RESEARCH ARTICLE

The acute effects of action observation on muscle strength/weakness and corticospinal excitability in older adults

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Abstract

Muscle weakness is a critical problem facing many older adults. Interventions targeting nervous system plasticity may show promise in enhancing strength. The purpose of this study was to examine the acute effects of action observation on muscular strength characteristics and corticospinal excitability in older adults. Isometric wrist flexion strength characteristics and corticospinal excitability of the first dorsal interosseous (FDI) were measured in 14 older adults (mean age = 73 years) in response to observation of (1) STRONG contractions of the hand/wrist, (2) WEAK contractions of the hand/wrist, and (3) a CONTROL condition. Results from repeated measures analyses of variance (ANOVAs) indicated that rate of torque development at 200 ms (RTD200) significantly decreased from PRE to POST observation for CONTROL and WEAK, but not STRONG. No other ANOVAs were significant. However, effect sizes indicated that maximal voluntary contraction (MVC) peak torque showed moderate declines following WEAK ($d = -0.571$) and CONTROL ($d = -0.636$), but not STRONG ($d = 0.024$). Similarly, rate of torque development at 30 (RTD30), 50 (RTD50), and 200 (RTD200) ms showed large declines from PRE to POST after WEAK and CONTROL, but small changes following STRONG. FDI motor-evoked potential (MEP) amplitude tended to increase over time, but these results were variable. There was a pronounced effect from PRE to 8MIN ($d = 0.954$) during all conditions. Action observation of strong contractions may exert a preservatory effect on muscular strength. More work is needed to determine whether this is modulated by increased corticospinal excitability. The study was prospectively registered (ClinicalTrials.gov Identifier: NCT03946709).

Keywords Muscular weakness · Mirror neuron system · Neuromuscular system · Transcranial magnetic stimulation

Introduction

Neural interventions are easily accessible techniques which have demonstrated promise as a means to enhance functional outcomes, from improved sports performance (Fekih et al. 2020) to better rehabilitation outcomes (Bellelli et al. 2010). One such technique is that of action observation, whereby an individual simply observes another's actions. In viewing the actions of another, cortical pathways associated with voluntary movement are stimulated, and mirror neurons are thought to become activated (di Pellegrino et al. 1992; Rizzolatti et al. 1996). A specialized type of neuron found in the human frontal, parietal, and temporo-occipital cortices (Caspers et al. 2010), mirror neurons fire not only when performing an action, but also when an individual observes the same action being performed by another (di Pellegrino et al. 1992; Rizzolatti et al. 1996). In the seminal work by Fadiga et al. (1995), the motor cortex was stimulated via transcranial magnetic stimulation (TMS) in response to observation of grasping objects, arm movements, and viewing static objects. Motor-evoked potentials (MEPs) obtained from the hand muscles indicated that corticospinal excitability was significantly increased during observation of movements, indicating a neural system matching action observation and execution. Since this seminal work, multiple TMS studies have reported increased corticospinal excitability in response to action observation (Fadiga et al. 1995;

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Nojima et al. 2012; Strafella and Paus 2000). For example, increased corticospinal excitability (as measured by MEPs) has been observed in response to acute action observation interventions, such as observation of handwriting and arm movements (Strafella and Paus 2000), observation of hand pinching movements (Loporto et al. 2012), and reaching and grasping movements (Clark et al. 2004). Additionally, several studies have demonstrated increased strength and motor performance in response to action observation interventions. Previous investigations have demonstrated an increase in grip strength (Salama et al. 2011) and isometric force of the elbow extensors (Di Rienzo et al. 2019) following acute action observation interventions, and an increase in finger abduction strength (Porro et al. 2007) and eccentric hamstring force (Scott et al. 2018) following longer training interventions.

There is some evidence of improved motor outcomes in clinical populations in response to action observation interventions, as evidenced by Bellelli et al. (2010), in which post-operative orthopedic patients that routinely viewed videos of others performing their daily rehabilitative exercises had better functional outcomes than patients who did not. This likely provides evidence that action observation therapy is an effective strategy to improve motor rehabilitation outcomes. Using a similar neural intervention technique of mental imagery, Clark et al. (2014) reported that participants undergoing wrist immobilization experienced ~50% less strength loss when practicing regular mental imagery of muscle contractions than those undergoing immobilization only. Further, in those that did not perform mental imagery, muscle weakness was strongly associated with decrements in percent voluntary activation and increased corticospinal inhibition.

