Neuroscience Letters 504 (2011) 330–335

Contents lists available at SciVerse ScienceDirect

Neuroscience Letters

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

The effects of instruction and hand dominance on grip-to-load force coordination in manipulation tasks

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ARTICLE INFO

Article history:
Received 23 June 2011
Received in revised form 8 September 2011
Accepted 22 September 2011

Keywords:
Control
Neural
Coupling
Scaling
Feed-forward
Feedback

ABSTRACT

The force applied upon a vertically oriented hand-held object could be decomposed into two orthogonal and highly coordinated components: the grip force (GF; the component perpendicular to the hand–object contact area that provides friction) and the load force (LF; the parallel component that can move the object or support the body). The aim of this study was to investigate the underexplored effects of task instruction and hand dominance on GF–LF coordination. Sixteen right-handed subjects performed bimanual manipulation against a horizontally oriented instrumented device under different sets of instructions. The tasks involved exertion of ramp-and-hold or oscillation patterns of LF performed symmetrically with two hands, while the instructions regarding individual actions were either similar (pull with both hands) or dissimilar (pull with one hand and hold with another). The results revealed that the instruction "to pull" leads to higher indices of GF–LF coordination than the instruction "to hold", as evidenced by a lower GF–LF ratio, higher GF–LF coupling, and higher GF modulation. The only effect of hand dominance was a moderate time lag of GF relative to LF changes observed in the non-dominant hand. We conclude that the instructions could play an important role in GF–LF coordination and, therefore, they should be taken into account when exploring or routinely testing hand function. Additionally, the results suggest that the neural control of GF of the non-dominant hand could involve some feedback mechanisms.

The ability to manipulate objects is crucial for living an independent and active life. Force analysis of manual manipulation tasks has usually been based on a simple mechanical model of holding a vertically oriented object [6,12,14]. The load force (LF) is the friction force applied in parallel to the hand–object contact surface to overcome the object's weight and inertia or, alternatively, to provide postural support using an externally fixed object. The grip force (GF) is the normal force applied perpendicularly against the object, providing friction and controlling object position. According to the aforementioned model, GF needs to be scaled high enough to prevent slippage, but not excessively high to avoid crushing the object or causing fatigue. Studies performed on healthy individuals have involved a variety of both static and dynamic tasks that were presumably ecologically valid due to mimicking routinely performed manipulation tasks. They consistently have shown a high level of GF–LF coordination through several properties of GF control [6,12,14,28]. First, GF is usually scaled to provide a relatively low and stable GF–LF ratio [14]. Second, a continuous coupling of GF with the ongoing changes in LF has been observed. This coupling has been revealed through high GF–LF correlation and low time-lag between them [6], which suggests involvement of 'feed-forward' neural control mechanisms that could be unaffected by visual feedback [14,15]. Third, to provide both the stable ratio and high coupling of GF and LF, GF needs to be highly modulated with respect to the changes in LF caused by ongoing manipulative actions [6,12,14,28]. However, a number of factors may affect this interplay between GF and LF, such as underlying neurological diseases [17,21], switching from uni-directional to bi-directional tasks [8,11], or increased task complexity [18,27]. Therefore, GF–LF coordination has been seen both as a window for studying some basic neural mechanisms of movement control [11,29] and an opportunity for development of routine quantitative tests of hand function in various patient populations [16].

Although instructions play a significant role in the selection of movement patterns [9,19], their role in GF–LF coordination remains underexplored. Distinctive effects of instructions to move "fast", "fast and accurate," or "accurate" on subsequent task performance are probably the best known example in the motor control literature [3,5]. It also has been shown for a mechanically constrained task that emphasizing the action on only one muscle group within a limb leads to a profoundly different activation pattern of individual muscles [20]. Regarding kinetic tasks, the instructions "to exert maximum force" and "to exert it rapidly" have been known to produce profoundly different effects on maximum force and the rate

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doi:10.1016/j.neulet.2011.09.059

