Title: Perceived effort for reaching is associated with self-reported fatigue

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Abstract (word count 119)

Perceived effort for goal-directed reaching may be impacted by the level of self-reported fatigue, however, the relationship between self-reported fatigue and perceived effort has not been examined. We examined how perceived effort changed under varied reach conditions and the relationship between fatigue, perceived effort and reach performance. Twenty-three young adults performed reach actions toward 9 different targets on a digitizing tablet. Perceived effort was measured using the Borg Rate of Perceived Exertion and Paas Mental Effort Rating Scale. Self-reported fatigue was quantified using the Fatigue Scales for Motor and Cognitive Functions. As reach conditions became more difficult, perceived effort increased significantly. Further, individuals who reported greater fatigue also reported greater perceived effort and showed greater endpoint error during reaching.

Keywords: motor control, fatigue, perception of effort, tiredness, reach

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Introduction

Voluntary movements generate not just motor outputs but also subjective experiences, such as conscious intention, sense of agency and perception of effort (de Morree et al., 2012; Zenon et al., 2015). Perceived effort during movement is defined as “the conscious sensation of how hard and strenuous the motor task is” (Marcora, 2009) or “the amount of mental or physical energy being given to a task” (Abbiss et al., 2015). Perception of effort during movement is often quantified by individuals’ self-report, for example using the Borg Rating of Perceived Exertion (Borg RPE). Force production tasks are the most commonly used paradigm to study perceived effort during movement (de Morree et al., 2012; Hampton et al., 2014; Slobounov et al., 2004). In general, there is a proportional relationship between the amount of force produced and the level of perceived effort. For instance, de Morree et al. reported that RPE increased when the weight lifted increased from 20% of 1RM to 35% of 1RM. Further, muscular fatigue induced by a fatiguing protocol often leads to an increase in perceived effort (de Morree et al., 2012; Guo et al., 2017; Hampton et al., 2014).

Perceived effort during reaching has received less attention in the literature compared to force production tasks. Perceived effort of reaching has been generally inferred indirectly by using an action choice paradigm (Morel et al., 2017; Potts, Pastel, et al., 2018; Rosenbaum & Gaydos, 2008). In this paradigm, reaching conditions that were chosen less frequently were thought to be perceived as more effortful or difficult (Rosenbaum & Gaydos, 2008). While action choice may be a proxy for perceived effort, it is also influenced by other factors such as self-efficacy, error, and success (Chen, 2012; Feghhi & Rosenbaum, 2020; Morel et al., 2017; Schweighofer et al., 2015) therefore making the interpretation difficult. To our knowledge, only one study to date has used a self-report rating to directly quantify perceived effort during reaching (Rosenbaum & Gregory, 2002). In the experiment 1 of that study, the reaching task involved flexing and extending the right elbow across different ranges of motion at different prescribed speeds. The authors found that self-reported rating of effort increased as movement amplitude and speed increased. Reaching tasks in daily activities, however, generally involve more than one joint (e.g. reaching toward a target placed at the contralateral workspace) and include both arms. In the present study, we aimed to study perceived effort with a reaching task paradigm that included variations in reach distance, reach direction and target size in both the dominant and non-dominant arms.

Intensified perceived effort during task performance is a common problem in individuals who suffer from chronic fatigue, especially those with a neurological diagnosis such as stroke, Parkinson's disease, and Multiple Sclerosis. The fatigue experienced by these individuals is different from muscular fatigue, defined as fatigability, because it is not always related to the level of physical exertion or muscle force production (Prak et al., 2018; Simon et al., 2009; Spiteri et al., 2019; Tseng et al., 2010). Moreover, chronic fatigue is not alleviated by rest while muscular fatigue is recoverable (De Doncker et al., 2018; Prak et al., 2018). Chronic fatigue is often quantified using subjective self-reported questionnaires and fatigability is objectively measured by the reduction in task performance (e.g. decreased force production) (Prak et al., 2018; Tseng et al., 2010). Previous investigations using force production tasks have shown that muscular fatigue significantly increased perceived effort (de Morree et al., 2012; Guo et al., 2017). To our best knowledge, there are no studies on how subjective fatigue modulates perceived effort during reach movements in healthy individuals.

Effects of subjective fatigue on movement control have been previously studied in patient populations suffering from chronic pathological fatigue (Goh & Stewart, 2019; Rasouli et al., 2017). Generally, individuals with greater subjective fatigue exhibited worse gross motor performance such as longer reaction time during gait initiation (Rasouli et al., 2017) and worse gait and balance performance (Goh & Stewart, 2019; Miller et al., 2013). The relationship between subjective fatigue and upper limb task performance (e.g. reaching or grasping), however, is less clear. Kuppuswamy et al. (2015) showed that participants with greater post-stroke fatigue exhibited longer movement time in a reaching task but Rasouli et al. (2019)

reported that individuals with chronic fatigue did not demonstrate significantly worse performance in a reach and grasp task (Kuppuswamy et al., 2015; Rasouli et al., 2017). The inconsistency between these two studies could be due to the inherent heterogeneity in diseased populations or variations in the reach task used. Nevertheless, previous investigations in clinical populations suggest that subjective fatigue might have an impact on the control of goal-directed movements. To date, no task paradigm for the investigation of reach control and subjective fatigue has been established in a nondisabled population. As the first step to investigate how subjective fatigue impacts upper limb motor task performance, we examined the relationship between reach performance, perceived effort and subjective fatigue in a group of healthy adults.

The purpose of this study was three-fold: first, we aimed to determine the level of perceived effort during goal-directed reaching under varied conditions. We hypothesized that perceived effort would be higher in more difficult reach conditions (e.g. increased target distance, decreased target size, contralateral reach direction). Second, we examined the relationship between subjective self-reported fatigue and perceived effort during reaching. We hypothesized that there would be a positive relationship between self-reported fatigue and perceived effort such that individuals with greater self-reported fatigue would report greater perceived effort during reaching. Third, we examined the relationship between self-reported fatigue and reach performance. We hypothesized that there would be significant relationships between self-reported fatigue and reach performance. Specifically, individuals with greater fatigue would demonstrate a longer reaction time and movement time, and greater endpoint error.

Materials and Methods

Participants

Twenty-three young adults (15 females and 8 males, mean age = 25.5 year-old) participated in this study. Previous studies on perceived effort in force production tasks and single-joint reaching tasks have reported effect sizes(f) ranged from 0.4 to 2.5 (de Morree et al., 2012; Hampton et al., 2014; Rosenbaum & Gregory, 2002). We estimated our sample size with a more conservative effect size of 0.40 because of more task variations employed than the previous studies and the possibly greater data variability in the reach task. A sample size of 18 was estimated to yield an 80% statistical power with alpha set at 0.05. To account for potential attrition, we enrolled 24 participants.

The inclusion criteria were: aged between 18-45 years, right-hand dominant or ambidextrous as determined by the Edinburgh Handedness Inventory, no history of neurological conditions (e.g. traumatic brain injury, spinal cord injury, or stroke), normal or corrected vision and hearing. Participants were excluded if they had an upper extremity condition that interfered with reaching task performance (e.g. fracture, significant joint pain, etc.). All participants signed a written informed consent prior to participation. Texas Woman's University institutional review board approved the protocol and consent (Protocol # 20105).

