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Motor affordance for grasping a safety handle

by

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A thesis submitted in partial fulfillment
of the requirements for the degree

of

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Abstract

Observation of objects in our environment can potentiate movement, a fact reflected by increased activity in motor cortical networks when participants simply view a graspable object. This suggests that specific areas in the motor cortex play an important role in processing visual information to rapidly determine an appropriate action. The present study was conducted to test if visual access to a wall-mounted safety handle – the type of handle commonly used to regain balance – results in activation of motor cortical networks. We hypothesized that the hand area of the primary motor cortex would be facilitated shortly after visual access to a safety handle versus when no handle was visible. To test this, we used transcranial magnetic stimulation (TMS) to measure corticospinal excitability (CSE) in hand muscles immediately after visual access while participants performed a seated reach-to-grasp task. Vision was controlled using liquid crystal lenses and TMS pulses were time-locked to occur shortly after the goggles opened but prior to movement. During visual occlusion, the environment was unpredictably changed to present either a handle or no handle (i.e. covered). Our results showed a rapid motor facilitation in muscles of the right hand when participants viewed a handle compared to trials where this handle was covered. First dorsal interosseus (FDI) and opponens pollicis (OP), synergists in closing the hand, were facilitated 120ms after visual access to the handle. Interestingly, this effect was absent at earlier (80ms) and later (160ms) points. By contrast, abductor digiti minimi (ADM) which moves the little finger away from the rest of the hand, was diminished when viewing the handle. These findings suggest a rapid engagement of muscles specific to grasping a handle based on visual access to the handle. The fact that this affordance effect was present for a wall-mounted safety handle has implications for automatically priming recovery actions based on our surroundings, even without awareness of an imminent fall.

Introduction

The idea of affordances, a term coined by James Gibson, is described as “the opportunities for action that the environment provides to an animal” (Gibson, 1979). In essence, we see the world around us in terms of how we can interact with it. When the visual centers of our brain receive input from an object, this information is thought to rapidly be directed to the brain’s motor areas associated with the muscles that would interact with the object (Cardellicchio 2011, Cisek 2007, Cisek & Kalaska 2010, Franca 2012, Ledberg 2006, Makris 2011, Rizzolatti 1998). For example, according to the affordances theory, if someone were to see a coffee mug sitting in front of them, there should be a raised level of excitability in the motor pathway associated with the fingers that would grab the handle of the mug. Because our central nervous system has physical limits for action potential transmission, a mechanism such as motor affordances would allow for a high degree of both speed and task relevance during interaction with objects in our environment. In cases where goal-directed action needs to happen quickly – such as quickly reaching for a nearby handrail to avoid a fall – the ability to automatically translate the visual environment into relevant action becomes very important when trying to avoid a fall in a complex environment. Consequently, the specific time course of this affordance phenomenon is important.

Animal models have been helpful in establishing the physiological basis for how visual processing areas of the brain can quickly lead to activation of specific cortical motor representations (Cisek 2007, Ledberg 2006, Rizzolatti 1998). For example, Ledberg and colleagues recorded activity across multiple cortical regions in macaques as they performed a go/no-go task (i.e. a task requiring interactive decision making based on a visual cue) and found cue-related differences in motor cortex excitation as early as 80ms after visual stimulus (Ledberg

et al., 2007). Following early activation of motor areas, activity across other frontal sites, including the prefrontal cortex, reflect the decision, and this process takes approximately 150ms in some tasks to integrate information to make a decision (Cisek & Kalaska 2005). This suggests that visual-based motor preparation for specific movements precedes the actual selection process.

