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The Quantification of Muscle Activation During the Loaded Carry Movement Pattern

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ABSTRACT

International Journal of Exercise Science 17(1): 480-490, 2024. The 'loaded carry' is a popular resistance training activity that activates core musculature across multiple movement planes while the body is in locomotion. 'Hold' exercises are similar to carry exercises but lack the locomotive aspect. Both carry and hold exercises can be completed bilaterally (farmer's carry (FC) and hold (FH)) or unilaterally (suitcase carry (SC) and hold (SH)). A deeper understanding of muscle activation between the FC and SC and intensity-matched FH and SH might improve their application. Healthy, college-aged individuals were recruited and surface electromyography of the rectus abdominis (RA), external oblique (EO), longissimus (LT), and multifidus (MF) was measured bilaterally using standard procedures. Participants completed time- and intensity-matched randomized sets of the plank, FC, SC, FH, and SH separated by 5-minute rests. A one-way ANOVA was utilized to compare exercises. The FC/FH load averaged 50.7±1.9 kg, where it was used across equally weighted dumbbells. The FC elicited higher activation bilaterally in the LT, MF, RA, and EO, compared to the FH. The SC/SH single-dumbbell load averaged 25.3±0.95 kg. There was greater activation bilaterally in the LT and MF during the SC compared to the SH. However, on the ipsilateral side of the SC, the RA and EO displayed greater activation compared to the SH, but this was not different on the contralateral side. The FC and SC were characterized by increased core muscle activation bilaterally, with the SC exhibiting unique additions to ipsilateral muscle activation.

KEY WORDS: Plank, farmers carry, farmers hold, suitcase carry, suitcase hold

INTRODUCTION

It was reported that in 2020, low back pain affected 619 million people globally, with estimates that this number will reach greater than 800 million by 2050 (5). According to the GBD 2021 Low Back Pain Collaborators (5), examples of modifiable risk factors noted for playing an important role in low back pain included exposure to lifting, bending, awkward posture, vibration, and other physically demanding tasks. A lack of core musculature strength may be a major contributing factor to low back injury associated with these risk factors. Therefore, as exercise scientists and allied health professionals, it is important that strengthening of 'core' musculature (defined herein as pertaining to the abdominal and lower back regions) gains increased attention.

The plank is a staple core exercise utilized by exercise scientists, strength and conditioning coaches, and physical therapists. This exercise is performed by having an individual assume and maintain a raised prone position with their shoulders and elbows flexed to 90 degrees, placing their weight through their forearms and toes. While not likely as popular, the 'loaded carry' movement pattern has gained an increase in attention, likely due to increased visibility provided by CrossFit and strongman training/competition. Loaded carry exercises are typically described as being a more 'functional' exercise than a plank, due to their relationship to agricultural and first-responder activities (i.e., lifting and traversing buckets, carrying a stretcher; 2, 6).

One of the simplest and most popular loaded carries, the Farmer's Carry (FC), requires an individual to pick up equally weighted resistance with each hand (e.g., two kettlebells) and walk from one point to another. It has been observed that this carry requires 'core' stabilization in multiple anatomical planes (15). When space to traverse a weight from one point to another is limited, individuals may instead opt to engage in a Farmer's Hold (FH). A FH is simply an exercise where one picks up equally weighted resistance with each hand and holds it for a specified duration. When performed unilaterally (e.g., one kettlebell held in one hand), the Suitcase Carry (SC) and Suitcase Hold (SH), have been shown to elicit unique patterns of spinal loading and muscle recruitment (11).

Previously, muscle activation during the plank has been compared to traditional resistance training exercises. For example, when compared to the plank, a 6-repetition max back squat elicited significantly greater erector spinae (ES) activation with no significant differences for the rectus abdominis (RA) or external oblique (EO) observed (14). It was postulated that this difference may be due to the prone nature of the plank compared to the back squat. Further, the back squat has a direction of force that promotes spinal flexion, increasing the degree of ES activation necessary to maintain spinal extension to complete the lift. In a similar vein, a carry exercise may elicit greater ES activation when compared to a hold exercise due to the increased trunk angle associated with walking.

