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The impact of object weight, reach distance, discomfort and muscle activation on the location of preferred critical boundary during a seated reaching task

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ABSTRACT

Successful performance of a goal-directed action requires the prospective actor to perceive the environment relative to their action capabilities and tailor their movements accordingly. The current study examined the roles of reach distance, object (power drill) weight, gender, discomfort, and muscle activation (anterior deltoid, upper trapezius, biceps, ventral and dorsal forearm) in determining the location of the transition between an arm-only and an arm-and-torso reach (preferred critical boundary) during a seated reach task in which participants had to direct a power drill toward a target. Generalized Estimating Equations (GEE) used extrinsic (independent of the participant) and intrinsic measures (relative to the biodynamic properties of the participant) of reach distance and drill weight, discomfort judgments, and EMG integral recordings for the five muscles to identify factors that best predicted the type of reach used. GEE revealed that intrinsic measures of reach distance and drill weight were superior predictors compared to extrinsic measures. Discomfort judgment and upper trapezius activity were also significant predictors of the location of the preferred critical boundary.

1. Introduction

Successful performance of a goal-directed action requires that relevant properties of the environment fall within a range determined by the actor's body scale and biodynamic capabilities. The limits of this range of environmental properties are referred to as critical boundaries, beyond which a different pattern of coordination (action mode) is necessary to achieve the goal. In the case of seated reaching, an increase in reach distance may necessitate a change from reaching by simple arm extension to an action in which the actor leans forward (or even stands up) in order to grasp the object. Spawned by Gibson's proposal that people perceive the possibilities for action supported by the layout of the environment, i.e., affordances, there is considerable evidence that people readily perceive these critical boundaries for a variety of goal-directed actions, e.g., bipedal climbing (Warren, 1984), reaching (Carello, Grosofsy, Reichel, Solomon, & Turvey, 1989; Mark et al., 1997),

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prehension (Newell, Scully, Tenenbaum, & Hardiman, 1989), stepping across gaps (Mark, Jiang, King, & Paasche, 1999), and sitting (Mark, 1987; Mark & Vogele, 1987).

In linking these studies of people's perception of critical boundaries to how people actually perform a goal-directed action as a function of relevant environmental properties, Mark et al. (1997) observed that if actors are allowed to reach in whatever manner they choose, the transition from an arm-only reach to an arm-and-torso reach occurred at a location closer than the maximum distance at which they can perform an arm-only reach (absolute critical boundary). Mark et al. referred to the location of this transition as the preferred critical boundary (PCB). The discrepancy between the locations of the absolute and preferred critical boundaries means that actors use a more complex pattern of coordination (leaning) at distances at which arm extension alone would suffice. The current investigation of seated reaching examines factors that are responsible for the location of the preferred critical boundary between arm-only and arm-and-torso reach modes.

1.1. Comfort/discomfort

Anthropometric constraints cannot be the sole determinant of the transition between seated reach modes because people can still reach successfully beyond the preferred critical boundary using an arm-only reach. In their initial investigation of the preferred critical boundary in seated reaches, Mark et al. (1997) observed that the location of the preferred critical boundary coincided with the distance at which more complex arm-and-torso reaches were judged to be more comfortable than the arm-only reach (also, Gardner, Mark, Ward, & Edkins 2001; Stasik & Mark, 2005). These data are consistent with the proposal that actors utilize the reach mode that minimizes discomfort or a related construct like exertion. The current study attempts to examine the activity of particular muscles that might underlie discomfort judgments.

1.2. Muscle activation

Discomfort judgments are thought to reflect some physical aspect of bodily activity during the course of a reach. Previous work on phase transitions in gait and bipedal stair climbing led us to consider the possibility that efforts to minimize energy consumption might be a determinant of the preferred critical boundary in seated reaching. Hoyt and Taylor (1981) measured energy expenditure across different gaits in horses. They reported that when horses were forced to locomote using a gait they would not normally use at a given speed (e.g., they were compelled to trot at speeds when they would normally gallop), oxygen consumption (per unit distance covered) significantly increased compared to energy consumption at the same speed had they been allowed to use their preferred gait. Similarly, race walkers move at velocities at which most people would run, as running would consume less energy per unit distance traveled (Ardigo, Saibene, & Minetti, 2003). In his study of bipedal stair climbing, Warren (1984) found that judgments of the preferred climbable riser height coincided with the riser height that minimized energy expenditure per unit vertical height.

When applied to the act of seated reaching, the proposal that actors attempt to minimize overall energy expenditure encounters two fundamental difficulties: first, we are unaware of any bodily mechanism for monitoring energy expenditure during such a brief act, such that modifications could be made during the time course of the act; second, the more complex arm-and-torso reach entails a larger expenditure of energy than an arm-only reach because of the torso muscles involved in leaning forward. Given the relatively low amount of energy expended in performing a seated reach, minimizing total energy expenditure is unlikely to be an important constraint in selecting a reach mode. Alternately, the prospective actor may tailor the action so as to avoid some threshold level of exertion of individual muscles. The challenge in evaluating this proposal is to identify a measure of muscle exertion. Toward this aim, we have chosen to use electromyography (EMG) to study the activity of five muscles involved in performing a seated reach. For each reach we will determine the EMG integral for each muscle. We are particularly interested in changes in EMG activity at reach distances before and after the preferred critical boundary. However, our use of EMG recordings is intended as an indicator of the level of muscle exertion, not a measure of energy expenditure, *per se*.

1.3. Overview of experiment and hypotheses

The current investigation attempts to identify predictors of the preferred critical boundary in seated reaching. Previous work has shown that reach distance (e.g., Gardner et al., 2001; Mark et al., 1997), object weight (Choi & Mark, 2004) and discomfort judgments (Mark et al., 1997; Stasik & Mark, 2005) are predictors of the preferred critical boundary between arm-only and arm-and-torso reaches. The current investigation examines whether levels of muscle activation as measured by surface EMG might also be predictors of the preferred critical boundary.

Participants reached to a circular target using a cordless power drill. The distance of the target from the seated participant and the weight of the drill were varied. During each reach, muscle activation in the reach arm and shoulder was measured using EMG (integral). Following each reach, participants rated the discomfort experienced during the action. In the unconstrained reach condition, participants were told to reach using whatever reach mode they felt was most natural. In the constrained reach condition, participants were required to keep their back in contact with the chair's backrest throughout the reach, that is, participants were not allowed to lean or rotate their torso during the reach.

Data were gathered with respect to the roles of reach distance, gender, drill weight, discomfort and muscle activation as determinants of the location of the preferred critical boundary between an arm-only reach and arm-and-torso reach. After