Human studies have used behavior and neuroimaging methods to provide evidence for a motor affordance effect. From a behavioral perspective, when participants are presented with a visual cue (e.g. handle of a hammer), the orientation of the object plays a large role in evoking motor affordances, evident as faster reaction times when specific hand responses are unconsciously primed (Tucker & Ellis 1998). In terms of neuroimaging, Grafton et al. (1997) used positron emission tomography (PET) scans to determine that observation of man-made tools activate the premotor cortex (Grafton, 1997). Similarly, Grezes et al. (2003) demonstrated that changes in select brain networks using magnetic resonance imaging (MRI) were related to the compatibility between a viewed object and a specific grip type (Grezes, 2003). Grezes and colleagues also showed that reactions were fastest when viewed objects were congruent with the type of grip used to respond (e.g. if the viewed object could be grasped with a precision grip, reactions were faster when subjects responded to the image using a precision grip) (Grezes, 2003). These studies have built off of animal models to reveal evidence for an affordance effect in humans.

While the previously mentioned studies provide useful evidence for affordance in humans, there is limited evidence on the time course of the effect, which is a critical factor when goal-directed actions must be generated quickly. One tool that will be extremely useful in helping to determine the time course of affordance is transcranial magnetic stimulation (TMS). TMS uses a strong electromagnetic coil to deliver a focal, temporally precise pulse to a targeted

area of the brain. When TMS is applied over the motor cortex, it can be used to excite the motor pathways associated with the muscles that would be used to grasp the objects measured as a motor-evoked potential (MEP) using surface electromyography (EMG). By sending this TMS pulse in different conditions such as with and without an object, and controlling the precise time when TMS is delivered, the excitability of specific motor pathways at a given time point following access to vision can be determined. The higher the amplitude of the MEP, the greater the excitability of the associated pathway. The time course of affordance elicited when viewing (3D) graspable objects by a resting observer has been explored (Franca, 2012). In this Franca (2012) study, TMS was used to observe the excitability in the motor cortical areas associated with the hand muscles used to grasp objects. Of the three time points tested, an affordance effect was only observed at 120ms after visual access, but not at later time points (150, 180ms). Cardellicchio et al. (2011) used TMS 50ms after visual access while either a graspable or non-graspable object was placed either within reach or out of reach of a seated participant (Cardellicchio, 2011). Although the objects were presented with the use of virtual reality, they not only observed an affordance effect, but determined that only objects within reachable space produced this effect.

While the Franca study showed a strong affordance effect at 120ms after visual access to the graspable objects, time points prior to 120ms may exhibit an affordance response according to other models both human and animal (Ciscek and Kalaska, 2010; Rizzolatti, 2001; Ledberg, 2007, Cardellicchio, 2011). Also, previous studies have typically only used small 2D visual stimuli such as pencils and coffee mugs presented on a computer screen, but never objects relevant for balance recovery (e.g. a safety handle). Therefore, the present study delivered TMS immediately after visual access to observe motor pathway excitability in grasping hand muscles

while viewing a 3D object (safety handle) that could be used to regain balance. Although this study did not look specifically at balance, it will inform future studies looking at affordance in compensatory balance reactions when a quick and accurate decision must be made to avoid a fall. The present study sought to determine if an affordance effect is evoked in grasping muscles of the hand when viewing a safety handle, and investigated the time-course for this effect immediately following access to vision. ***Our hypothesis was that viewing a safety handle would result in greater corticospinal excitability in intrinsic hand muscles of the hand versus conditions where the handle was covered.***

Methods

Participants

25 young adults (13 Male, 12 Female) between 18-29 years of age (mean = 22.8 +/- 2.9 years) were recruited from the student population at Utah State University. All participants provided written informed consent to the procedures prior to testing. All procedures received approval from the Institutional Review Board at Utah State University and were conducted in accordance with the Declaration of Helsinki. Participants with neurological illness were excluded from the study. Furthermore, participants were screened prior to testing to assess the suitability for TMS using guidelines developed by a consortium of experts (Rossi, Hallett, Rossini, Pascual-Leone, & Safety of TMS Consensus Group, 2009).