The FC is a functional exercise that requires stabilization in multiple planes. McGill and colleagues compared the muscle activation of the FC to the SC (30 kg in one hand compared to 15 kg in two) and reported that the SC displayed greater muscle activation of the lumbo-hip complex (9). Successfully completing an FC or SC requires stabilization of core musculature on top of a rotating pelvis in order to maintain a safe, upright position. Compared to the plank and FH or SH, both of which require minimal dynamic movement, the FC and SC may display greater degrees of activation in the oblique muscles to stabilize the side-to-side motion that occurs with locomotion.

While prior research from our lab has developed a method to determine an adequate load for a SC (8), there is currently no comprehensive research that compares muscle activation during the plank, loaded carries, and loaded holds. This comparison may provide keen insight into the proper use of these exercises and tailor them to the specific strength needs of an athlete or patient. While these core exercises are popular in strength and conditioning spaces, there is a clear gap in the research regarding their specific muscle activation and, therefore, their optimal application. The purpose of this study was to investigate muscle activation when performing planks, carries, and holds. More precisely, the investigators examined electromyographic (EMG) activity of the RA, EO, longissimus (LT), and multifidus (MF) during the plank, compared to the FC, FH, SC, and SH to better understand what makes these exercises unique. It was hypothesized that EO and RA activation would be greatest in the plank and EO opposite of the SC and SH. Additionally, MF and LT activation was hypothesized to be greater in the carry, when compared to a hold exercise and the plank.

METHODS

Participants

This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (12). This study was approved by the Slippery Rock University Institutional Review Board. Before data collection, all participants reviewed and signed an informed consent document. To determine a minimum adequate sample size, an a priori power analysis was conducted (G*power V 3.1.9.4). A conservative estimate of a medium effect size was used to determine a minimum adequate sample size. The following parameters revealed the need for a sample of 13 subjects to reach adequate power: F test, repeated measures ANOVA (within factors), effect size 0.4, $\alpha = 0.05$, $1\text{-}\beta = 0.8$.

Twenty-six apparently healthy, college-aged individuals from the Slippery Rock University community were recruited to participate, with 18 providing usable data. Individuals were at least 18 years of age and free from current musculoskeletal injuries. Exclusion criteria included current musculoskeletal injuries or health conditions that prohibited safe participation in the plank, FC, FH, SC, and/or SH and no previous completion of an upper-level resistance training course. Reasons for the removal of data included the inability of one participant to hold dumbbells due to lack of grip strength and un-usable EMG data. During data collection, poor electrode adhesion (possibly due to sweat), led to inaccurate EMG data. This was monitored throughout the study and, when observed, participant data were excluded from data analysis.

Protocol

Each participant attended one data collection session. During this session, informed consent was obtained, along with demographic information, medical history, and confirmation of the completion of an upper-level resistance training course. The upper-level resistance training course involved education on the safe and effective completion of a variety of resistance training movements, including the FC, FH, SC, and SH. Once cleared, each participant's estimated body composition was measured a medical body composition analyzer (SECA mBCA, Chino, CA, USA). With the SECA, each participant's body mass (kg), body fat percentage (%), fat-free mass (kg), and skeletal muscle mass of the upper extremities (kg), lower extremities (kg), and trunk (kg) were calculated.

Participants were then weighed while performing a traditional plank exercise with their forearms on a scale (SECA 777, Hamburg, Germany). The weight recorded during the plank was used as the workload for the FC, FH, SC, and SH. This was done to standardize the workload between the plank, carries, and holds. Before EMG sensor placement, investigators recorded the time it took the participants to walk twenty-five meters. The standard time that participants held the plank, FH, and SH; and would complete the FC and SC was calculated by adding five seconds to the 25-meter walk time. Participants then engaged in a brief warm-up. They walked for five minutes on a treadmill at a self-selected pace and then completed dynamic stretching movements, twenty meters each of high knees, butt kicks, Frankensteins, inside/outside marches, and lunges.

