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Full Length Article

# Distinct neural control of intrinsic and extrinsic muscles of the hand during single finger pressing

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ABSTRACT

Single finger force tasks lead to unintended activation of the non-instructed fingers, commonly referred to as enslaving. Both neural and mechanical factors have been associated with this absence of finger individuality. This study investigates the amplitude modulation of both intrinsic and extrinsic finger muscles during single finger isometric force tasks. Twelve participants performed single finger flexion presses at 20% of maximum voluntary contraction, while simultaneously the electromyographic activity of several intrinsic and extrinsic muscles associated with all four fingers was recorded using 8 electrode pairs in the hand and two 30-electrode grids on the lower arm. The forces exerted by each of the fingers, in both flexion and extension direction, were recorded with individual force sensors. This study shows distinct activation patterns in intrinsic and extrinsic hand muscles. Intrinsic muscles exhibited individuation, where the agonistic and antagonistic muscles associated with the instructed fingers showed the highest activation. This activation in both agonistic and antagonistic muscles appears to facilitate finger stabilisation during the isometric force task. Extrinsic muscles show an activation independent from instructed finger in both agonistic and antagonistic muscles, which appears to be associated with stabilisation of the wrist, with an additional finger-dependent modulation only present in the agonistic extrinsic muscles. These results indicate distinct muscle patterns in intrinsic and extrinsic hand muscles during single finger isometric force pressing. We conclude that the finger specific activation of intrinsic muscles is not sufficient to fully counteract enslaving caused by the broad activation of the extrinsic muscles.

## 1. Introduction

The human hand is capable of intricate individual finger movement patterns as playing the piano or typing, while most common movements – like grasping – involve simultaneous use of multiple fingers. The analysis of both types of movement show that fingers do not move independently from one another (Fish & Soechting, 1992; Häger-Ross & Schieber, 2000; Ingram, Körding, Howard, & Wolpert, 2008; Kaplan, 1965; Kim, Shim, Zatsiorsky, & Latash, 2008; Sanei & Keir, 2013; Soechting & Flanders, 1997). A recent study showed that this lack of individuation only starts after an initial range of movement in which independent movement is possible (Van Den Noort et al., 2016). Previous studies on force enslaving, i.e. the involuntary force production by non-intended fingers, investigated the factors limiting this independence (Kim et al., 2008; Van Duinen & Gandevia, 2011; Zatsiorsky, Li, & Latash, 1998).

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Both neural and mechanical constraints limit finger independence, and while these constraints may simplify the control of certain common multi-finger movements, they also enforce limitations on single finger mobility (Schieber & Santello, 2004; Soechting & Flanders, 1997; Zatsiorsky, Li, & Latash, 2000; Zatsiorsky et al., 1998). Another corroborated finding is that the highest indices of unintended movement can be found in the non-instructed fingers adjacent to the instructed ones (Kilbreath, Gorman, Raymond, & Gandevia, 2002; Kim et al., 2008; Schieber, 1991; Slobounov, Johnston, Chiang, & Ray, 2002; Van Beek, Stegeman, van den Noort, Veeger, & Maas, 2016; Van Den Noort et al., 2016; Zatsiorsky et al., 2000).