Data Acquisition

Electromyography (EMG) readings were collected from three intrinsic hand muscles and a forearm muscle. The intrinsic hand muscles measured were the First Dorsal Interosseus (FDI),

Opponens Pollicis (OP), and Abductor Digiti Minimi (ADM) given the important role of these muscles in gripping objects and past TMS-based studies exploring hand affordance on intrinsic hand muscles (Buccino et al., 2009; Cardellicchio et al., 2011; Franca et al., 2012; Makris et al., 2011). In addition to grasp-related hand muscles, a wrist extensor (Extensor Carpi Radialis, ECR) was measured given the role of this muscle when initiating the reach to support handle from a resting arm position on the lap (observed during pilot testing).

TMS Protocol

Single-pulse TMS was delivered over the hand motor cortical representation while participants completed the experiment. These TMS pulses were time-locked to the opening of liquid crystal goggles (described below) for all experimental conditions. The purpose was to investigate the influence on motor preparation immediately upon receiving visual access to the environment. Notably, TMS was delivered soon after visual access, but prior to any movement (in trials where movement was required). Recall that the essential feature of this study was the preparatory state of the motor system related to perception of the environment, which means that TMS pulses were not delivered at any time when the body was in motion. Magnetic stimuli were delivered to the left primary motor cortex (M1) by a Magstim 200 (monophasic waveform) stimulator (Magstim Company Ltd., Whitland, UK). Stimulation was applied using a figure of eight D70² Coil (Double 70mm² Coil - Magstim Company Ltd., Whitland, UK), located at the position specified to obtain a motor evoked potential (MEP) in representative muscles of the contralateral hand. Specifically, TMS pulses were delivered over the site which consistently elicited an MEP for the right FDI (**Figure 1**). To allow hotspot localization and consistent coil placement markings were made directly on the scalp. Once this hotspot was located, the resting

motor threshold (RMT) was determined, a stimulator intensity where 5/10 MEPs exceed 50 microvolts peak-to-peak (Rossini & Rossi, 2007). The test stimuli used throughout the experiment was set at 1.2x RMT.

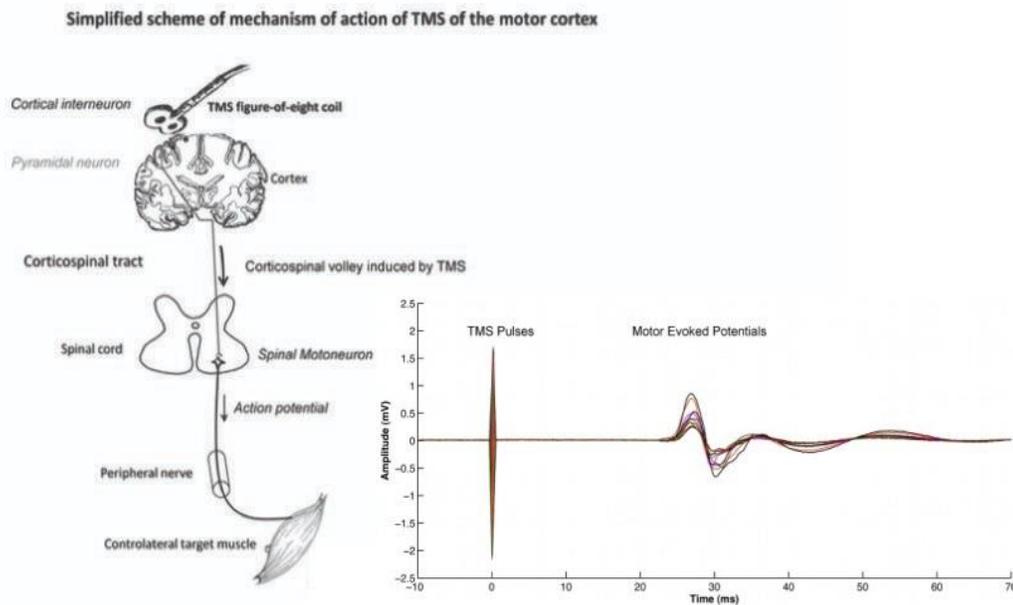


Figure 1. Motor pathway activity is transmitted from the TMS pulse on the motor cortex through motor neurons to specific muscles within the hand. The amplitude of the MEP recorded by the EMG electrodes in the hand muscles show excitability within the motor pathway. Adapted from Klomjai, W., Katz, R., & Lackmy-Vallée, A. (2015). Basic principles of transcranial magnetic stimulation (TMS) and repetitive TMS (rTMS). *Annals of physical and rehabilitation medicine* (Klomjai, 2015).