Experimental set-up & procedure

Each participant visited the laboratory once. The experiment started with a baseline assessment in which the Fatigue Severity Scale (FSS) and Fatigue Scale for Motor and Cognitive Functions (FSMC) were administered. Participants were then seated in front of a table facing a computer monitor ~40 cm away from the participant with the height adjusted to eyelevel. The reaching task involved using a non-inking electronic pen (Wacom ZP-130) to draw on a digitizing tablet (Wacom Intous 3) to targets displayed on the computer monitor. The tablet was positioned centrally on the table in line with the participant's trunk and was approximately 14-16 cm in front of the trunk. The tablet itself did not include a display; targets and pen position were displayed on the computer monitor (Figure 1A). Participants were instructed to draw a line from a starting position to one of the designated targets projected on the computer monitor. The pen position (X and Y coordinates) was recorded at a sampling frequency of 130Hz. MovAlyzeR (NeuroScript LLC, Tempe, AZ) was used to record the data, present the stimuli and control all trial events. During task performance, visibility of the arm and tablet/pen was blocked by a wooden shield such that participants would primarily use the display on the computer monitor to guide their movements. The height of the chair was adjusted such that the participant's elbow was in approximately 90° of flexion and the shoulder was in approximately 0°-5° of flexion when the hand was placed on the table.

[Figure 1 near here]

The reaching task began with a familiarization block in which participants performed 5 reach actions with their right arm to a target (diameter = 2 cm) located 10 cm away from the starting position. When the trial began, the starting position (a white square) and the target (a white circle) appeared on the monitor for 3 s and participants were instructed to move the pen to the starting position. After 3 s, the target turned from white to blue accompanied by an audio tone; participants were instructed to initiate the reach action as soon as the target turned blue. The task goal was to reach to the target as quickly and accurately as possible. The target remained on the monitor throughout the movement and the reach trajectory was displayed in real time. After each trial, feedback about reaction time and movement time were displayed on the monitor and participants were instructed to use the feedback to improve their reach performance on subsequent trials. The inter-trial interval was set at 3 s.

After the familiarization block, the experiment began. The experiment involved reaching to 9 different targets that varied in distance (6 cm and 12 cm from the starting position), direction (ipsilateral, center, and contralateral relative to the performing arm), and size (1 cm and 2 cm in diameter) with both right and left arms (Figure 1B). The targets were designed partly based on the Fitt's law in which target distance and width are used to index task difficulty(Fitts, 1954). The index of difficulty (ID) is calculated as $\log_2$ (2A/W) in which A is the target distance and W is the target width. In addition to target distance and size, previous studies have suggested that reach direction also modulates reach performance (Collins et al., 2018; Sainburg &

Kalakanis, 2000; Stewart et al., 2013). We therefore varied reach condition by manipulating target distance, size, direction and performing arm.

Half of the participants started with the right arm and the other half started with the left arm. Targets were presented in a pseudo-randomized order and in 3 blocks of 5 trials each. For each target, the first block consisted of 5 trials with the target and reach trajectory displayed on the monitor during movement. At the end of the first block, participants were asked to rate their perceived effort using the Borg Rating of Perceived Exertion scale (RPE) and Paas Mental Effort Rating scale (MERS). The second block of 5 trials was similar to the first block except that perceived effort was not assessed at the end of the second block. In the third block, participants were asked to reach to the target they had been practicing while the target was *not* displayed on the monitor. This block was designed to address a separate research question on the effect of visual information on reach control; the data collected in this block is not included in the current paper. The time interval between blocks was approximately 30 s. A 1-minute break was provided after participants finished all 3 blocks to a single target (15 trials) before moving on to the next target. Participants finished all 9 targets with one arm before moving on to the other arm.

Outcomes

Reach performance outcomes

Reaching performance was recorded and stored for off-line analysis. Position data were first filtered with a 4th-order low-pass filter with a cut-off frequency of 7Hz. Four performance outcomes were derived from the pen position data over time: reaction time, movement time, endpoint error, and hand path straightness. Reaction time was defined as the time interval between the ‘Go’ signal (target turned blue with the audio tone) and the onset of movement. Movement onset was defined as the first data point when the velocity exceeded 5% of the maximal velocity of the trial. Movement offset was defined as the first data point after the peak velocity that fell below 5% of the maximal velocity. Movement time was defined as the time interval between movement onset and offset. The distance from the center of the target to the pen position at movement offset was defined as endpoint error. Given the size of the targets (1 cm or 0.5 cm in radius), even trials that ended within the target could generate an endpoint error score greater than zero. Hand path straightness was calculated as the ratio of the actual traveled distance to the resultant distance (distance between XY position at movement onset and XY position at movement offset). A ratio closed to 1 represents a relatively straighter hand path (Cruz & Kamper, 2006). Each outcome was averaged across block 1 and 2 (10 total reach trials) for each target.

Perceived effort and fatigue outcomes

Perceived effort during reach movements was assessed using the Borg RPE and Paas MERS. The RPE scale ranges from 6 to 20 (6 = no exertion at all; 20 = maximal exertion). It has been widely used to measure perceived physical exertion in various activities and has been validated in a variety of populations (Borg & Dahlstrom, 1962; Doherty et al., 2001; Hampton et al., 2014). The MERS scale ranges from 1 to 9 and each number is associated with a descriptor. The descriptor for 1 is 'very, very low mental effort' and the descriptor for 9 is 'very, very high mental effort' (Paas et al., 1994). MERS has been used to quantify cognitive load in several studies (Blissett et al., 2018; Claros-Salinas et al., 2013; Khalil et al., 2010). We chose to use both physical and mental effort scales to quantify perceived effort because reach actions could be both physically and mentally challenging (McCrea et al., 2002). After the first block of reach trials for each target, participants were asked "For the target you just completed, please rate your perceived physical effort using this scale." The tester presented the written RPE scale to the participant and recorded the participant's verbal response. A similar question, "Please rate your perceived mental effort using this scale", was asked while the printed MERS scale was presented to the participants.

To quantify self-reported fatigue, we administered two different fatigue assessment scales prior to the performance of the reach task, Fatigue Severity Scale (FSS) and Fatigue Scale of Motor and Cognitive Function (FSMC). The FSS scale was developed to quantify pathological fatigue commonly found in individuals with neurological disorders such as Multiple Sclerosis (Krupp et al., 1989). It consists of 9 items and each item is rated on a Likert scale from 1 to 7. An example of an FSS item is “Fatigue is among my most disabling symptoms”. Individual item scores are summed to yield a total score. A higher total score indicates more fatigue and a total score over 36 suggests clinically significant fatigue (Krupp et al., 1989). The FSMC consists of 20 items (10 for motor function and 10 for cognitive function) and each item is rated on a Likert scale ranging from 1 to 5 (Penner et al., 2009). An example item for FSMC-Motor is “When I am experiencing an episode of exhaustion, my movements become noticeably slower” and an example item for FMSC-Cognitive is “When I am experiencing episodes of exhaustion, I lose concentration considerably quicker than I used to”. The sum of item scores yields a motor function score (FSMC-Motor, maximum = 50) and a cognitive function score (FSMC-Cognitive, maximum = 50). For both scales, participants were asked to rate their fatigue level over the last week.