Despite these promising findings, to the best of our knowledge, the fact that action observation appears to activate specific cortical regions has not been fully explored in clinical aging research. However, the health implications associated with the aging musculoskeletal system are becoming increasingly recognized (Briggs et al. 2016). Among these critical problems is muscle weakness, with many older adults reporting an inability to lift loads as small as 10 pounds (Louie and Ward 2010). The inability to perform activities of daily living and associated loss of independence have been linked to depression (Chang et al. 2017), anxiety (Pasco et al. 2015), and all-cause mortality (Newman et al. 2006). Whereas age-related weakness has traditionally been attributed to muscle atrophy, or sarcopenia, the decrease in muscle mass only explains a portion of strength loss (Delmonico et al. 2009; Frontera et al. 2000; Goodpaster et al. 2006). Several studies have demonstrated that the decline in strength occurs more rapidly than

the concomitant loss of muscle mass (Delmonico et al. 2009; Frontera et al. 2000). For example, in a 12-year longitudinal study of older men, Frontera et al. (2000) observed a 20–30% loss in strength of the knee extensors, despite only 12.5–16.1% loss in muscle cross-sectional area (CSA). Similarly, Delmonico et al. (2009) observed losses in muscle torque that were 2–5 times greater than accompanying losses in CSA in older adults over a 5-year period. Emerging evidence suggests that impairments in the neuromuscular system's ability to voluntarily generate force plays a more central role in strength production than previously believed (Clark et al. 2014; Clark and Manini 2008; Clark and Taylor 2011). Therefore, it is likely that the age-associated loss in muscle strength, or dynapenia, is related to the aging central nervous system's ability to recruit and control motor units, and not solely dependent on muscle mass. Indeed, studies have shown that the motor units of older adults display lower peak firing rates (Kamen et al. 1995), altered recruitment and de-recruitment (Erim et al. 1999), recruitment threshold compression (Girts et al. 2020), poor force steadiness (Galganski et al. 1993), and exceptions to the typical inverse relationship between firing rate versus recruitment threshold (Kamen and De Luca 1989).

As muscle weakness has largely been considered symptomatic of atrophy, many investigations have focused on influencing muscle protein synthesis or tissue size more so than neural function. If a strong link between corticospinal activation and muscle force output exists in older adults, interventions that curtail muscle weakness by consistent activation of appropriate cortical regions might be extremely valuable. Given the lack of participation in resistive activities (NHIS— National Health Interview Survey 2021), combined with bouts of illness, injury, or immobilization that often accompany advanced age and prevent strength training, interventions to preserve muscle strength could undoubtedly enhance recovery and improve quality of life.

As it appears that factors influencing muscle weakness in older adults are not solely occurring at the level of the muscle tissue (Clark and Manini 2012), further inquiry into the neurophysiological aspects of muscle strength and weakness is necessary. Therefore, the purpose of this study was to examine the acute effects of action observation on muscular strength, rapid strength development, and corticospinal excitability in older adults. We hypothesized that observation of strong muscle contractions would acutely increase strength, and such changes would be facilitated by enhanced corticospinal excitability. In contrast, we hypothesized that observation of very weak muscle contractions would result in no change in muscle strength or even acute muscle weakness, accompanied by decreased corticospinal excitability.

Methods

Study design

This controlled laboratory study utilized a repeated measures design in healthy adults aged ≥ 60 years. Voluntary strength of the wrist flexors and corticospinal excitability of the first dorsal interosseous (FDI) was measured in response to: (1) observation of very strong, forceful contractions of the hand and wrist flexors, (2) observation of very weak, feeble contractions of the hand and wrist flexors, and (3) a control condition involving no action observation. Including a familiarization visit to minimize the influence of a learning effect, participants visited the laboratory a total of four times. Experimental conditions were randomized and counterbalanced. The laboratory was kept consistent and quiet for every testing visit. Each visit was separated by ≥ 24 h, but not more than 1 week. All visits occurred at the same time of day ± 1 h. The study was prospectively registered (ClinicalTrials.gov Identifier: NCT03946709) with a final sample size goal of $N = 20$; however, our final N goal was not achievable due to the COVID-19 global pandemic. As such, these findings should be considered preliminary, rather than confirmatory. All study procedures were approved by the University Institutional Review Board (#SBE-18-14657).

