was fastened around the pelvis and table to minimize lateral pelvis movement and to support a constant hip angle of 90°. The upper leg was supported with a 5 cm wide strap, secured to a 7 cm wide padded bar positioned behind the thigh, with middle of the bar placed ~15 cm proximal to the knee joint line. Neither strap was used in the unconstrained task (position-unconstrained: PU, Fig. 1A). For the force-control task (force-constrained: FC, Fig. 1C), participants were required to maintain constant force (20% MVC) exerted by pulling against a strain gauge attached via a cable to the table and lower leg until force could no longer be maintained within 5% of the target force. For this condition the upper leg and pelvis were constrained as for PC.

During the three test conditions, participants were provided with feedback of their target position/force represented by a line on a standard 32.5 cm computer monitor fitted to the table and positioned ~1 m above the participant's head. As resolution and gain of feedback can influence TTF (Hong and Newell, 2008; Mottram et al., 2006), feedback was set to 1°/cm for the position-control task and 1% MVC/cm for the force-control task (Rudroff et al., 2010b), with a 10-s time display. The investigator verbally encouraged participants to correct their position or force if they over- or under-shot their target by 5° (position) or 5% MVC (force). When necessary, participants received verbal feedback to correct the position of the hip to 90° hip flexion or correct any internal or external hip rotation. Tasks were discontinued when position/force could no longer be maintained within 5° (position) or 5% (force) of the target value for 5 consecutive seconds.