Statistical analysis

To ensure the reach paradigm generated various levels of task difficulty, we performed separate repeated measures ANOVAs for each reach performance outcome. Because the reach paradigm did not consist of the small targets at the 12 cm reach distance, we conducted two separate repeated measures ANOVA for each reach outcome and adjusted the alpha level to .025. The first repeated measures ANOVA included 2 arms (right vs. left) x 3 reach directions (ipsilateral, central vs. contralateral) x 2 target distances (6 cm vs. 12 cm) and included targets 1 to 6 (see

Figure 1B). The second repeated measures ANOVA included 2 arms x 3 reach directions x 2 target sizes (2 cm vs. 1 cm) and included targets 1-3 and targets 7-9 (see Figure 1B).

To test the first hypothesis whether perceived effort increased as reach conditions became more difficult, we performed 2 separate repeated measures ANOVAs for each effort measure (RPE and MERS) with an adjusted alpha level of .025. The first repeated measures ANOVA included 2 arms x 3 reach directions x 2 reach distances while the second repeated measures ANOVA included 2 arms x 3 reach directions x 2 target sizes. Post-hoc Bonferroni adjusted pairwise comparisons were conducted if a significant main effect or interaction was found.

Pearson correlation coefficients were used to quantify the relationship between perceived effort (RPE and MERS) and self-reported subjective fatigue (FMSC-Motor and FMSC-Cognitive scores), and between reach performance outcomes (reaction time, movement time, endpoint error, and hand path straightness) and subjective fatigue. To reduce the number of correlational tests and minimize type I error, we averaged the RPE and MERS across all 9 targets for each arm, yielding 2 (right and left arms) average RPE and 2 average MERS values for each participant. Similarly, reach performance outcomes were averaged across all 9 targets for correlational analysis. The strength of correlations was interpreted as follows: $r < 0.25$ = little or no relationship; r of 0.25 to 0.5 = fair; r of 0.5 to 0.75 = moderate; and $r > 0.7$ = strong relationship (Portney & Watkins, 2015). For correlation analyses, alpha was set at .05.

Results

Twenty-four participants were enrolled but data from one participant were incomplete due to a disruption in data collection. Therefore, data from 23 participants were included in the analysis. Table 1 summarizes participant demographic information. Our sample consisted of 15 females and 8 males with a mean age of 25.5 years (SD = 5.5). All participants, except one, were right-hand dominant. The FSS sum score had a mean of 30.0 and ranged from 16 to 46. Seven participants had a FSS sum score greater than 36 indicating clinically significant fatigue.

[Table 1 near here]

We first analyzed reach outcomes across varied reach conditions to ensure that the reach paradigm led to the expected performance. We expected that as reach difficulty increased, reach performance would decline (e.g. longer movement time when reach distance increased). Figure 2 shows reach performance under varied reach conditions. Reaction time (Figure 2A) was comparable under most conditions with one exception. Reaction time was longer when participants reached with the right arm toward Target 7 (contralateral small target, see Figure 1B) compared to Target 1 (contralateral large target, see Figure 1B) (Figure 2A3, $p = .02$). Movement time (Figure 2B) was significantly longer when reaching toward the small targets than the large targets ($p < .01$) and when reaching toward the farther targets compared to closer targets ($p < .01$). Movement time was also longer for reaches with the left arm compared to the right arm, but only for reaches to the ipsilateral (Figure 2B1) and central targets (Figure 2B2) (both $p < .01$). Endpoint error (distance from target center) was lower for the small targets compared to the large targets (Figure 2C, $p < .01$). For the ipsilateral and central targets (Figure 2C1 and 2C2), increased target distance corresponded to increased endpoint error (both $p < .01$). Hand paths were less straight for reaches with the left arm compared to the right arm (Figure 2D, $p = .01$). Together, these findings suggest that the reach task used in the current study provided variations in task demands that led to variations in reach performance.

[Figure 2 near here]

Figure 3 shows participants' perceived effort under various reach conditions. RPE was significantly higher for the left arm compared to right arm ($F(1,21) = 7.58$, $p = .01$, partial $\eta^2 = 0.30$ and $F(1,21) = 6.24$, $p = .02$, partial $\eta^2 = 0.26$), for the farther targets compared to the closer targets ($F(1,21) = 22.44$, $p < .01$, partial $\eta^2 = 0.39$), and for the small targets compared to the large targets ($F(1,21) = 17.84$, $p < .01$, partial $\eta^2 = 0.41$) (Figure 3A). MERS was also higher for the farther targets compared to the closer targets ($F(1,21) = 18.60$, $p < .01$, partial $\eta^2 = 0.47$) and for the small targets compared to the large targets ($F(1,21) = 36.55$, $p < .01$, partial $\eta^2 = 0.64$). MERS tended to be higher for the left arm than the right arm but the differences were not statistically significant with the adjusted alpha level ($F(1,21) = 5.17$, $p = .03$, partial $\eta^2 = 0.20$ and $F(1,21) = 4.84$, $p = .04$, partial $\eta^2 = 0.19$).

[Figure 3 near here]

Table 2 summarizes the correlation coefficients between perceived effort and FSMC scores. There were significant and positive correlations between the FSMC scores and perceived effort (both RPE and MERS) measured during right arm reaching (Table 2, r = 0.42-0.52, p = .01 - .05). Perceived effort measured when reaching with the left arm did not correlate with the FSMC scores (r = 0.18 – 0.30, p = .16 - .40). Figure 4 illustrates the correlation between FMSC-Motor and RPE (4A) and the correlation between FMSC-Motor and MERS (4B) measured during right arm reaching.

[Table 2 near here]

[Figure 4 near here]

Table 3 presents the correlational analysis between reach performance and fatigue measures. Participants who reported greater motor fatigue (i.e. higher score on the FSMC-Motor) showed greater endpoint errors (Figure 5; right arm: r = 0.45, p = .03; left arm: r = 0.50, p = .02). Other reach performance outcomes did not correlate significantly with the FSMC scores.

[Table 3 near here]

[Figure 5 near here]

Discussion

The purpose of this study was to examine the effect of varied reach demands on perceived effort during reaching and how self-reported fatigue related to perceived effort and reach performance. Consistent with previous work by Rosenbaum and Gregory (2002), perceived effort increased as reach difficulty increased. The novel finding of our study was the positive correlation between self-reported subjective fatigue and perceived effort; individuals with higher levels of fatigue tended to have higher levels of perceived effort during reaching. We also showed that self-reported fatigue was associated with reach accuracy (higher fatigue, lower accuracy). The findings of this study provide an important foundation for future research to investigate the role of subjective fatigue on movement control.