Participants

Seventeen healthy older adults enrolled in this study. Three participants elected to voluntarily leave the study during or immediately after the familiarization visit due to discomfort with the TMS procedures. Fourteen healthy older adults (5 men, 9 women; mean $\pm$ SD age $= 73 \pm 6$ years; height $= 1.67 \pm 0.06$ m; mass $= 78.0 \pm 24.1$ kg; hand grip strength $= 0.37 \pm 0.12$ kg/kg) completed all study visits and were included in final data analysis. Participants completed the SARC-F Questionnaire, which is a five-question survey designed to rapidly screen for sarcopenia (Malmstrom and Morley 2013). Briefly, the SARC-F assesses strength, assistance needed with walking, ability to rise from a chair, ability to climb stairs, and number of falls within the last year. Each question is scored from 0 to 2, with 0 being the ideal score (e.g., no trouble climbing stairs, no falls in the last year). Total scores range from 0 to 10, with scores of four or more predicting sarcopenia. In the present sample, only one participant scored ≥ 4, suggesting that the sample was largely high-functioning and non-sarcopenic. Before enrollment, participants completed an extensive screening process that included detailed health history and a TMS-specific screening questionnaire based on the recommendations described by Rossi et al. (2009). Major exclusion criteria included a history of seizures, neuromuscular disease, pain/arthritis in the upper limbs, and any other health-related illnesses that would prohibit safe testing. Participants were asked to provide detailed information on recent hospitalizations and a complete list of current medications. Due to the broad range of exclusion criteria, decisions for inclusion were considered on a case-by-case basis under the guidance of the laboratory physician. Before study enrollment, all participants read and signed an informed consent document.

Maximal voluntary contraction torque

Maximal isometric strength of the non-dominant wrist flexors was assessed with a Biodex System 4 isokinetic dynamometer (Biodex Medical Systems, Inc., Shirley, NY) according to manufacturer guidelines. Hand dominance was determined via use of the Edinburgh Handedness Questionnaire (Oldfield 1971). Prior to maximal strength testing, participants performed a warm-up of isometric wrist flexion at 50% of their perceived maximum. Following the warm-up, participants performed maximal voluntary contractions (MVCs) to assess isometric wrist flexion strength. Each MVC was 3–4 s in duration, separated by at least 3 min rest. During each MVC, participants were given strong verbal encouragement to "push hard and fast." Additionally, visual feedback of torque–time curves was displayed on a monitor in front of them. Three MVCs were performed before each action observation condition and the mean peak torque value was used to quantify the pretest (PRE) value. A final MVC was performed following each action observation condition, with the peak torque corresponding to the posttest (POST) strength value.

Surface electromyography (EMG)

Throughout all testing procedures, a wireless bipolar surface EMG sensor (inter-electrode distance $= 10$ mm; Trigno EMG, Delsys, Inc., Natick, MA) was placed over the belly of the non-dominant FDI muscle, which was visually determined by asking the participant to abduct their index finger against light, manual resistance. Prior to sensor placement, the skin was shaved with a disposable razor, tape was used to remove dead skin cells and debris, and rubbing alcohol was used to cleanse the site. Following skin preparation, double-sided tape was applied to secure the EMG sensor over the muscle. Prior to testing, participants performed

several submaximal contractions to ensure low baseline noise ($\leq 20\ \mu V$) and minimal line interference. EMG signal quality was monitored throughout the study, and additional skin preparation or repositioning of the sensors was performed as necessary.

TMS

Single-pulse TMS was performed using a MagStim 200^2 stimulator (The Magstim, Whitland, UK). A 70-mm figure-of-eight focal coil was positioned tangentially to the scalp with the handle pointing backwards and laterally at 45° from the midline. The hotspot was determined as the location over the motor cortex that elicited the largest peak-to-peak amplitude for FDI MEPs. To determine this, the vertex of the scalp was found by marking the area measured at the intersection of the lines of length (from nasion to inion) and width (from tragus to tragus). A spot 5 cm lateral from the vertex, in line with the tragus, was then marked as the ideal starting point for stimulating the contralateral FDI. Once the 5 cm location was determined, four additional spots were marked in 1 cm increments surrounding the center point, in the manner of a compass: north, south, east, and west. Including the initial center point, this resulted in a total of five spots for initial hotspot testing. Five single pulses were delivered to each location, beginning at a stimulator output of 50% and the resulting MEPs were quantified and averaged at each point. The point with the highest average was determined the "new center" and surrounding compass points were marked around that spot. This process was repeated for a total of three rounds, until the area with the highest MEP peak-to-peak amplitudes was determined as the hotspot. Once identified, this location was marked on a Lycra® cap to ensure consistent coil placement. After hotspot determination, resting motor threshold was defined as the lowest stimulator intensity that could reliably produce a MEP of $\geq 50\ \mu V$ for five out of ten pulses. The hotspot location and resting motor threshold were retested during every visit to the laboratory.

