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Internal consistency and test–retest reliability of an instrumented functional reaching task using wireless electromyographic sensors

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ABSTRACT

The purpose of this study was to establish the internal consistency and test–retest reliability of the electromyographic and accelerometric data sampled from the prime movers of the dominant arm during an antigravity, within-arm's length stand-reaching task without trunk restraint. Ten healthy young adults participated in two experimental sessions, approximately 7–10 days apart. During each session, subjects performed 15 trials of both a flexion- and an abduction-reaching task. Surface EMG and acceleration using wireless sensors were sampled from the anterior and middle deltoid. Reliability was established using Cronbach's alpha, intraclass correlation coefficients (ICC 2, k) and standard error of measurements (SEM) for electromyographic reaction time, burst duration and normalized amplitude along with peak acceleration. Results indicated high degrees of inter-trial and test–retest reliability for flexion (Cronbach's α range = 0.92–0.99; ICC range = 0.82–0.92) as well as abduction (Cronbach's α range = 0.94–0.99; ICC range = 0.81–0.94) reaching. The SEM associated with response variables for flexion and abduction ranged from 1.55–3.26% and 3.33–3.95% of means, respectively. Findings from this study revealed that electromyographic and accelerometric data collected from prime movers of the arm during the relatively functional stand-reaching task were highly reproducible. Given its high reliability and portability, the proposed test could have applications in clinical and laboratory settings to quantify upper limb function.

1. Introduction

Assessing upper limb function, both in the laboratory and clinic, can be challenging because of the complexities arising from its involvement in discrete tasks, multiple degrees of freedom and requirement of action preparation in the form of information processing and postural adjustments. Among the functions of the upper limb, reaching activities are the earliest to develop (Shumway-Cook and Woollacott, 1995), comprise a majority of its uses and are often followed by grasp and/or manipulation. Current methods to assess upper extremity dysfunction lack sensitive quantification, clinical translatability, functionality and/or repeatability. This limits the detection of early signs of improvement, the progression of disease, the level of structural impairment and how these influence the individual with respect to function and participation. Evaluating selective upper extremity tasks using appropriately designed, adequately controlled and reliable outcome measures is a defensible way of quantifying such changes (Long and Scott, 1994).

The advantages of clinical scales include their universal availability, cost-effectiveness and portability. Unfortunately, these measures can be highly subjective, lack sensitive quantification (necessary to measure the small changes that result from training, e.g. convalescing individuals) or have floor or ceiling effects, which limit their use in individuals who might be at the cognitive or autonomic stages (e.g. high-performing athletes) of performance, respectively, of a certain motor skill. Additionally, there are not as many tools available to assess general motor function of upper limbs in otherwise normal older adults, who are known to manifest rather silent symptoms of aging that contribute to poor performance in day-to-day activities.

With advances in portable, wireless technology, some laboratory-based measures can be conveniently used as sensitive clinical tools for the assessment of upper limb function. In the literature, many such measures have been developed and used for research purposes (Bertucco et al., 2013; Piovesan et al., 2013; Sciutti et al., 2012) yet have not been translated to the clinical setting. This could be possibly due to the infeasibility of having expensive, highly sophisticated measurement systems in the clinic, poor functionality of the testing design, lack of sufficient information to reproduce the given protocol, or unavailability of reliability estimates for the outcome variables. Especially, in the context of upper

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limb reaching measures, laboratory-developed reaching tasks lack one or more functional aspects such as the plane of reaching, starting position from which it is performed and/or use of physical trunk restraint. This adds to the inability of lab-designed measures to be replicated in clinical settings.

The functionality of the design affects the task and environmental constraints of the test and weigh largely on individual performance. With respect to reaching, the plane of and starting position from which it is performed address two different aspects of motor control underlying the skill. Reaching tasks have been predominantly measured in the horizontal plane (Almeida et al., 2006; Hollerbach and Flash, 1982; Piovesan et al., 2013; Trent and Ahmed, 2013). It is well known that movements, including reaching, in the anti-gravity plane are more resistive, necessitating greater muscle contraction in order to generate sufficient torque to overcome limb inertia, and thus more challenging. Nevertheless, they are more functional than reaching in a horizontal plane and are required by almost all activities of daily living. Despite this fact, only a few studies use an anti-gravity reaching measure (Papaxanthis et al., 1998a; Sciutti et al., 2012; Tyler and Karst, 2004).