Previous studies have shown that rating of perceived effort is proportional to isometric force production (Guo et al., 2017; Hampton et al., 2014; Slobounov et al., 2004), reach amplitude, and reach speed (Rosenbaum & Gregory, 2002). In the current study, we showed a similar relationship: as reach conditions became more difficult, perceived effort increased. Collectively, these findings suggest that motor task demands modulate perception of effort. Interestingly, manipulation of reach conditions led to significant increases in both physical and mental perceived effort as indexed by the Borg RPE and MERS, respectively. Increases in the Borg RPE were generally lower than the increases in MERS. For example, RPE increased from an average of 8.7 to 9.4 (about 8%) when reach distance increased from 6 cm to 12 cm while MERS increased from an average of 3.2 to 3.6 (about 15%). The difference suggests that the current reaching task might impose relatively greater mental effort and lesser physical effort in healthy adults without any physical impairments. As such, the manipulations adopted in our study might not be sufficiently difficult to lead to a profound change in perceived physical effort in this population. Alternatively, it might be that reach actions may require more mental effort than physical effort for movement planning and execution. Nevertheless, both physical and mental perceived effort changed significantly as reach conditions were altered, suggesting that the perceived effort can be systematically measured in reach actions. The established reach task was a sensitive paradigm to capture perceived effort during skilled reach actions and could expand future investigations on the relationship between perceived effort and motor control.

An important finding of this study was the positive associations found between self-reported fatigue and perceived effort. To our best knowledge, this study was the first to demonstrate an association between these outcomes in healthy adults. Previous investigations in healthy adults have primarily focused on the relationship between muscular fatigue and perceived effort (de Morree et al., 2012; Guo et al., 2017). Subjective fatigue is conceptualized as a different construct from the muscular fatigue because it is not always explained by the level of physical exertion and often not alleviated by rest (Tseng et al., 2010). Therefore, these previous investigations on muscular fatigue may have limited implications for the understanding of subjective fatigue (Goh & Stewart, 2019; Prak et al., 2018; Tseng et al., 2010). The findings from the current study provide a critical step for the investigation of pathological fatigue by demonstrating an association between subjective fatigue and perceived effort during reaching. Individuals with greater subjective fatigue, as expected, reported greater perceived effort when reaching. However, correlation coefficients between subjective fatigue and perceived effort were fair to moderate in strength (r ranged from 0.42 to 0.51), suggesting that the majority of variance was accounted for by factors other than subjective fatigue. Interestingly, only perceived effort measured during right arm performance significantly correlated with self-reported fatigue. Participants might have a better estimation of effort with their dominant arm because of an overall higher amount of experience using this arm during skilled motor tasks. The dominant arm might provide a better reference to judge effort during reaching than the non-dominant arm.

Among all measured reach performance outcomes, endpoint error was the only outcome that exhibited a reliable correlation with self-reported fatigue. Endpoint error measured from both arms was correlated with the FMSC-Motor. This finding suggests that subjective fatigue might have an impact on the performance of goal-directed movements even though the movements themselves were not fatiguing. Experimental induced physical or mental fatigue has been shown to impair both movement speed and movement accuracy (Le Mansec et al., 2019; Rozand et al., 2015; Smith et al., 2016). The reach distances used in this study were short (6 cm and 12 cm) and the participants was provided continuous visual feedback on position during reaching. Therefore, the task might not have been challenging enough to capture the influence of self-reported fatigue on movement time. Although the correlation between self-reported fatigue and endpoint error was significant, the endpoint error reported here was generally small (see Figure 2C). Most endpoint errors were below 1 cm for the large targets and below 0.5 cm for the small targets. This suggests that even though individuals with greater fatigue showed a greater endpoint error measured from the center of the target, they were still within the target margin.

Overall, the relationship between self-reported fatigue and perceived effort was stronger than the relationship between self-reported fatigue and reach performance. It could be that individuals with greater fatigue could still maintain an optimal level of task performance even though the perceived effort was high, especially when the reach task was relatively simple and did not require sustained performance (e.g. high repetitions or long duration) (Rosenbaum & Bui, 2019). A similar observation has been reported for the relationship between mental effort and cognitive task performance, suggesting a possible common principle of effort between cognitive and motor tasks (Shenhav et al., 2017; Verguts et al., 2015). Another possible explanation for the weak to no correlation between reach outcomes and self-reported fatigue is the potential bias introduced by the task instruction. In this study, we instructed the participants to reach as quickly and accurately as possible. Feedback on reach performance was provided after each trial. The instruction might have optimized the task performance and subsequently obscured the effect of self-reported fatigue on task performance. Similarly, the feedback received at the end of the trial might have provided an intrinsic reward. It is well-documented that effort can be modulated by both task demand/cost and reward associated with the task (Shenhav et al., 2017; Verguts et al., 2015). Rewards have been found to discount effort in reaching tasks (Summerside et al., 2018). Lastly, reach performance measures (e.g. endpoint error) might not be a suitable measure to capture the relationship between fatigue and reach control. Rosenbaum and colleagues have developed a two-alternative forced choice paradigm to study perceived effort/task difficulty across various motor tasks, including reaching (Feghhi &

Rosenbaum, 2020; Potts, Callahan-Flintoft, et al., 2018; Rosenbaum & Gaydos, 2008; Rosenbaum & Gregory, 2002). Investigations in cognitive psychology have reported an equivocal role of error in effort-based decision making (Dunn et al., 2019; Kool et al., 2010). Together, these findings implicate that action outcome (e.g. error) might not be critical in mediating the relationship between fatigue, effort and task performance. Action selection or decision might be more influenced by subjective fatigue than action outcomes. For example, individuals with greater fatigue might be more likely to choose a less effortful task condition (a closer target or slower speed) when they are given the opportunity to choose. When they are only given the task goal as in the current study, they may be able to achieve the goal even though they experience a greater level of effort. Future investigations incorporating rating of perceived effort, action selection and reach performance outcomes are recommended to further examine how these different constructs are related to self-reported fatigue.

Limitations

The purpose of the present study was to determine the levels of perceived effort during reaching in healthy adults with the long-term goal of developing a paradigm that could be used to examine pathological fatigue and perceived effort during motor task performance in clinical populations. Overall, the levels of fatigue in this healthy cohort were not clinically significant; therefore, translation of this paradigm to clinical populations with significant fatigue may yield different results. Moreover, the self-reported fatigue assessment was based on each individual's past week experience which might introduce biases during memory recall. Our sample also showed relatively small, although statistically significant, increases in perceived effort as reach difficulty increased. These increases in perceived effort might not be clinically meaningful.

The associations between self-reported fatigue and perceived effort, and reach performance were fair to moderate in strength, suggesting the majority of the variances were not accounted for in our analysis. The strength of associations might be skewed by combining outcomes across the 9 targets; the associations between self-reported fatigue and perceived effort or reach performance might vary based on targets. However, our sample size did not permit a target-by-target analysis. We only adopted two levels of index of difficulty (ID) in the present study which could limit the generalizability of the findings. We recommend future studies to include more targets with various ID, such as small targets at the 12-cm distance, to further explore how interactions among fatigue and perceived effort are mediated by task difficulty. The reach space in the current study was relatively small and 2-dimensional. The challenges imposed by this set-up might be too low to have a significant impact on perceived effort and the relationship between reach performance and self-reported fatigue. Future studies are recommended to investigate the relationship between fatigue and perceived effort during reaching with a more challenging set-up (e.g. reaching against gravity).