Once resting motor threshold was determined, 130% of this value was used to deliver six TMS pulses before and every 2 min during the action observation intervention. This resulted in a total of five rounds of six pulses during action observation, delivered at pretest (PRE), 2 min (2MIN), 4 min (4MIN), 6 min (6MIN), and 8 min (8MIN). For each visit and time interval, the mean peak-to-peak amplitude value of the six pulses was used for statistical analyses.

Action observation

Throughout action observation, participants observed a video 8 min in length which displayed an older adult of the same sex performing either maximal effort (STRONG) or weak (WEAK) hand and wrist flexion contractions. The intent of the STRONG and WEAK videos was to showcase a strong older adult and a weak older adult, respectively. The actors in the STRONG videos had no problem performing the requisite tasks, while the actors in the WEAK videos struggled to complete the tasks. Observed actions included cutting paper, lifting bags of groceries, squeezing a stress ball, crushing soda cans, pinching objects, and lifting dumbbells (Fig. 1). During STRONG, the actors performed the tasks with ease. In contrast, during WEAK, the actors struggled to perform the tasks (e.g., an inability to lift/dropping objects). Participants were instructed to sit quietly and focus on the action being performed. During both familiarization and CONTROL, participants observed the blank screen.

Signal processing

All torque, TMS, and EMG signals were acquired in-sync with EMGworks software (version 4.7.5, Delsys Inc., Natick, MA, USA). The EMG sensor bandwidth was 20–450 Hz, the input range was 11 mV, and the sampling rate was 1926 Hz. The peak-to-peak amplitude (μV) of each EMG signal during TMS hotspot and resting motor threshold testing was quantified in real-time. Torque and EMG signals were processed off-line using custom LabVIEW software (version

Fig. 1 Action observation setup (**a**). Actions observed included using scissors (**b**), squeezing a clip (**c**), crushing cans (**d**), and squeezing a stress ball (**e**)
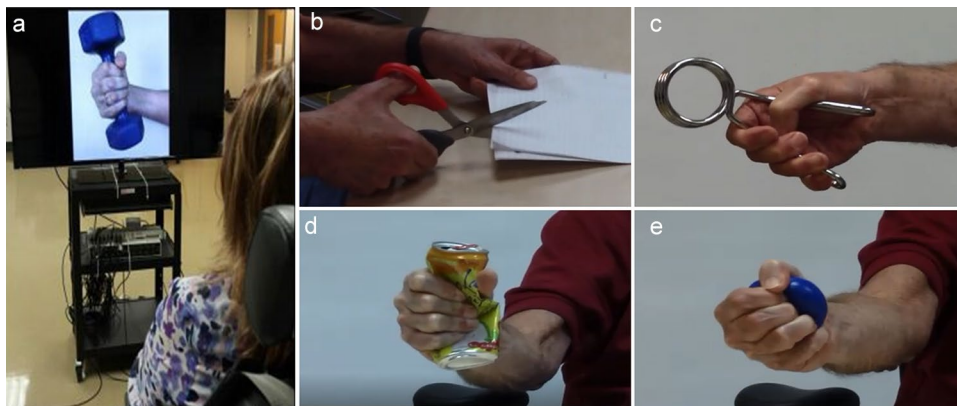
20.0, National Instruments, Austin, TX). Peak torque (Nm) was calculated as the highest 500 ms epoch throughout the duration of the MVC. The signal onsets were determined manually via visual inspection as the point when the signal first deflected from baseline (Gerstner et al. 2017). Rate of torque development (RTD) was quantified from the linear slope of the ascending portion of the torque-time curve at 30, 50, and 200 ms from onset. A custom LabVIEW program was used to quantify the peak-to-peak amplitude from the condition data (i.e., PRE, 2MIN, 4MIN, 6MIN, 8MIN). The primary investigator was blinded to condition and time during all data analyses.