Bilateral surface EMG of the RA, EO, LT, and MF were sampled at 1000 Hz using the Noraxon Mini DTS system (Noraxon, Scottsdale, AZ). To prepare for EMG sensor placement, each participant's skin was shaved, gently abraded, and cleaned using standard procedures. Dual EMG Ag/AgCl electrodes (interelectrode distance of 2cm) were placed over the RA, EO, LT, and MF muscles. Sensor location was determined by prior literature. Specifically, the RA sensor was placed 3 cm lateral to the umbilicus (9). The EO sensor was placed 3 cm lateral to the linea semilunaris, at the same level as the RA sensor (9). The LT sensor was placed 3 centimeters lateral of the spinous process of the 1st lumbar vertebrae (7). The MF sensor was placed 3 cm lateral from the midline of the 5th lumbar vertebrae and aligned from the caudal tip posterior spina iliaca superior to the interspace of the 1st and 2nd lumbar vertebrae (7).

Following the placement of EMG electrodes, participants engaged in maximal voluntary isometric contraction (MVIC) testing to allow for direct comparison of muscle activation across the five exercises. Specific starting positions and manipulations were followed from previously published sources to ensure safe and effective MVIC measures (4,13). More specifically, MVIC testing for the MF and LT was completed by having the participant lie prone, with their forehead resting flat on the table and their hands behind their head. The participant's feet were held down with knees maintained in an extended position while they extended their trunk to lift their chest off the table. This was designated as the start position. Increasing resistance was then applied in a downward direction on the participant's scapula until an MVIC was obtained. This position was held for three seconds before the participant was given a quick break (2-3 seconds), and the process was repeated three times. Testing for the RA involved the participant assuming a fully flexed curl-up position with their feet held down and their knees flexed to 90 degrees. Participants were then instructed to curl forward while an investigator simultaneously pulled back on their shoulders from behind until an MVIC was obtained. This isometric contraction was held for three seconds, and the process was repeated three times. Testing for the EO involved the participant returning to the fully flexed curl-up position, as previously described. Participants were then instructed to rotate their right shoulder towards their left knee while the investigator simultaneously pulled their right shoulder in the opposite direction from behind until an MVIC was obtained. This isometric contraction was held for three seconds, and the process was repeated three times on each side.

Participants then completed the plank, FC, FH, SC, and SH exercises, in a randomized order using the loads and durations specified above. For the SC and SH, participants used their right arm to hold the weight. The exercise order was altered for each participant until all perturbations were utilized, at which point the exercise order was repeated. A simultaneous video recording was taken from both a diagonal and sagittal view. The video recordings were reviewed to ensure proper carry technique and form. Participants took a complete 5-minute rest period in between each exercise, and data collection session took approximately 75-90 minutes to complete.

Statistical Analysis

A one-way repeated measures analysis of variance test was used to compare the dependent variables across the independent variable. Bonferroni corrections were applied for multiple comparisons. An effect size was calculated for the main effect of condition across each measured muscle. These effect sizes are reported below and correspond to the following scale (r^2: small effect = 0.1, medium effect = 0.3, large effect = 0.5). The exercise (plank, FC, FH, SC, or SH) was the independent variable. Dependent variables were the average root mean square (RMS) value for the RA, EO, LT, and MF muscles. Prior to statistical analysis, raw EMG data was amplified, band-pass filtered (20 and 450 Hz), rectified and smoothed using a root mean squared integration of 100ms. Each participant's filtered EMG data were normalized via the MVIC procedures described above. RMS values for the middle 15 seconds of each exercise were recorded and averaged for use in the analysis. An a-priori p value was established at $p = 0.05$. Data were analyzed using GraphPad Prism 9 for Windows (GraphPad Software, San Diego, CA, USA).

RESULTS

Twelve female and six male participants completed all the requirements for the study. Anthropometric characteristics of these participants are shown in Table 1. Female and male participants were not compared, rather, tested within subjects.