Fatigability (objective fatigue) was not addressed in the current study. It might be valuable for future investigations to examine if individuals with greater subjective self-reported fatigue are more susceptible to a fatiguing protocol, such as repetitive muscular contractions (muscular fatigue) or prolonged cognitive activities (mental fatigue). Based on the findings from the present study, it is reasonable to predict that individuals with greater subjective fatigue would demonstrate greater increase in perceived effort and deterioration in reach performance after a fatiguing protocol than those with lower subjective fatigue. Perceived effort was only assessed after the first but not the second block of practice. Therefore, effects of practice on perceived effort were not examined. It remains unclear if perceived effort would decrease as participant's reach performance improves (Hyllegard & Bories, 2008) or if practice-induced changes in perceived effort are modulated by subjective fatigue. Future studies including fatiguing conditions or training are recommended to further determine the impact of subjective fatigue on motor control and motor learning.

In conclusion, we showed that perceived effort during reaching changes systematically with variations in reach difficulty. Importantly, self-reported fatigue was associated with both perceived effort and reach accuracy. The findings from our study establish the basis for future investigation of pathological fatigue observed in clinical populations.

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Figure legends

Figure 1: Experimental set-up (A) and target configuration (B). A: The model participant sat in front of a computer monitor while holding the digitizing pen to perform the task on the tablet placed on the table. The vision of arm and pen were blocked by a wooden platform. The participant used the information projected on the monitor (square: start position; circle: target) to guide the arm movement. B: The 9 targets were different in their distances and directions from the start position, and sizes. Target 1 to 3 have an index of difficulty (ID) of 2.6, Target 4 to 9 have and ID of 3.6.

Figure 2. Participants' reach performance on different reach outcomes (A: Reaction Time; B: Movement Time; C: Endpoint Error) towards targets presented at different directions across 2 blocks. Symbols (Black: right arm; Grey: left arm) represent group means and error bar represent standard error of means.

Figure 3. Participant's perceived physical exertion measured by Borg RPE (A) and perceived mental effort measured by Paas MERS (B) for different targets. Symbols (Black: right arm; Grey: left arm) represent group means and error bars represent standard error of means.

Figure 4. Correlations between FSMC-Motor and RPE (A) and MERS (B) measured during right arm reaching. * indicates a significant correlation coefficient ($p < .05$).

Figure 5. Correlations between FSMC-Motor and endpoint error measured in the right arm (A) and left arm (B). * indicates a significant correlation coefficient ($p < .05$).

Table 1

Participants demographics (N = 23)

	N or mean	% or SD
Gender (Female: Male)	15: 8	64.2%: 34.8%
Age	25.48	5.45
Fatigue Severity Scale (max = 63, cut-off = 36)	30.00	9.63
Fatigue Scale for Motor and Cognitive Functions-Motor (max = 50)	24.78	7.15
Fatigue Scale for Motor and Cognitive Functions-Cognition (max = 50)	23.61	5.90
Fatigue Scale for Motor and Cognitive Functions-Total (max = 100)	48.39	12.48

Table 2

Correlation coefficients (r) between Fatigue Scales for Motor and Cognitive Functions (FSMC) and perceived efforts measured by Borg Rate of Perceived Effort (RPE) and Mental Effort Rating Scale (MERS)

		RPE		**MERS**	
		r	p	r	p
Right arm					
	FSMC-Motor	0.50*	.02	0.51*	.01
	FSMC-Cognitive	0.44*	.04	0.42*	.04
Left arm					
	FSMC-Motor	0.30	.17	0.30	.16
	FSMC-Cognitive	0.25	.26	0.18	.40