Control of Vision

Access to vision was manipulated in this study by use of liquid crystal goggles (Translucent Technologies Inc. Toronto, ON, Canada). These goggles can be programmed to open or close at very distinct time points, allowing a means for controlling the onset of visual stimuli in the environment. While closed, these goggles allow an illuminated view without access to the visual scene therefore participants were unaware of the upcoming response setting. During this visual occlusion period, the handle was covered or uncovered by the experimenter on each trial in a random order. Participants needed to quickly perceive and select their action once the

goggles opened for viewing. Because some small amount of auditory noise coincided with adjusting the environment in front of participant's field of view, noise-reducing earplugs were worn throughout all test sessions.

Experimental Procedure

All testing was conducted with participants seated directly in front of a safety handle mounted on a wall, within comfortable grasping range (**Figure 2**). Throughout testing, participants were told to remain relaxed with their hands resting on their lap while looking at the handle. They were instructed to move only when: (a) the handle was visible (i.e. uncovered) AND (b) if an auditory tone cued a reach to grasp the handle. Participants were briefly familiarized with reaching to the handle from a seated position prior to testing. Once testing commenced, they were instructed to remain as relaxed as possible unless prompted to move by imperative stimuli (i.e. presence of a handle and tone). Participants were encouraged throughout testing to reach as fast as possible upon hearing the tone when the handle was visible. Each trial started with the occlusion goggles closing for 6 seconds after which point the goggles open to offer a full view. The visual response environment included one of two possible configurations: (a) handle visible (REACH), or (b) handle covered (STAY). For the REACH condition, participants were required to reach-to-grasp the support handle with their right arm as quickly as possible once they heard the tone. TMS pulses were delivered at three different time points (80ms, 120ms, 160ms) in separate randomized test blocks. Each block consisted of 45 trials which lasted approximately 10 minutes per block (135 trials total for the experiment). Each trial was 10 seconds with short pauses before the next trial to allow participants a chance to reset as needed. Furthermore, participants were given a brief rest period in between each test block. TMS

pulses were always delivered after opening the goggles but prior to any auditory cues (if present). This tone was presented after the goggles opened with an onset delay of either 200ms or 1500ms. For one third of these trials, no auditory cue was presented acting as a ‘catch’ trial to prevent anticipatory reactions. In addition to the two visual conditions listed above, ‘no-vision’ reference trials were randomly interspersed throughout collection blocks to deliver TMS without opening the goggles. The purpose of this condition was to provide a baseline reference to account for any task-related changes in motor activity (e.g. heightened arousal). These reference trials also offered a baseline for normalizing MEP amplitudes in this study.

