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Characteristics of grasping movements in a laboratory and in an everyday-like context

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ABSTRACT

To understand the principles of motor control, it is useful to know whether movements with the same physical constraints can be governed by different rules depending on the behavioral context. We therefore have recently introduced a paradigm in which subjects grasp from the same starting position to the same final object, once as a typical laboratory task and once as part of everyday-like behavior. In the laboratory context, grasping was repetitive, externally triggered and purposeless; in the everyday-like context, it was embedded in a complex activity, intentionally initiated, and served a purpose. Here we present a comprehensive analysis of data from that paradigm. Among 38 response parameters that reflected hand transport, grip shaping and object manipulation, 20 differed significantly between groups. Factor analysis further reduced them to four orthogonal factors: response speed, finger-object contact, response variability, and hand path curvature. This shows, for the first time, that behavioral context influences the execution of grasping movements in four independent ways, possibly reflecting four distinct functional modules in the motor system. This fits well with the view – derived from neurological data – that grasping is controlled by a set of interconnected brain areas which are differentially recruited to achieve different behavioral goals.

1. Introduction

Human grasping movements consist of a transport component which brings the hand near the object of interest, and a grasp component which shapes the hand such that it approximates the size, form

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and orientation of the object. These two components have distinct kinematic features and different neural substrates, but they are issued in a coordinated fashion (Castiello, 2005; Dubrowski, Bock, Carnahan, & Jüngling, 2002; Jeannerod, 1981; Wing, Turton, & Fraser, 1986), and both exhibit a speed-accuracy tradeoff (Girgenrath, Bock, & Jüngling, 2004) similar to that of pointing movements (Fitts, 1954). Once the fingers are in contact with the object, they apply grip and load forces to it in a well-coordinated fashion, leaving a small safety margin of the grip force over the load force to prevent slipping and breaking (Flanagan & Tresilian, 1994; Johansson & Cole, 1992). This force coupling is highly automatized, yet flexible enough to allow corrections based on sensory feedback (Haggard & Wing, 1995; Johansson & Cole, 1992; Rand, Shimansky, Stelmach, & Bloedel, 2004) and to compensate even for massive changes of the gravito-inertial environment (Hermsdörfer et al., 2000).

These and other principles of grasping have been well documented in a number of laboratory studies, but they may not necessarily hold for real-life behavior, e.g., in application areas such as workplace ergonomics and motor rehabilitation. This is so because typical laboratory tasks differ from the latter scenarios in multiple ways: they focus subjects' attention on the grasping act, induce them to perform at their best, offer no ecologically meaningful purpose, and are triggered by extrinsic signals rather than initiated by the actor's own intention (Bock & Hagemann, 2010). It is both of theoretical and of practical relevance to find out whether motor acts such as grasping are performed differently in a laboratory and in an everyday context: of theoretical relevance since context-dependence would imply that movements from a common starting to a common final position can be governed by different control processes, and of practical relevance since it would caution against predicting real-life performance from laboratory findings.

Available literature provides very little information about the dependence of motor control on the behavioral context. One study registered hand gestures during daily routines, but didn't compare them to the same gestures in a different context (Ingram, Kording, Howard, & Wolpert, 2008). A second study observed that age-related differences of the gait pattern observed in the laboratory are absent when subjects walking in a community park (Bock & Beurskens, 2010), and a third provided preliminary evidence that grasping kinematics registered in a typical laboratory context differ from those in an everyday-like context even if the physical constraints are comparable (Bock & Hagemann, 2010). While the latter study focused on introducing the new method, our present work undertakes a comprehensive analysis of the collected data to find out whether context-dependence can be traced back to a single underlying cause, or rather has multiple independent origins.

2. Methods

Fifty-two subjects (34 male and 18 female, 24 ± 2.7 years of age) participated after signing their informed consent to this study, which was pre-approved by the Ethics Committee of the German Sport University. All subjects were right-handed, naïve as to the purpose of our study, and exhibited no overt sensorimotor deficits except corrected vision. They were randomly assigned to group L (18 males and 5 females, 24.7 ± 3.0 years of age) or group E (16 males and 13 females, 23.4 ± 2.3 years of age). Different group sizes emerged because some of the original 60 subjects had to be excluded from analysis due to a partial loss of data.

As described in detail elsewhere (Bock & Hagemann, 2010), subjects sat at a table in front of a joystick and a computer monitor, both centered about their mediosagittal plane. To the right of the monitor was a cylindrical lever with a horizontal axis of 4 cm length and two vertical caps of 1.6 cm diameter. The lever could slide towards the subject along a rail, reaching a mechanical stop after 3.5 cm. A force transducer (ATI Nano 17) registered the forces and torques applied to the caps in x, y and z with a resolution of ±0.006 N, ±0.016 Nm and 4 ms, and a laser-based position encoder (Way-Con LAS-T500) registered lever position with a resolution of ±0.06 cm and 4 ms. To reach from the joystick to the lever, subjects had to move their hand 50 cm right- and forward in a horizontal plane, and to increase the distance between thumb and index finger from 1.2 cm (i.e., joystick diameter) to 4 cm. The 3D positions of thumb and index fingertips were recorded with an optical motion capture system using passive, wireless markers (Vicon-MX-F20), with a resolution of $1600 * 1280$ pixels and 4 ms.