Statistical analyses

All torque data were normalized to body mass prior to statistical analyses. Four separate two-way repeated measures (time [PRE, POST] × condition [STRONG, WEAK, CONTROL]) analyses of variance (ANOVAs) were used to examine mean differences for MVC peak torque, RTD30, RTD50, and RTD200. Two additional two-way repeated measures (time [PRE, 2MIN, 4MIN, 6MIN, 8MIN] × condition [STRONG, WEAK, CONTROL]) ANOVAs were used to examine mean differences in MEP amplitude for the FDI during 2-min intervals throughout action observation. If the sphericity assumption was violated, Greenhouse–Geisser corrections were applied. Partial eta-squared statistics (η_p^2) were used as a measure of the effect size for each ANOVA, with values of 0.01, 0.06, and 0.14 representing small, medium, and large effects, respectively (Cohen 1988). Follow-up analyses included Bonferroni post hoc comparisons. An alpha level of 0.05 was used to determine statistical significance for all repeated measures ANOVAs and Bonferroni post hoc comparisons. Cohen's d effect sizes were used to highlight important pairwise differences, with values of 0.2, 0.5, and 0.8 corresponding to small, medium, and large effects, respectively (Cohen 1988). All statistical procedures were carried out with JASP software (version 0.14.1, University of Amsterdam, Amsterdam, The Netherlands).

Results

MVC peak torque

Results from all measured torque characteristics are presented in Table 1.

Results from the Greenhouse–Geisser corrected two-way repeated measures ANOVA indicated that there was not a significant time x condition interaction ($F = 2.335$, $p = 0.143$), though the effect size was large ($\eta_p^2 = 0.152$). The results further demonstrated that there was no main effect for time ($p = 0.051$, $\eta_p^2 = 0.246$) or condition ($p = 0.137$, $\eta_p^2 = 0.152$). However, it should be noted that the p value of 0.051 for the main effect for time very nearly achieved significance. Based on Cohen's d effect sizes, MVC peak torque showed moderate declines following WEAK ($d = -0.571$) and CONTROL ($d = -0.636$), but not STRONG ($d = 0.024$) (Fig. 2a).

RTD30

Results from the Greenhouse–Geisser corrected two-way repeated measures ANOVA indicted that there was not a significant time x condition interaction ($F = 2.451$, $p = 0.124$), though the effect size was large ($\eta_p^2 = 0.159$). The results further demonstrated that there was no main effect for condition ($p = 0.685$, $\eta_p^2 = 0.020$), but there was a significant main effect for time (PRE > POST; $p = 0.013$, $\eta_p^2 = 0.388$). Based on Cohen's d effect sizes, RTD30 showed a large decline following WEAK ($d = -0.881$), but small changes following STRONG ($d = -0.304$) and CONTROL ($d = -0.025$) (Fig. 2b).

RTD50

Results from the repeated measures ANOVA indicated that there was not a significant time × condition interaction ($F = 2.371$, $p = 0.113$), though the effect size was large ($\eta_p^2 = 0.154$). The results further demonstrated that there was no main effect for condition ($p = 0.724$, $\eta_p^2 = 0.025$) but there

	MVC	RTD30	RTD50	RTD200
STRONG PRE	0.087 ± 0.025	0.039 ± 0.029	0.058 ± 0.048	0.122 ± 0.067
STRONG POST	0.087 ± 0.032	0.028 ± 0.023	0.042 ± 0.038	0.104 ± 0.067
WEAK PRE	0.085 ± 0.027	0.051 ± 0.054	0.075 ± 0.078	0.125 ± 0.079*
WEAK POST	0.075 ± 0.022	0.020 ± 0.011	0.030 ± 0.018	0.092 ± 0.046*
CONTROL PRE	0.088 ± 0.027	0.032 ± 0.022	0.051 ± 0.040	0.133 ± 0.074*
CONTROL POST	0.077 ± 0.025	0.031 ± 0.028	0.041 ± 0.039	0.087 ± 0.046*