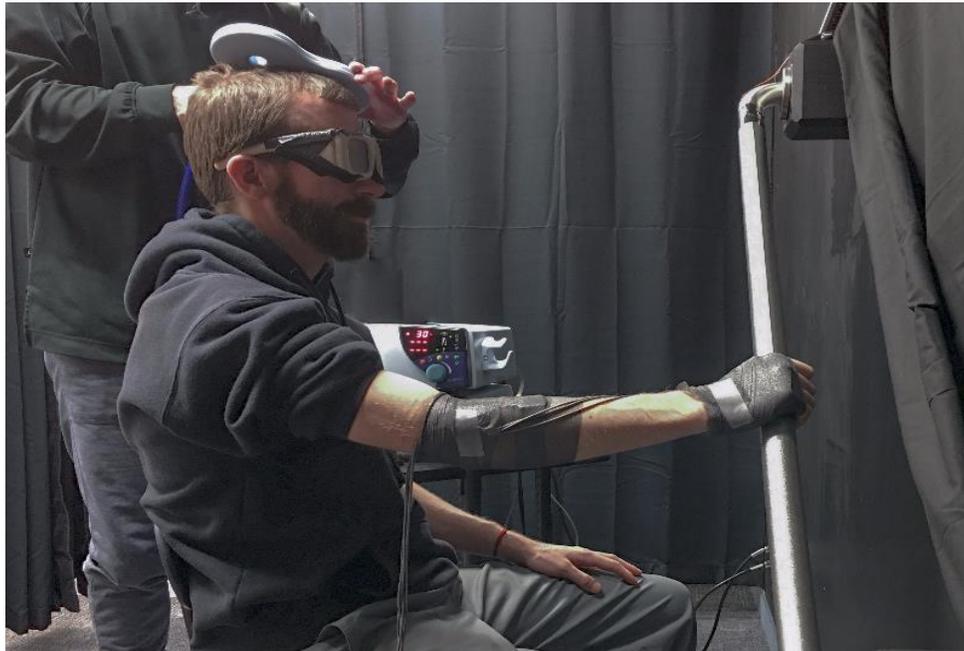


Figure 2. Participant seated within comfortable graspable range of a wall-mounted handrail wearing EMG electrodes on intrinsic muscles in the right hand. Liquid crystal goggles were used to occlude vision, and TMS was applied to the hand area of the motor cortex (left hemisphere).

Data Processing

Only trials where an appropriate behavioral response occurred were included in the analysis. An appropriate response was defined as ‘reaching for the handle following the tone

AND when a handle is visible'. Consequently, any trials where the participant either (a) reached for the handle when it was covered, or (b) reached prior to the tone - even if the handle was visible - were excluded. Background EMG was determined from the root mean square of EMG activity in a time window of 100ms immediately prior to TMS onset. If background EMG in this time window exceeded $10\mu\text{V}$ for a given muscle, the trial was discarded. Moreover, any trials where a muscle produced a very small MEP amplitude (i.e. $< 100\text{mV}$ peak-to-peak) were excluded. Finally, outliers were identified as those values falling outside the threshold defined by 1.5 times the interquartile range, and these outliers were excluded from further analysis.

MEP amplitude was determined as the rectified EMG area beginning at the positive EMG signal deflection for each hand muscle, and ending 50ms post TMS (~15ms – 50ms). To help standardize data, MEP amplitudes were converted into z-scores to reduce potential variability between test blocks within an individual and to reduce inter-subject variability (Hasbroucq et al., 1999; Klein-Flügge & Bestmann, 2012). The mean and standard deviations of the MEP amplitudes during 'no-vision' trials for each test block were used as a reference, for each participant separately. The individual MEP amplitudes observed in the other two 'vision' conditions (handle, no-handle) were converted into z-scores calculated from this reference. These normalized values were subsequently grouped for statistical analysis. Note that all MEP analyses were limited to the intrinsic hand muscles (FDI, OP and ADM) whereas ECR was only be used to monitor reaching behavior *following* the imperative tone. Our data revealed that the TMS over the hand representation resulted in comparable FDI and OP responses. Given the synergistic nature of these muscles they were averaged together to assess grasping affordance. Conversely, the ADM was analyzed separately consistent with the distinct role this muscle has

shown when performing different grip types (Cattaneo et al., 2005) and further consistent with the disparate influence of an affordance effect on FDI and OP versus ADM (Franca et al., 2012).

Statistical Analysis

A 2 x 3 repeated measures ANOVA was performed to test for main effects and interactions between the factors 'Handle' (Handle, No-Handle) and 'Time' (80ms, 120ms, and 160ms). Two separate 2 x 3 ANOVAs were completed for (a) FDI/OP_{average}, and (b) ADM respectively. Planned comparisons were used to test the hypothesis that the presence of an available handle would facilitate corticospinal excitability in the hand muscles relative to trials where the handle was covered with significance levels set at $p < 0.05$.