It must be noted that most of these gravity-eliminated, horizontal plane reaching, and some other gravity-resisted reaching, tasks were performed from a seated position, sizably obviating the need for postural action preparation (Atkeson and Hollerbach, 1985; Chevalot and Xuguang, 2004; Klein Breteler et al., 1998; Nishikawa et al., 1999; Sciutti et al., 2012; Zhang and Chaffin, 2000). Performing a reaching task from a standing position is far more challenging than it is from a seated one (Christina et al., 1982; Christina and Rose, 1985). Most of the previously mentioned studies limited their scope to understanding simple or choice reaction times of the arm prime-mover without introducing any form of task complexities, and hence used a rather balanced seated position. On the other hand, some studies in the literature have reported the use of a stand-reaching task (Bertucco et al., 2013; Huang, 2009; Tyler and Karst, 2004), however the focus of these studies was limited to examining postural responses and did not consider kinetics or kinematics of the prime mover of the arm. Conversely, the few studies that explored upper limb reaching during standing (Paizis et al., 2008; Papaxanthis et al., 1998b; Tyler and Karst, 2004) did not report test–retest reliability of the lab-developed measure, impeding its use in other laboratory or clinical settings.

Keeping these functional traits in mind, we aimed to design a novel stand-reaching task that accounts and controls for some complexities of arm reaching, thus making it a sensitive yet functionally robust measurement tool. In order to ensure its utility as an outcome measure, it is imperative to know if such a task is feasible and repeatable over time under controlled circumstances. The purpose of this study, therefore, was to estimate the internal consistency and test–retest reliability of an antigravity, within-arm's length stand-reaching task of the dominant arm without trunk restraint.

2. Methods

2.1. Participants

Ten healthy, young and right-handed adults (8 females, 2 males; age = 23.6 ± 3.75 years; height = 162.6 ± 8.47 cm; weight = 127.1 ± 26.59 lb; arm length = 28.1 ± 1.63 in.) were recruited from the student pool of the University of Illinois at Chicago via flyers and volunteered to participate in the study. All participants visited the lab for testing two times within a span of 7–10 days. The Institutional Review Board of the University of Illinois at Chicago approved the study protocol. All subjects signed an informed consent form before participating in the study.

2.2. Design

The set-up primarily consisted of a custom-made arm reaching apparatus (Fig. 1) that comprised of a larger load-bearing clamp that was fixed to a stationary pole in the lab with the long-shaft of the clamp perpendicular to the length of the pole. This was adjusted to the shoulder height of the subjects. Another movable, smaller clamp was used to attach a 36-in. wooden ruler perpendicular to the shaft of the large clamp. This was adjusted to 90% of the subject's arm length. A 4-in. (diameter) circular foam with a distinctly marked smaller central target of 1-in. (diameter) was attached to one end of the wooden ruler. A passive marker, in line with the target, was taped to the top-end of the screw of the small clamp at a fixed distance of 3.5 in. to serve for gaze fixation. Electrical activity of the muscle was measured using Delsys® Trigno™ wireless electromyography sensors. These sensors also have tri-axial accelerometers embedded in them that sampled the rate of change of velocity.

2.3. Protocol

Subjects stood with shoulder-width base of support on a paper foot-mat with their arms at their side. Feet were marked on the paper mat in order to maintain a constant base of support throughout the period of testing. The target was set by adjusting the ruler to 90% of the subject's maximum arm-length-reach (defined as the distance between the acromion to the tip of the middle finger). Subjects were instructed before and intermittently throughout the period of testing to keep their back supported against the wall. They received two computer-generated auditory cues. The first cue (preparatory) – *"Get Ready"* – was given at 2 s, at which subjects visually focused their attention at the passive marker. The final cue – *"Go"* – was given at 4 s, at which subjects reached out and touched the target "as quickly and as accurately" as possible and returned to the starting position. On reporting to have missed the target during a certain trial, that trial was repeated to ensure achievement of the task each time. Subjects also received a short break after every five trials so as to avoid fatigue. Fifteen trials each of verbally cued forward reaching (through shoulder flexion) and sideways reaching (through shoulder abduction) were performed following three familiarization trials. Instructions to be "quick and accurate" were given from time-to-time to ensure continued adherence to the protocol. We tested the dominant arm due to its reported advantage for error correction and effective and consistent movement planning (Bagesteiro and Sainburg, 2002; R. Sainburg and Kalakanis, 2000).

2.4. Data recording and analysis

Delsys® Trigno™ wireless sensors were used to record surface electromyographic activity of the anterior (prime mover for shoulder flexion) and middle (prime mover for shoulder abduction) deltoid muscle of the dominant arm. The sensors were affixed to the skin surface using hypodermal tape, in line with the muscle over its belly, as recommended by Cram et al., 1998. Each sensor has four 5 × 1 mm contact surfaces made of 99.9% pure silver. Electromyographic signals were sampled at 2000 Hz, hardware band-pass filtered over a bandwidth of 20–450 Hz, using a common mode rejection ratio of >80 db. Tri-axial accelerometers embedded in these sensors rendered signals sampled at 148.1 Hz over a bandwidth of 50 Hz and amplitude range of ±1.5 g. To smooth the EMG data, signals were digitally high-pass filtered using a fourth order zero-lag Butterworth filter (MathWorks, Inc., MATLAB) with