Table 1 Torque characteristics results

Results presented in mean ± SD. Units = Nm/kg

*Statistically significant differences were observed (PRE > POST)
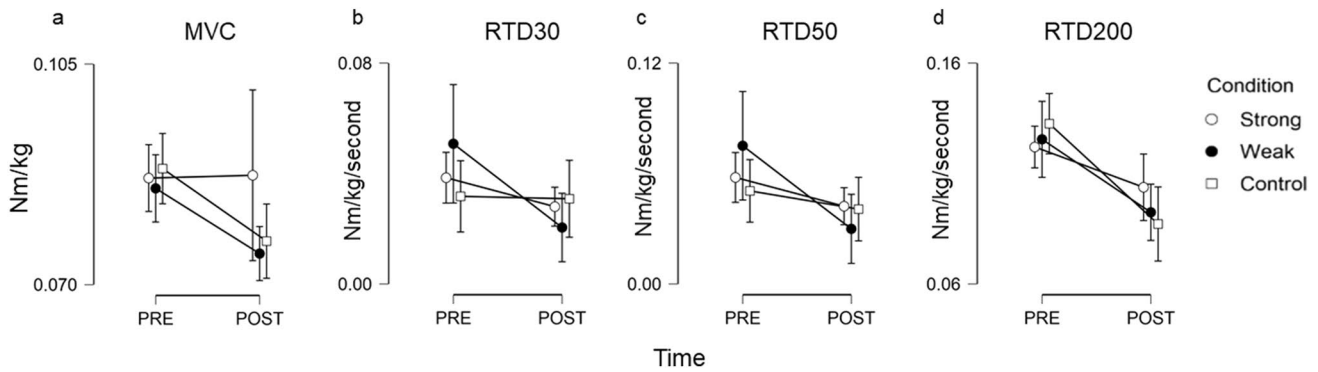
Fig. 2 PRE to POST test results. **a** MVC peak torque, **b** RTD30, **c** RTD50, **d** RTD200. All data points represent mean ± SD

Table 2 FDI MEP amplitude values

	Strong	Weak	Control
PRE	1.987 ± 1.727	1.765 ± 2.907	1.324 ± 1.117
2MIN	1.659 ± 1.343	1.330 ± 1.612	1.574 ± 1.243
4MIN	1.698 ± 1.440	1.549 ± 1.750	2.154 ± 2.321
6MIN	1.691 ± 1.265	1.288 ± 1.670	1.800 ± 1.822
8MIN	3.530 ± 5.470	1.835 ± 2.156	2.566 ± 2.217

Results presented in mean ± SD. Units = mV

Fig. 3 FDI MEP amplitude throughout action observation conditions. All data points represent mean ± SD

was a significant main effect for time (PRE > POST; $p = 0.005$, $\eta_p^2 = 0.467$). Based on Cohen's d effect sizes, RTD50 showed a large decline following WEAK ($d = -0.988$), but small changes following STRONG ($d = -0.342$) and CONTROL ($d = -0.216$) (Fig. 2c).

RTD200

Results from the repeated measures ANOVA indicated that there was a significant time × condition interaction ($F = 3.752$, $p = 0.037$, $\eta_p^2 = 0.224$). Bonferroni post hoc comparisons indicated that RTD200 significantly decreased from PRE to POST only for CONTROL ($p = 0.002$, $d = -1.207$) and WEAK ($p = 0.044$, $d = -0.878$) (Fig. 2d).

FDI MEP amplitude

Results from the Greenhouse–Geisser corrected repeated measures ANOVA indicated that there was not a significant time × condition interaction ($F = 0.677$, $p = 0.467$, $\eta_p^2 = 0.049$). The results further demonstrated that there was no main effect for time ($p = 0.054$, $\eta_p^2 = 0.213$) or condition ($p = 0.374$,
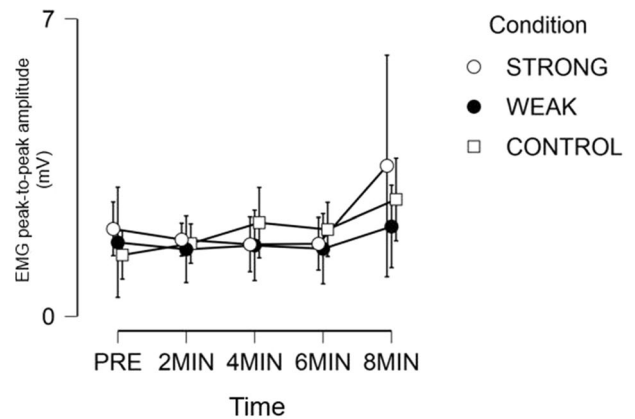
$\eta_p^2 = 0.072$). Results are presented in Table 2. However, when examining effect sizes, FDI MEP amplitude tended to increase over time, though these responses were highly variable (Fig. 3). There was a large effect from PRE to 8MIN for all conditions ($d = 0.954$).