Results

Repeated measures ANOVA showed a significant interaction between the handle and time conditions for the averaged FDI/OP ($F_{2,48} = 3.654$, $p = 0.033$) but no main effects for handle ($F_{1,24} = 2.532$, $p = 0.125$) or time ($F_{2,48} = 1.680$, $p = 0.197$). Comparisons between the two handle conditions at each time interval revealed increased corticospinal excitability during the handle condition versus no-handle condition for the averaged FDI/OP at 120ms following access to vision ($t_{24} = 2.042$, $p = 0.026$), but not at the other time points (80ms $t_{24} = -1.157$, $p = 0.129$; 160ms $t_{24} = 1.057$, $p = 0.151$) (**Figure 3A**). Interestingly, ADM values showed that viewing the handle was associated with lower amplitude MEPs across all time points reflected in the main effect test for the handle condition ($F_{1,22} = 4.306$, $p = 0.049$), but no significant interaction ($F_{2,44} = 0.332$, $p = 0.719$) or main effect for the time condition ($F_{2,44} = 0.809$, $p = 0.452$) (**Figure 3B**). Comparisons between the two levels of the handle condition at each time condition showed

decreased corticospinal excitability in the presence of the handle versus no-handle condition for ADM at 120ms following access to vision ($t_{22} = -1.834$, $p = 0.04$), however this was not significant at other time points (80ms $t_{22} = -0.945$, $p = 0.129$; 160ms $t_{22} = -0.583$, $p = 0.151$).