When considering both the neural and the mechanical constraints to the independence of finger movements, mainly the extrinsic hand muscles have been considered (Kaplan, 1965; Kilbreath et al., 2002; Sanei & Keir, 2013; Slobounov et al., 2002). However, the intrinsic muscles, located within the hand, are largely involved when it comes to the fine control of single finger movements. When performing different types of hand movements, the intrinsic and extrinsic muscles have distinct tasks. In a precision grip, all muscles are co-activated, and the muscle activity will increase with force (Adewuyi, Hargrove, & Kuiken, 2016; Maier & Hepp-Reymond, 1995). But while intrinsic muscles show high correlations to grip force, the extrinsic muscles have lower correlations (Milner & Dhaliwal, 2002; Winges, Kornatz, & Santello, 2008). More specifically, the intrinsic hand muscles have been indicated to control individuated and subtle manipulations of finger movements (Adewuyi et al., 2016; Milner & Dhaliwal, 2002; Winges et al., 2008). The lumbricals, at the palmar side of the hand, are not only involved in the flexion of the metacarpophalangeal (MCP) joints, but also in the extension of proximal interphalangeal (PIP) and distal interphalangeal (DIP) joints (Valero-Cuevas, 2005; Valero-Cuevas, Zajac, & Burgar, 1998). The agonistic and antagonistic extrinsic hand muscles together appear to be mainly used to stiffen the wrist and finger joints and play a role in providing the main force for the movement (Johnston, Bobich, & Santello, 2010; Li, Zatsiorsky, & Latash, 2000, 2001; Milner & Dhaliwal, 2002).

This study aims to investigate (1) the neural control of both intrinsic and extrinsic muscles during single finger presses, and (2) how this relates to finger force enslaving. To focus on the neural drive, received by both muscle groups, this study uses static finger presses as the influence of mechanical connections within the hand appears to be small in such conditions (Zatsiorsky et al., 1998, 2000). We test the following hypothesises: (1) Both intrinsic and extrinsic muscles will show co-activation of agonistic and antagonistic muscles in order to stabilize the finger and wrist; (2) In the intrinsic muscles, we expect to see modulation of this co-activation based on the instructed finger; (3) In the extrinsic muscles, we expect to see a more broad activation in both agonistic and antagonistic muscles, independently of the instructed finger, required for wrist stabilization.

## 2. Methods

### 2.1. Subjects

The study was approved by the local ethical committee (CMO Regio Arnhem-Nijmegen, The Netherlands), and written informed consent was obtained from all subjects. Thirteen healthy volunteers were included in the study, of which one was excluded from the analysis due to technical difficulties with the electromyography (EMG) recordings. Thus, the analysis was performed on 12 participants (age 25 ± 3 years, 5 men and 7 women).

### 2.2. Experimental setup

The index, middle, ring, and little finger of the right hand were taped to 4 individual force sensors (Micro Load Cell CZL635, Phidgets Inc, Calgary, Canada). The placement of the force sensors was adjusted both in the direction of the length and width of the

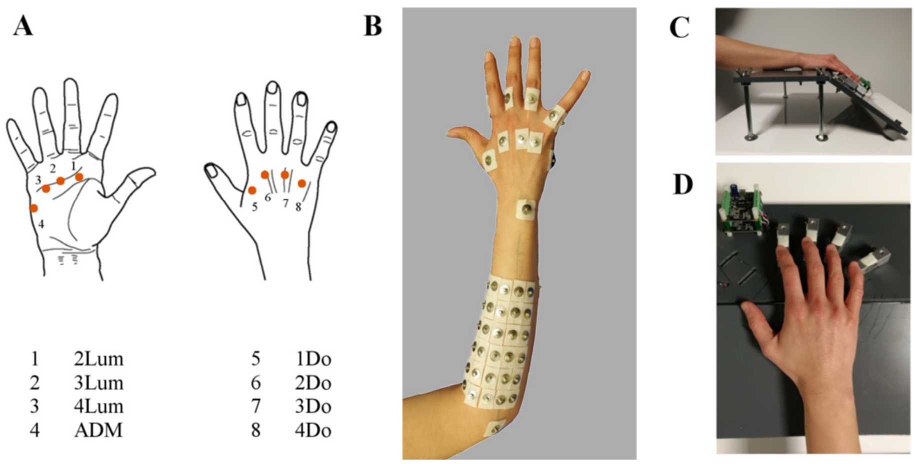


**Fig. 1.** (A) Position of intrinsic EMG electrodes. (B) View of placement electrodes on posterior side of the hand and arm. (C) Side view of custom force device. (D) Top view of custom force device. To insure clarity of the force device, pictures in (C) and (D) were taken before the application of EMG electrodes and taping of the fingers.