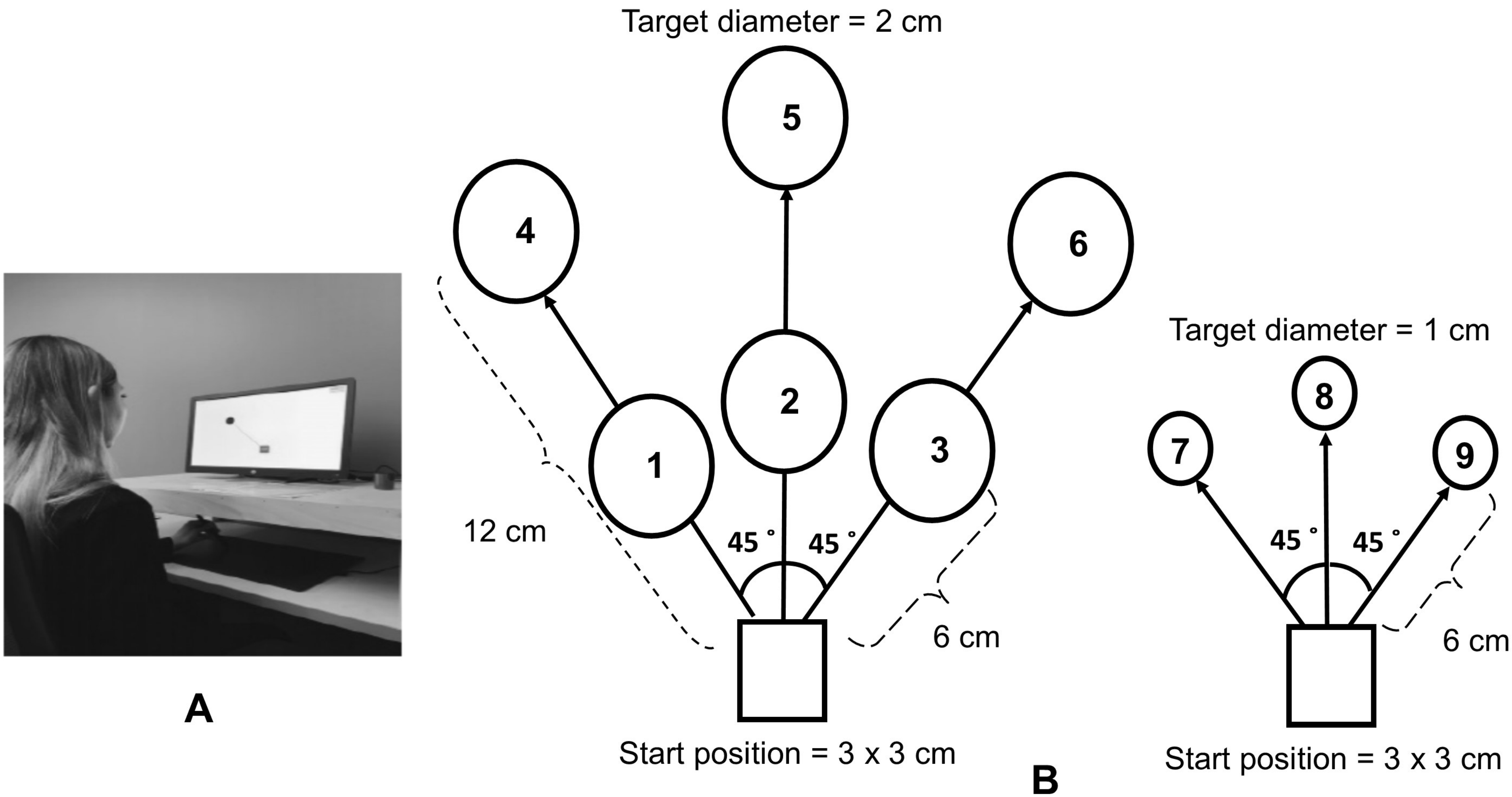
* $p < .05$

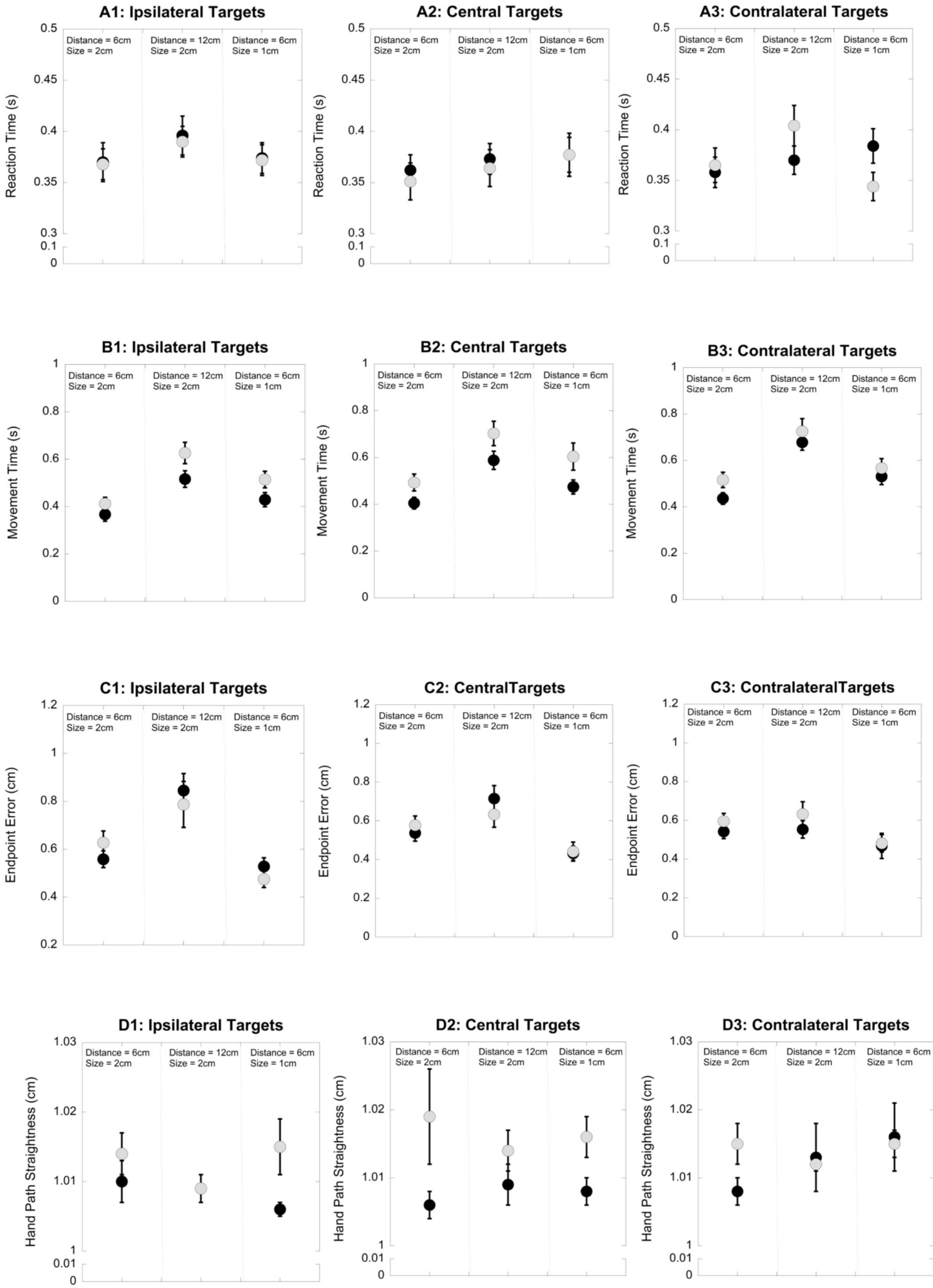
Table 3

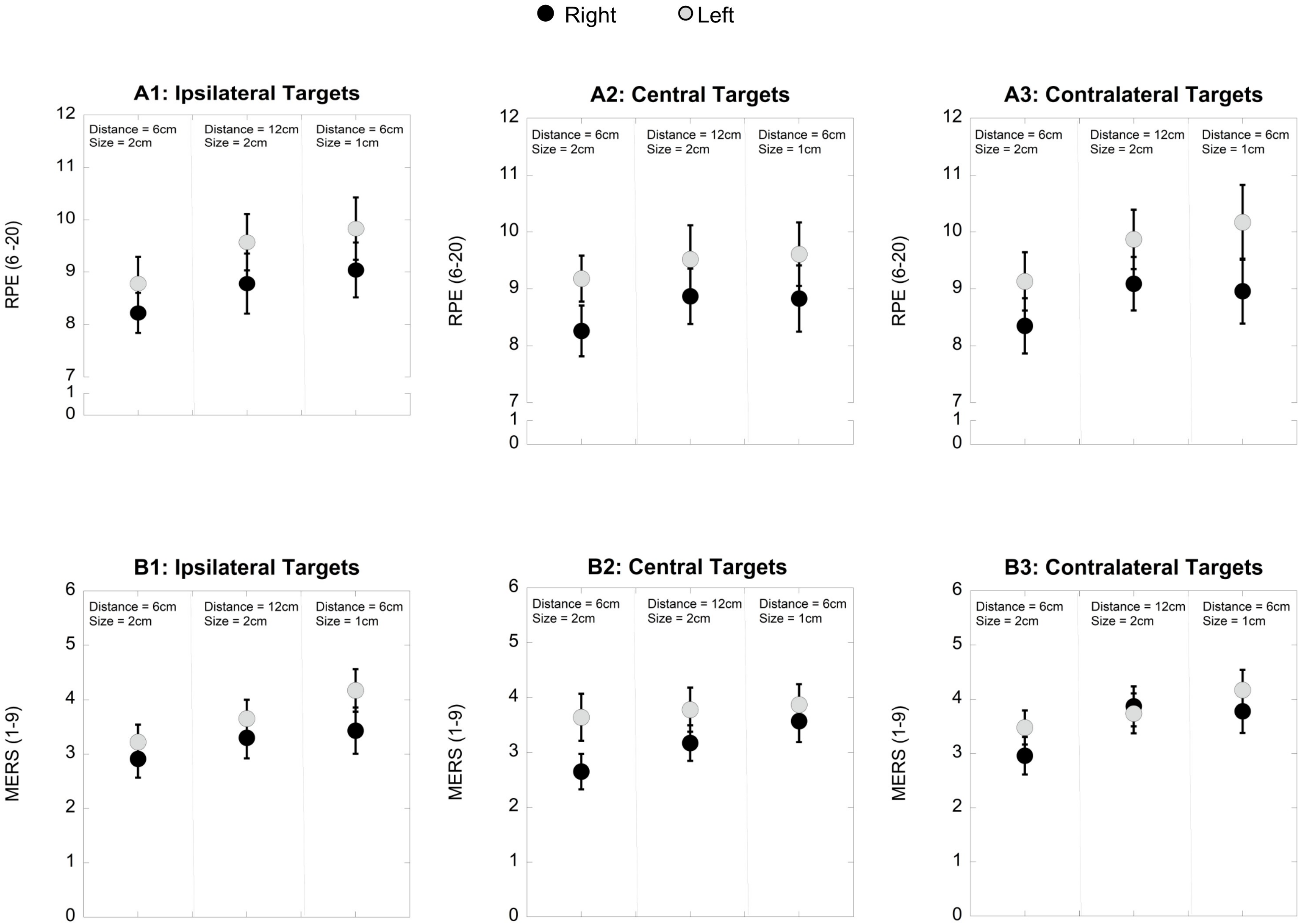
Correlation coefficients between Fatigue Scale for Motor and Cognitive Functions (FMSC) and reach performance.