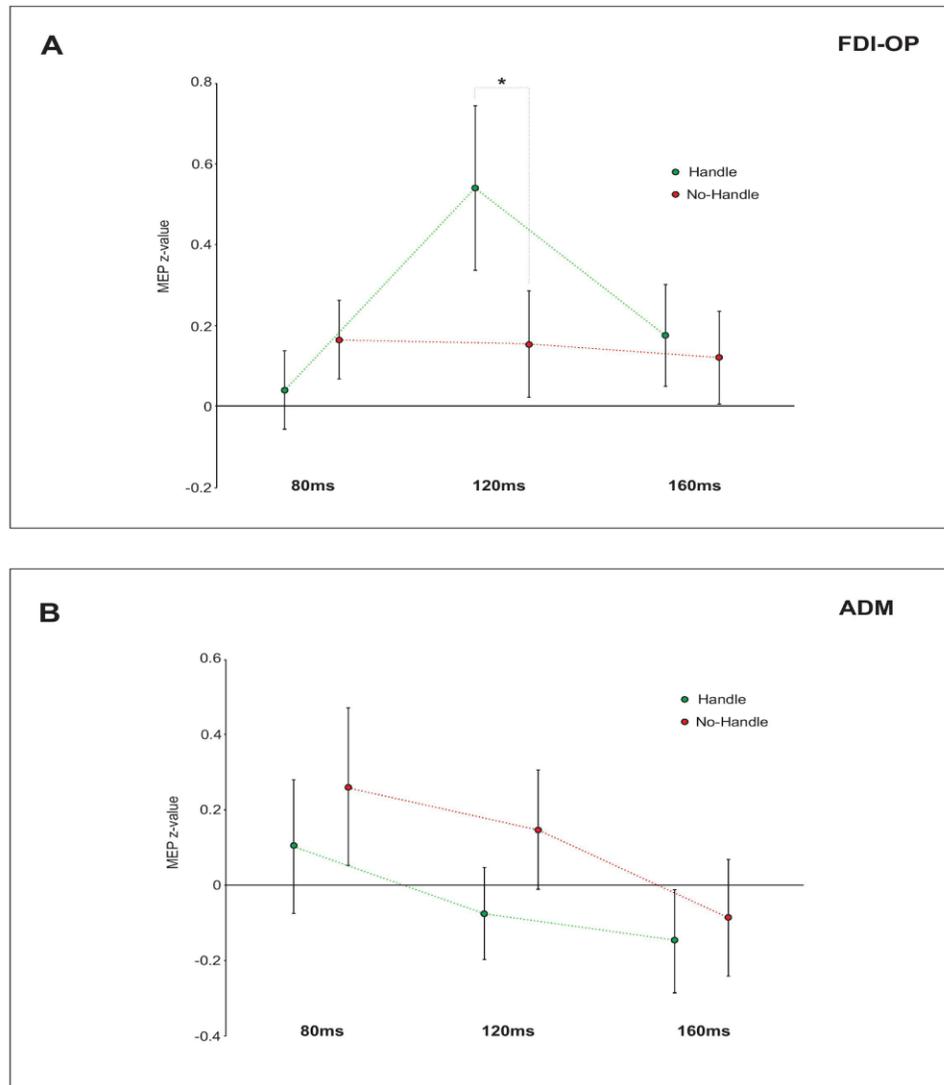


Figure 3. (A) Corticospinal excitability shows an increase in the FDI/OP when viewing the handle only at 120ms post visual access. (B) Interestingly, with the handle present, the ADM showed a reduction in corticospinal excitability at each time point. The offset plots for conditions at the same time interval is only to avoid overlap in range values.

Discussion

Cortical motor output from intrinsic hand muscles was rapidly modulated when participants viewed a wall-mounted safety handle compared to trials when the handle was covered. The changes in corticospinal excitability were selective in terms of the muscles affected, as well as the timing when a motor affordance effect was most prominent. The synergist grasping muscles (FDI and OP) showed increased excitability 120ms after viewing the handle. The effect was notably absent at earlier (80ms) and later (160ms) stages following access to vision. In comparison, the ADM muscle, an antagonist to hand opposition (i.e. closing the hand), did not show increased excitability when viewing the handle, and was actually diminished when the handle was made available. These findings suggest a rapid and selective priming of intrinsic hand muscles specific to grasping a safety handle shortly after visual access.

The previously discussed studies demonstrate how visual cues can facilitate relevant motor regions even before the decision to act, and exhibit a neural mechanism for how vision can prepare actions prior to a decision to move. Our data agrees with the previous studies that show this affordance effect is not present by 80ms, possibly due to neural transmission limits when activating the associated motor areas (Cisek & Kalaska, 2005; Ledberg, 2007; Rizzolatti & Fadiga, 1998). Furthermore, this effect appears to diminish quickly. The rapid dissipation of the affordance effect may be specific to instances when action is not immediately required, however this remains to be experimentally verified.

Though this study did not look at balance per se, present results offer an important first step in bridging past affordance research to the area of reactive balance control. A key bridge between previous studies and future balance studies is the use of a safety handle associated with maintaining balance, and the use of temporally precise TMS probes to show the time course for

corticospinal excitability immediately post-vision. Future studies will need to extend the current findings to test if an affordance effect can be measured in a standing context, which is an important consideration given the noted corticospinal excitability differences between seated and standing postures (Tokuno 2009; Kantak 2013). Furthermore, future studies should use stimuli that are more relevant to reactive balance control. In particular, rather than using arbitrary audible tones, postural perturbations could be used to create a context of instability to test if postural threat amplifies the affordance effect.

In conclusion, present findings show a rapid and selective priming of intrinsic hand muscles relevant to grasping a handle shortly after visual access. These results are consistent with the previously discussed concept of motor affordances where vision automatically translates viewed objects into appropriate motor terms. Since this affordance effect was observed in wall-mounted safety handle trials (an object commonly used to regain balance), it has potential implications for automatically priming compensatory arm reactions based upon our surroundings, even without the immediate danger of a fall. The next step will be to determine if this affordance effect is observed while standing when compensatory balance reactions are necessary, and with the safety handle presented in peripheral vision.

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