Discussion

The primary finding of this investigation was that STRONG appeared to exert a preservatory effect on torque characteristics from PRE to POST action observation. While moderate to large declines in peak torque, RTD30, RTD50, and RTD200 were observed after WEAK, minimal changes were observed following STRONG. This is partially aligned with our hypothesis. While STRONG did not result in increased strength, WEAK appeared to exert a negative influence on strength. Given the prevalence of age-related dynapenia, the results of this intervention indicate that action observation may be a promising means

of preserving muscular strength during periods of illness, injury, or when strength training is not feasible.

It has long been accepted that the nervous system is a key determinant of muscular strength (Moritani and deVries 1979). However, the role of the motor cortex in strength production has only recently garnered attention, as the motor cortex has historically been associated with motor control and task execution (Wong et al. 2015). Nevertheless, recent investigations utilizing mental imagery have demonstrated positive changes in strength in the absence of muscle contraction, likely due to activation of areas of the brain associated with movement preparation and execution (Di Rienzo et al. 2019; Hétu et al. 2013). While the current intervention did not result in strength improvements after STRONG, it is possible that the observation of strong contractions did offer a preservatory effect on torque output, as strength parameters during STRONG did not change, but tended to decrease throughout WEAK.

While the literature on the effects of observing weak muscle contractions on strength is lacking, there has been some investigation of the effects of observing subpar exercise tasks on subsequent performance. Wrightson et al. (2016) found that observation of fast arm ergometry improved performance, while observation of slow arm ergometry had no effect on performance. There are several possible reasons for this outcome. It has previously been suggested that changes in exercise performance are due to changes in arousal, rather than changes within the action observation network (Wrightson et al. 2016). In mental imagery studies, which activate similar neural pathways as action observation, it has been postulated that changes in neural control as a result of mental imagery may underlie the observed effect of imagery training on muscle force production (Zijdewind et al. 2003). Further, these types of neural interventions may enhance the neural drive of contractions, thereby modulating force production (Zijdewind et al. 2003). In the present study, it is possible that neural drive and increased arousal associated with the STRONG condition helped to preserve strength, while the lack of similar drive in WEAK and CONTROL resulted in torque decrements. This may have also been partially responsible for the observed decrements in RTD200 from PRE to POST during WEAK and CONTROL, but not during STRONG. Late rapid torque characteristics have been observed to be impaired in older adults more so than early rapid torque characteristics (Gerstner et al. 2017; Klass et al. 2008; Olmos et al. 2020). This is thought to be partially due to an inability to sustain muscle activation during late rapid torque development (Klass et al. 2008), as well as maximal strength capability (Andersen and Aagaard 2006). Given the observed decrements in MVC torque during WEAK and CONTROL, it is possible that the lower torque production in these conditions impacted RTD200, but not earlier rapid torque development at RTD30 and RTD50. Further,

although we did not measure voluntary activation, it is possible that the STRONG conditions resulted in a preservation of muscle activation during late RTD, but not early RTD.

Several investigations that have observed performance improvements in response to action observation have utilized action observation in combination with mental imagery (Di Rienzo et al. 2019; Ranganathan et al. 2004) or during longer/training interventions (Bellelli et al. 2010; Porro et al. 2007; Scott et al. 2018). It is therefore possible that the acute nature of this intervention was insufficient to cause pronounced changes in strength and corticospinal excitability. Similarly, the length of the intervention video may have not been long enough to produce an observed response. A recent investigation by Yasui et al. (2019) demonstrated that at least 10 min of action observation in combination with mental imagery and electrical nerve stimulation was required for MEP enhancement. Further, while we cannot know with certainty what the participants were thinking during action observation, they were encouraged to focus their attention externally, on the hand/wrist of the actor, rather than to internally imagine performing the actions themselves. In an effort to ensure that participants were focusing on the working muscles, a screen of text was included with each video action, explaining what the actor was doing and where to concentrate attention ("The man/woman will try to crush the can. Focus your attention on the muscles of the hand and wrist.") While the intention of the text was to ensure attentional focus, it may have detracted from strict observation of the presented actions. It has previously been demonstrated that "distractors" in the video frame can alter corticospinal responses during action observation (Sartori et al. 2012a, b). While this is primarily thought to be due to subtle kinematic differences in movements when distractors are present near the actor, it is possible that the inclusion of text, as well as objects in the background of videos, did in fact distract from the primary task of action observation. Additionally, many participants found it difficult to remain silent throughout the intervention period and had to be consistently reminded to please sit and observe quietly, which may have interrupted their focus.