	Reaction Time		Movement Time		Endpoint Error		Hand path Straightness	
	r	p	r	p	r	p	r	p
Right arm								
FSMC-Motor	0.28	.20	- 0.12	.59	0.45*	.03	0.23	.29
FSMC-Cognitive	0.21	.32	-0.11	.58	0.39	.06	0.07	.75
Left arm								
FSMC-Motor	0.41	.05	- 0.29	.17	0.50*	.02	-0.16	.47
FSMC-Cognitive	0.24	.27	-0.19	.39	0.29	.18	-0.13	.57

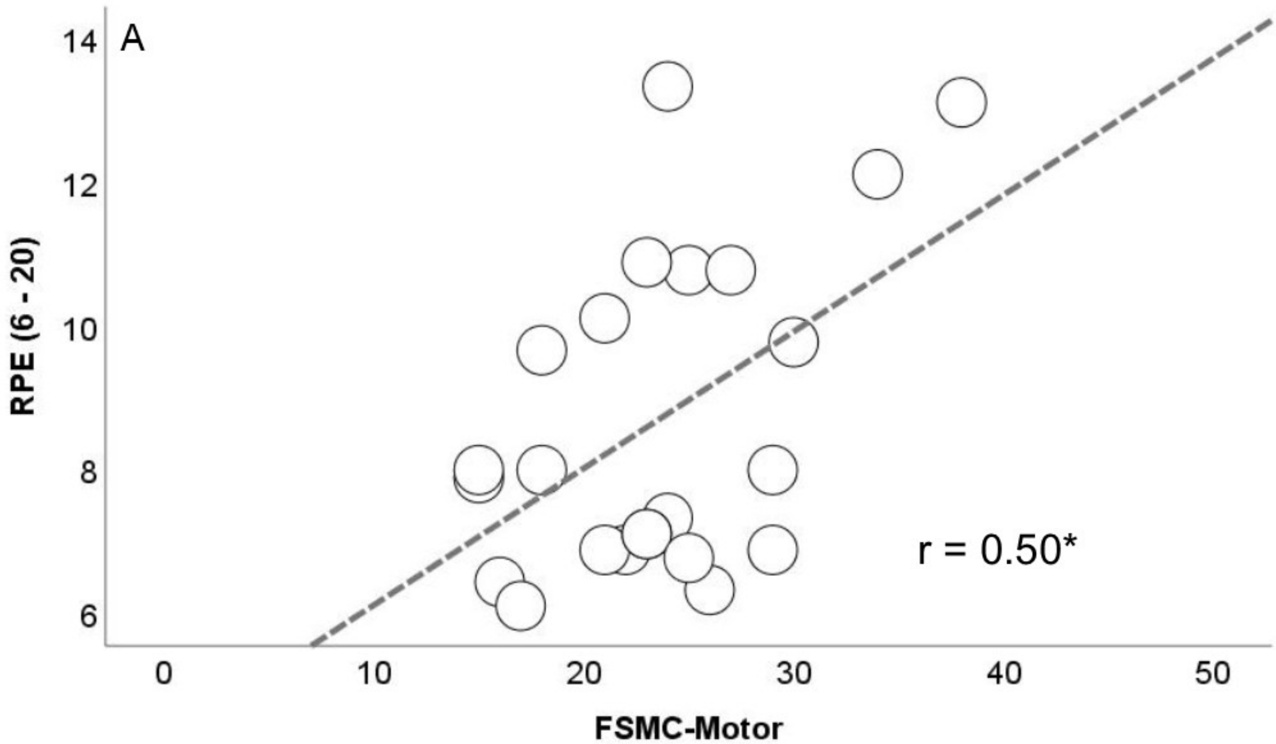
* $p < .05$

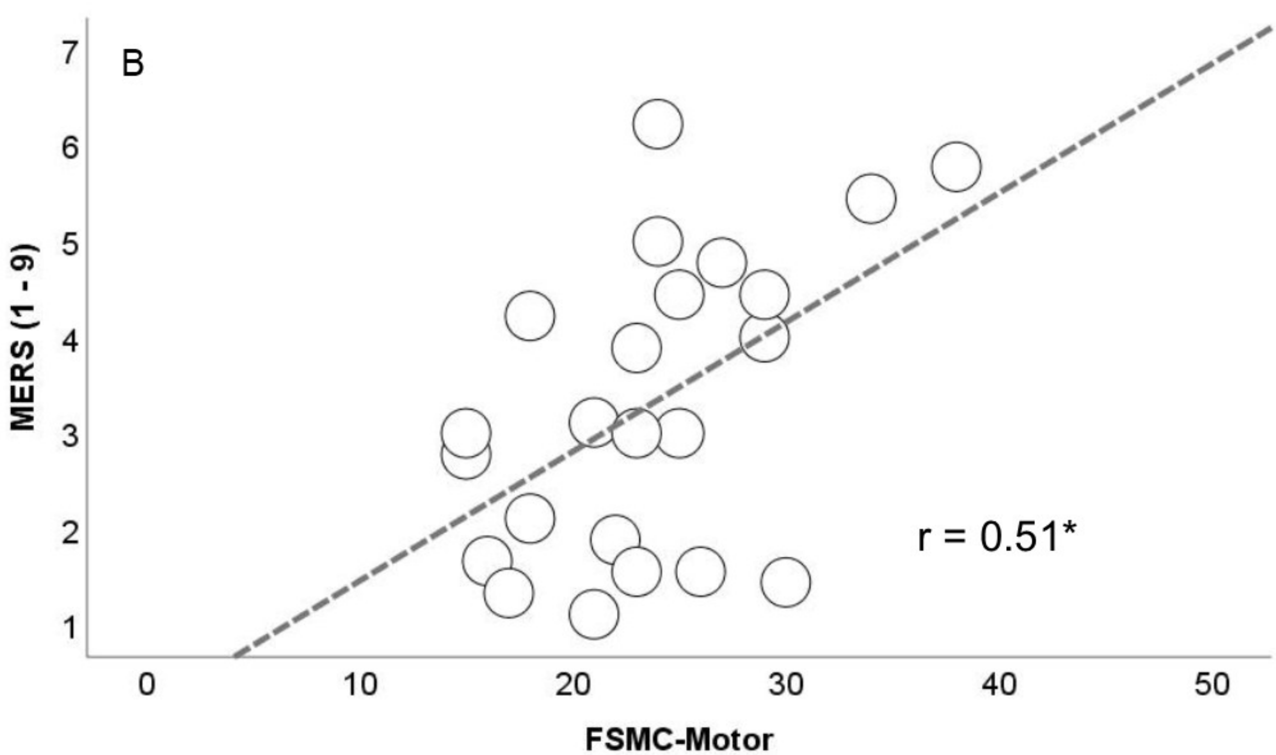

A
Target diameter = 2 cm
5
4
6
2
1
3
12 cm
45 °
45 °
6 cm
Start position = 3 x 3 cm
B
Target diameter = 1 cm
8
7
9
45 °
45 °
6 cm
Start position = 3 x 3 cm

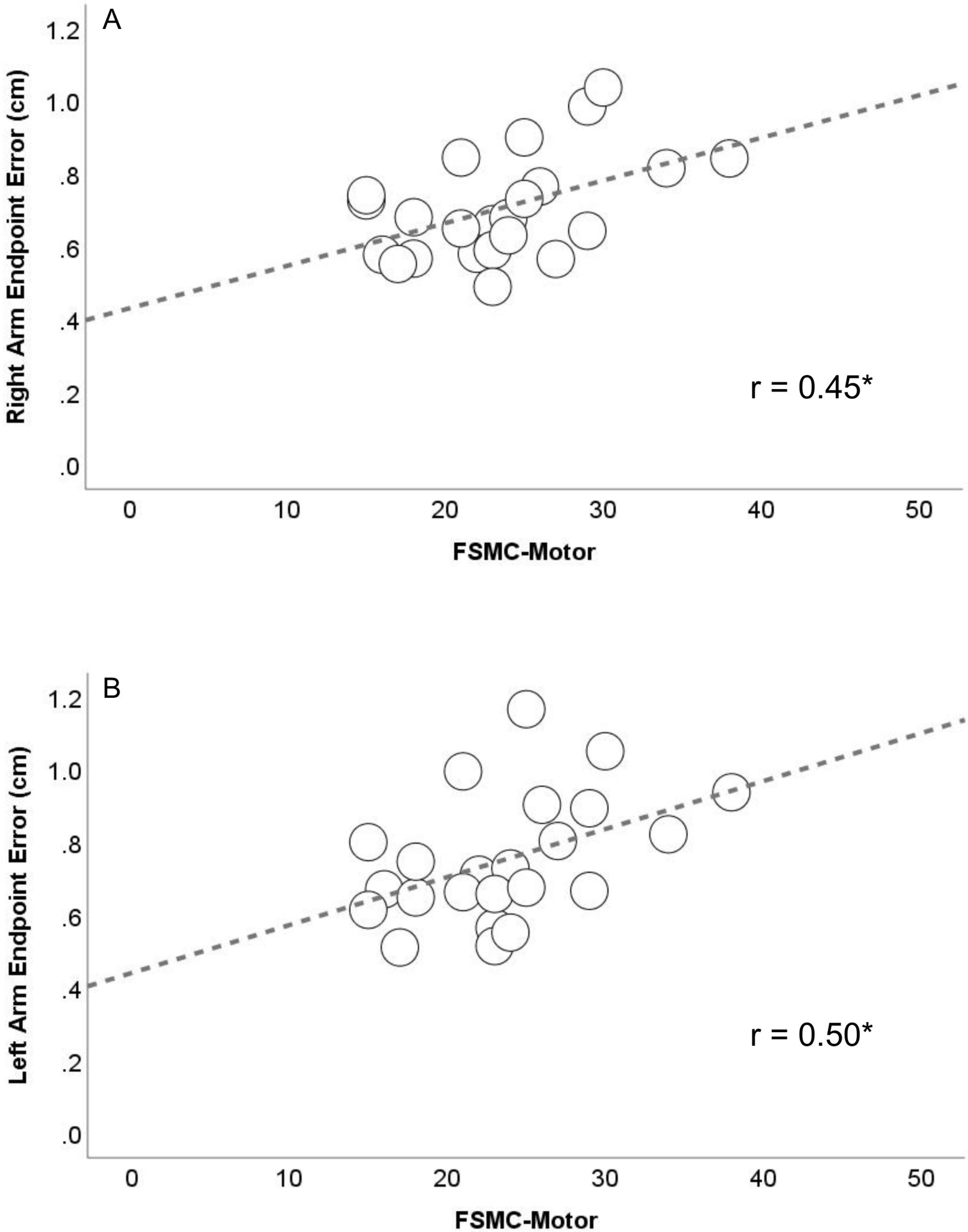

A1: Ipsilateral Targets
A2: Central Targets
A3: Contralateral Targets
Reaction Time (s)
B1: Ipsilateral Targets
B2: Central Targets
B3: Contralateral Targets
Movement Time (s)
C1: Ipsilateral Targets
C2: CentralTargets