Main effects were found in the LT_R ($p < 0.0001$; F (1.410, 23.97) = 37.08; $r2 = 0.6857$), LT_L ($p < 0.0001$; F (1.945, 33.06) = 68.30; $r2 = 0.8007$), MF_R ($p < 0.0001$; F (1.298, 22.06) = 30.40; $r2 = 0.6414$), MF_L ($p < 0.0001$; F (2.174, 36.96) = 50.22; $r2 = 0.7471$), RA_R ($p < 0.0001$; F (1.336, 22.71) = 91.13; $r2 = 0.8428$), RA_L ($p < 0.0001$; F (1.487, 25.28) = 57.90; $r2 = 0.7730$), EO_R ($p < 0.0001$; F (1.500, 25.51) = 57.09; $r2 = 0.7705$), and EO_L ($p < 0.0001$; F (2.471, 42.01) = 35.29; $r2 = 0.6749$).

The load for the FC and FH averaged 50.7±1.9 kg and was divided into two equally weighted dumbbells. The FC elicited higher activation bilaterally in the LT (+9.2% left, $p < 0.0001$; +10.8% right, $p < 0.0001$), MF (+9.6% left, $p < 0.0001$; +11.3% right, $p < 0.0001$), RA (+4.3% left, $p < 0.0001$;

+6.1% right, p = 0.0324), and EO (+4.8% left, p < 0.0031; +7.3% right, p < 0.0003), respectively, compared to the FH (Table 2).

Table 1. Participant demographics.

Characteristic	Females (n=12)	Males (n=6)
Age (y)	20.8±0.2	20.7±0.2
Weight (kg)	71.0±2.6	87.0±3.9
Height (cm)	167.6±2.0	178.6±3.2
BMI (kg/m^2)	25.2±0.9	27.2±2.1
Body Fat Percentage (%)	29.1±1.7	19.0±2.9
FFM (kg)	49.2±1.4	69.5±2.1
SkMMass$_{ARMS}$	2.8±0.1	4.5±0.3
SkMMass$_{LEGS}$	10.6±0.4	13.9±0.5
SkMMass$_{TORSO}$	9.8±0.3	15.7±0.7
Plank, FC, FH (kg)	46.8±2.0	58.8±2.1
SC, SH (kg)	23.4±1.0	29.4±1.0

Values are expressed as MEAN±SEM. BMI- body mass index. FFM- fat free mass. SkMMass- skeletal muscle mass. FC- farmers carry. FH- farmers hold. SC- suitcase carry. SH- suitcase hold.

The load for the SC and SH averaged 25.3±0.95 kg. There was greater activation bilaterally in the LT (+7.5% left, p = 0.0041; +2.8% right, p < 0.0005), and MF (+8.2% left, p < 0.0001; +4.5% right, p = 0.0001) during the SC compared to the SH (Table 2). Conversely, on the ipsilateral side of the SC, the RA (+1.7%, p = 0.0070) and EO (+2.2%, p = 0.0257) displayed greater activation compared to the SH, but this was not different in the contralateral side (Table 2).

When comparing two static, bilateral exercises (FH and plank), there was no difference in the LT (p = > 0.9999) or MF activation (p > 0.9999; Table 2). Contrarily, the RA (+50.0% left, p < 0.0001; +44.2% right, p < 0.001) and EO (+28.1% left, p < 0.0001; +29.2% right, p < 0.001) displayed markedly greater activation during identical duration plank compared to the FH (Table 2).

When comparing two bilateral exercises, FC and plank, the FC displayed greater bilateral activation in the LT (+8.7% left, p = 0.0005; +10.9% right, p = 0.0003) and the MF (+10.9% left, p = 0.0004; +11.4% right, p = 0.0009; Table 2). Similar to the FH and plank comparison, however, the plank elicited greater bilateral muscle activation in the RA (+45.7% left, p < 0.0001; +38.1% right, p < 0.0001) and EO (+23.3% left, p < 0.0001; +21.9% right, p < 0.0001) when compared to the FC (Table 2).