In an effort to allow the participants to identify with the videos they were viewing, we used age and sex-matched actors. While the WEAK videos appeared extremely feeble (e.g., shaky movements, difficulty grasping objects), the STRONG videos showed healthy, efficient movements (e.g., successfully lifting dumbbells) performed by other older adults. It is possible that WEAK resulted in decreased torque values due to the extreme weakness showcased, while the viewing of an older adult during STRONG was not pronounced enough to garner observable strength increases. In fact, several participants remarked that they were stronger than the actors in the STRONG videos, or that they would never allow themselves to become as weak as those in the WEAK videos. It is also

important to note that, at the culmination of videos, we showed particularly pronounced STRONG/WEAK movements. At this point during STRONG, we utilized videos of a young (i.e., no longer age matched) bodybuilder performing heavy dumbbell wrist and bicep curls. This may explain the particularly pronounced FDI MEP values obtained at the end of STRONG, as well as the large effect from PRE to 8MIN. In support of this hypothesis, the level of observed or imagined contractions has been demonstrated to modulate corticospinal responses (Helm et al. 2015; Mizuguchi et al. 2013). It is therefore possible that the increased effort/strength displayed by the bodybuilders at the end of the observation period played a role in both strength preservation and increased corticospinal excitability. However, as a large effect from PRE to 8MIN was evident in all conditions, it may be more likely that the anticipation of the POST MVC effort caused observed MEP increases at the 8MIN mark, as increases in corticospinal excitability have been observed prior to action execution (Derosiere et al. 2020; Wong et al. 2015). As the participants were aware that the action observation period would last 8 min, it is possible that they were mentally preparing to perform the POST MVC during the last TMS pulses, leading to increases from PRE to 8MIN for all conditions.

This study had several limitations worth discussion. In an effort to create a controlled environment, the lab was kept very quiet throughout the action observation period. However, sitting in silence while watching a blank screen during CONTROL proved to be challenging for several of our participants, as they began to fall asleep. While we did our best to wake them as soon as we noticed, this may have altered both strength and corticospinal responses, as the POST MVC and 8MIN TMS pulses were now occurring after a brief bout of sleep. This may be partially responsible for the declines in torque observed during CONTROL. Further, previous investigations have observed depression of MEPs during and immediately after sleep (Avesani et al. 2008; Grosse et al. 2002), which likely impacted the corticospinal excitability results. It is also possible that corticospinal excitability results were impacted by the number of MEPs measured at each time point. While several studies have shown measurement of as few as five MEPs to be reliable, (Christie et al. 2007; Doeltgen and Ridding 2010), others have demonstrated that analyzing a greater number of MEPs provides increased reliability (Bastani and Jaberzadeh 2012). Additionally, the action of isometric wrist flexion was challenging for many participants. Although this was practiced during the familiarization visit, it is possible that it continued to be a challenge throughout. Further, many participants found it difficult to remain quiet throughout the intervention period, which may have interrupted their focus. Finally, due to the COVID-19 pandemic and increased risk of severe illness in older adults (Carrillo-Garcia et al. 2021), we were unable to complete data collection on our target sample size. As such, the study may be underpowered.

Conclusion

The acute effects of action observation on muscle strength characteristics and corticospinal excitability in older adults appear promising. Although the results are limited due to a small sample size, it appears that observation of very strong contractions of the hand/wrist may confer a preservatory effect on strength. While this may be modulated by increased corticospinal excitability over time, more work is needed in this area. To fully determine whether action observation is an effective treatment for older adults, further intervention studies are necessary. Future research should examine larger sample sizes, fewer on-screen distractors, longer training interventions, and a more pronounced STRONG condition.

Data availability Data will be made available by the corresponding author upon reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no conflicts of interests or competing interests.

Ethics approval All study procedures were approved by the University Institutional Review Board in accordance with the ethical standards set forth in the 1964 Declaration of Helsinki.

Consent to participate Informed consent was obtained from all individual participants included in this study.

Consent for publication The authors affirm that participants provided consent for publication of images.

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