C3: ContralateralTargets
Endpoint Error (cm)
D1: Ipsilateral Targets
D2: Central Targets
D3: Contralateral Targets
Hand Path Straightness (cm)
Distance = 6cm
Size = 2cm
Distance = 12cm
Size = 2cm
Distance = 6cm
Size = 1cm



Right
Left
A1: Ipsilateral Targets
A2: Central Targets
A3: Contralateral Targets
RPE (6 -20)
RPE (6-20)
RPE (6-20)
Distance = 6cm Size = 2cm
Distance = 12cm Size = 2cm
Distance = 6cm Size = 1cm
12
11
10
9
8
7
1
0
B1: Ipsilateral Targets
B2: Central Targets
B3: Contralateral Targets
MERS (1-9)
6
5
4
3
2
1
0


A
RPE (6 - 20)
14
12
10
8
6
0
10
20
30
40
50
FSMC-Motor
r = 0.50*


B
MERS (1 - 9)
7
6
5
4
3
2
1
0
10
20
30
40
50
FSMC-Motor
r = 0.51*


A
Right Arm Endpoint Error (cm)
1.2
1.0
.8
.6
.4
.2
.0
0
10
20
30
40
50
FSMC-Motor
r = 0.45*
B
Left Arm Endpoint Error (cm)
1.2
1.0
.8
.6
.4
.2
.0
0
10
20
30
40
50
FSMC-Motor
r = 0.50*