During the SH, when compared to the plank, the ipsilateral side LT (-1.5%, p < 0.0231) displayed lower activation, while the contralateral side LT (+16.6%, p < 0.0001) displayed greater activation (Table 2). Likewise, the contralateral MF (+8.8%, p < 0.0001) displayed greater activation during the SH compared to the plank (Table 2). In the RA (+38.9 left, p < 0.0001; +43.1 right, p < 0.0001), there were marked bilateral differences in favor of the plank when compared to the SH (Table 2). A similar response was observed in the ipsilateral EO (+28.8%, p < 0.0001), but not contralateral EO (*p* > 0.9999), as the plank increased activation when compared to the SH (Table 2).

When comparing the SC to the plank, there was no difference in activation observed on the ipsilateral side LT (*p* = 0.6095), though conversely, there was higher ipsilateral MF (+3.8%, *p* = 0.0204) activation during the SC (Table 2). On the contralateral side, both the LT (+24.1%, *p* < 0.0001) and MF (+16.9%, *p* < 0.0001) displayed greater activation during the SC compared to the plank (Table 2). The plank again elicited a marked increase in bilateral activation in the RA (+35.2% left, *p* < 0.0001; +41.4% right, *p* < 0.0001) when compared to the SC (Table 2). The plank prompted an increased activation in the ipsilateral EO (+26.6%, *p* < 0.0001), but not contralateral EO (*p* > 0.9999), over the SC (Table 2).

There was increased activation observed in ipsilateral LT (+9.6%, *p* < 0.0001), MF (+7.7%, *p* < 0.0003), and EO (+4.6%, *p* = 0.0196), but not RA activation (*p* = 0.4656), during the FC compared the SC (Table 2). As expected, the SC elicited a higher activation than the FC in the contralateral LT (+15.4%, *p* < 0.0001), MF (+6.1%, *p* = 0.0190), RA (+10.6%, *p* < 0.0068), and EO (+21.9%, *p* < 0.0001; Table 2).

Table 2. Comparison of muscle activation between equally loaded plank and carry variants.

Muscle Activation (%MVIC)	Farmer's Carry	Farmer's Hold	Plank	Suitcase Carry	Suitcase Hold
Longissimus R	16.4±1.8[bcde]	5.6±0.8[a]	5.5±0.6[ae]	6.8±0.7[ae]	4.0±0.4[acd]
Longissimus L	13.7±1.5[bcde]	4.5±0.7[ade]	5.0±0.7[ade]	29.1±2.5[abce]	21.6±1.8[abcd]
Multifidus R	16.3±2.2[bcde]	5.1±0.7[ad]	4.9±0.7[ad]	8.7±1.1[abce]	4.1±0.5[ad]
Multifidus L	14.9±1.9[bcd]	5.3±0.8[ade]	4.1±0.5[ade]	21.0±1.3[abce]	12.8±1.1[bcd]
Rectus Abdominis R	10.7±2.1[bc]	4.6±0.7[acd]	48.8±4.6[abde]	7.5±0.8[bce]	5.7±0.7[cd]
Rectus Abdominis L	8.4±0.8[bcde]	4.1±0.4[acde]	54.1±5.5[abde]	18.9±2.9[abc]	15.2±1.6[abc]
External Oblique R	14.2±2.1[bcde]	6.9±1.2[ac]	36.1±4.0[abde]	9.6±1.7[ace]	7.3±1.4[acd]
External Oblique L	11.1±1.8[bcde]	6.4±1.2[acde]	34.5±4.8[ab]	33.0±4.2[ab]	31.4±4.2[ab]

All values reported as mean±standard error of the mean. Statistically significant findings: [a]Different from Farmer's Carry. [b]Different from Farmer's Hold. [c]Different from Plank. [d]Different from Suitcase Carry. [e]Different from Suitcase Hold. *p* = 0.05.