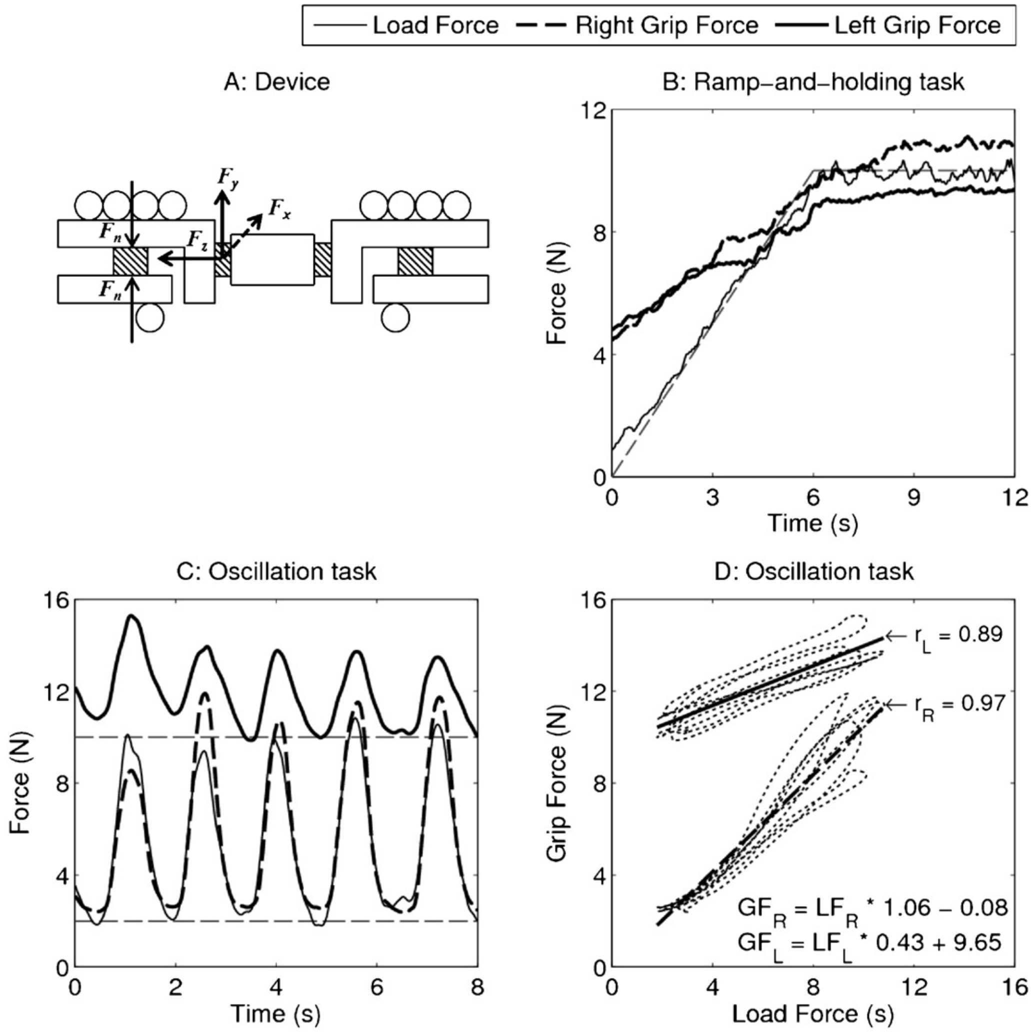

Fig. 1. (A) The experimental device and the forces exerted (transducers represented by shaded blocks) by the tips of the digits (circles). Force profiles recorded in a representative subject during ramp-and-hold (B) and oscillation task (C) are shown, together with the GF–LF diagram (D) obtained from the depicted oscillation trial. The correlations (r) reveal GF–LF coupling, while the slopes of the regression lines show GF modulation. The thin dashed lines (B and C) illustrate the lines shown at the computer monitor.

of force development in standard strength tests [24]. Therefore, the possibility exists that switching the instructional emphasis within the same manipulation task (e.g., "pull" instead of "hold") could affect the GF–LF coordination pattern.

Hand dominance could also play a role in GF–LF coordination. The model of motor lateralization suggests that the dominant limb is specialized for dynamic, feed-forward controlled tasks [1,25], while the non-dominant limb is specialized for feedback mediated error correction mechanisms [2]. The few studies that have explored the effect of hand dominance on GF–LF coordination have suggested that the non-dominant hand could have an advantage in providing somewhat lower GF scaling and more accurate directional accuracy [4,7]. However, bimanual tasks have not been tested in the context of the effect of motor lateralization in manipulation activities.

In the present study we designed an experimental protocol based on exerting opposing LF patterns by two hands while symmetrically holding an instrumented device. We hypothesized that the studied GF–LF coordination in otherwise identical tasks would be higher under the instruction to "pull" than to "hold." We also hypothesized that the non-dominant hand would perform relatively better in the task requiring feedback controlled corrections, while the dominant hand could reveal an advantage in the tasks predominantly based on the feed-forward control mechanisms. The expected findings could be of importance for understanding important aspects of force coordination, as well as for refining the testing protocols in both research studies and routine tests of hand function in various clinical populations.

16 healthy right-handed participants (as assessed by maximum scores on the Edinburgh Inventory Questionnaire; [23]) were recruited (8 males and 8 females, 20–25 years of age). The experiment was approved by the IRB of the University of Delaware and conducted in accordance with the Declaration of Helsinki. All participants signed an informed consent prior to beginning the experimental protocol.

A custom designed device, used in previous studies of hand function [10,11] was used to record GF and LF exerted by the participants (Fig. 1A). Two identical handles were connected through a short rod ending with two multi-axis force transducers (Mini40, ATI, USA). They recorded the same tension force applied against the handles. The handles consisted of two parallel plates covered with high friction rubber with a single-axis force sensor (WMC-50, Interface Inc., USA) installed in between to record the compression force exerted against them. The signals allowed us to record LF as the tension force, as well as GF as the average force acting against the handle plates [27].