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Motor learning of cue-dependent pull-force changes during an isometric precision grip task

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ABSTRACT

The "raspberry task" represents a precision grip task that requires continuous adjustment of grip and pull forces. During this task subjects grip a specialized grip rod and have to increase the pull force linearly while the rod is locked. The aim of this study was to determine whether an associated, initially neutral cue is able to evoke pull-force changes in the raspberry task. A standard delay paradigm was used to study cued pull-force changes during an ongoing movement resulting in unloading. Pull force and EMG activity of hand and arm muscles were recorded from 13 healthy, young subjects. The cue was associated with a complex change in motor behavior.

In this task, cued force changes take place more rapidly than in protective reflex systems (in median after the second presentation of the cueing stimulus). A cued force change was detectable in two-thirds of paired trials. Although the force change is produced by a decrease of the EMG activity in several grip- and pull-force-producing muscles, the most significant effect in the majority of the subjects was an increase of the activity of the flexor carpi ulnaris muscle which antagonises corresponding pull-force-producing muscles. Cued force changes require adequately and precisely controlled activation of the muscle groups involved in the movement.

Abbreviations: EMG, electromyography; EDC, extensor digitorum communis muscle; FDI, first digital interosseous muscle; FCU, flexor carpi ulnaris muscle; TH, thenar muscle.

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1. Introduction

Grip behavior in humans is studied often by employing a lifting or an unloading task. Typically, the lifting task is divided into three phases. First, the grip phase, when the hand reaches the object and the fingers makes contact. In this phase the grip aperture and the grip force at contact are determined by the object's size and the expected weight (Gordon, Westling, Cole, & Johansson, 1993; Paulignan, Jeannerod, Mackenzie, & Marteniuk, 1991). The second phase, the load or lifting phase, begins when subjects begin to lift the object from its support until lift-off. The duration of the load phase depends on the weight of the object (Johansson & Westling, 1984, 1988a) and lasts for up to 800 ms for the first lift of a novel object with a weight of 1 kg (Gordon et al., 1993). Changing the weight of the object results in a variation of the duration of the load phase. In general, the heavier the object the longer time required to lift it. During the load phase finger and hand muscles function under isometric conditions. Hence, force control depends primarily on tactile signals. The third phase, the hold phase, starts with the lift-off of the object and subject's holding of the object. Handled objects frequently tend to rotate due to the relation of the individual finger forces with respect to the object's center of mass (Burstedt, Flanagan, & Johansson, 1999; Flanagan, Burstedt, & Johansson, 1999). Subjects compensate for the initial rotation by changing their individual finger forces. In general, during the load phase individual finger forces increase conjointly. After the transition to the hold phase individual finger forces must be programed separately. Hence, a broad change in the motor program is required during this transition. The duration of the hold phase depends on the experimental constraints and lasts several seconds (e.g. Johansson & Westling, 1984, 1987).

The three phases are separated by two sequential, fast-adapting-II (FA-II) afferent signals (Pacinian corpuscles). The first signals contact with the object, the second signals the lift-off of the object (Johansson & Cole, 1992; Johansson & Westling, 1991; Westling & Johansson, 1987). On basis of this observation those authors introduced the "*sensory driven control model*" for lifting objects, arguing that the FA-II activity triggers different control modes in the lifting task. The first such mode provokes increasing, conjoint finger force production to lift the object, whereas the second causes the switch to independent finger force production to prevent object rotation (Johansson & Cole, 1992).

Unloading tasks are used to study the ability of humans to anticipate load-force changes due to external or self-produced perturbations (Witney, Goodbody, & Wolpert, 1999). Anticipation is a fundamental characteristic of the human motor system and enables adequate adjustment of muscular activation; even before proprioceptive or kinesthetic information is available. Generating such anticipatory adjustments requires prediction to counteract a perturbation (Diedrichsen, Verstynen, Hon, Lehman, & Ivry, 2003). In the unloading task the object is held with one hand at rest and the grip force depends both on the weight of the object, i.e. load force, and the coefficient of friction of its surfaces. The object is then lifted, either self-induced with the subject's other hand or by an external device e.g. by a robot. In the first case anticipatory adjustments can be produced based on an efferent copy of the voluntary action (Diedrichsen et al., 2003). In the second case, subjects produce force adjustments after the perturbation (e.g. Johansson, Riso, Hager, & Backstrom, 1992). Anticipatory adjustments are produced only when the robot-induced perturbation coincides with a cueing stimulus. In this case the unloading task also tests the ability to predict the time of the anticipatory adjustment (Witney et al., 1999). Hence, the technique is comparable to classical conditioning for testing associative learning of reflex systems.

Recently, we have introduced a new experimental approach, termed the "raspberry task", which combines the loading task with the unloading task. In the raspberry task can the duration of the pull phase—the equivalent to the load phase—be changed randomly from 1 to 5 s (Kutz, Wölfel, Meindl, Timmann, & Kolb, 2009a). Subjects are required to grip a specialized grip rod equipped with a force-sensor array to measure grip force of individual fingers (Kutz, Wölfel, Timmann, & Kolb, 2007, 2009b). After having established a firm grip, isometric conditions are fulfilled for finger and hand muscles. Subjects are then asked to pull the locked rod steadily with a linearly increasing pull force until unpredictably, the rod is unlocked (UUR). After unlocking, the rod moves and pull force is unloaded. Subjects are asked to stop the pull movement of the rod immediately. The transition from the locked to the unlocked rod required changes from increasing pull force to an immediate and rapid decrease of