DISCUSSION

There were a variety of findings in the present study. First, there was a significantly greater activation of the LT and MF, bilaterally, when comparing the equally loaded FC and FH exercises (Table 2). It appears the instability afforded by the carry exercises increased this activation, in these defined spinal stabilizers (3, 15). Further, the SC displayed significantly greater muscle activation in the LT and MF compared to the SH (Table 2). Despite the increased posterior trunk activation elicited by the carries (FC and SC), anterior, contralateral trunk activation (left RA and EO) was significantly greater in the SC than in the FC (Table 2). A possible explanation for this can be found in previous literature where it is reported that lateral abdominal wall muscles, like the EO, stiffen the pelvis in order to prevent side bending during the stepping process of unilateral exercises such as the SC (3, 10). While the RA is not a lateral abdominal wall muscle like the EO per se, its insertion on the pelvis could still allow it to provide an element of stability during unilateral exercises such as the SC or SH.

Interestingly, the SC and SH displayed no significant difference between one another in the activation of the RA and EO on the contralateral side. However, the SC did elicit a significantly increased muscle activation of the ipsilateral RA and EO (Table 2). We can infer that the unstable nature of the SC compared to the SH has a lower impact on the anterior trunk musculature (RA and EO) than it does on the posterior trunk musculature (LT and MF), further exemplifying the stability properties of the LT and MF muscles seen in prior literature (3, 10, 11, 15).
Another unique finding was the increased activation of the RA during the plank exercise compared to the carries and holds investigated (Table 2). This is likely due to the prone nature of the plank exercise. Conversely, however, Van den Tillaar and colleagues found no difference in RA activation between a loaded plank and a 6 RM back squat (14). This could be indicative that moving the resistance posteriorly, like in the back squat, compared to having the resistance in line with the glenohumeral joint, like in the FC/SC/FH/SH, may have a large impact on the RA muscle activation. In support of this notion, Bautista and colleagues found that the plank displayed significantly greater RA activation compared to a front or overhead squat (1). This is likewise a logical observation, as the posterior load position in the back squat would likely promote more trunk extension than the front or overhead squat, and therefore require more contraction of the RA to stabilize the movement. Further, holding the resistance in an anterior (front squat) or superior (overhead squat) position to the midline places the individual in greater trunk flexion but should not largely impact RA activation.

Despite its significant increase in RA activation, the plank did not elicit significantly greater muscle activation in the left side EO, when compared to the SC and SH. The left side EO was contralateral to the arm holding the resistance implement. This finding implies that the SC or SH may be an appropriate exercise selection to train the EO. Van den Tillaar and colleagues, similarly, did not observe a difference in EO activation between the loaded plank and the 6 RM back squat (14). This follows the logical observation that the EO typically works primarily in the frontal plane (i.e., promoting lateral flexion of the trunk) and not in the sagittal plane (i.e., promoting trunk flexion) due to its position and diagonal fiber direction (10). The plank, however, did produce significantly greater left side EO activation when compared to the left side EO during the FC (Table 2). These findings generally align with McGill an colleagues (3, 10), such that the EO was more activated in conditions where there was a greater demand to stiffen the pelvis (unilateral holds and carries and the plank). It appears that the equal bilateral resistances of the FC and FH balanced each other out, reducing the demand to stiffen the pelvis, therefore failing to activate the EO to the same degree as a unilateral movement (i.e., SC or SH). It is important to note that in order to effectively utilize the SC or SH to train the EO, instead of utilizing the plank, one would have to perform the SC and SH on both sides.

Regarding the posterior musculature, bilateral static exercises such as the plank and FH resulted in low levels of activation (≤5.5±0.6%) in the LT and MF muscles compared to the FC, SC, and

SH. This is partially aligned with literature that demonstrates upright movements (i.e., back squat) produce greater activation in erector spinae muscles when compared to the plank (14). It appears that the locomotive aspect of carries and the stiffness needed in a unilateral exercise contributed to greater muscle activation of the MF and LT.

The purpose of this study was to illuminate the unique nature of the increasingly popular carry/hold exercises compared to the plank. The FC appears to be defined by significantly greater muscle activation in the LT and MF, with significantly lower muscle activation in the RA and EO (Table 2). The FH was defined by low levels of muscular activation overall (all muscles ≤6.9±1.2%), with the plank eliciting significantly greater activation in the RA and EO. The SC was defined by significantly greater activation in the contralateral LT and MF, in addition to a slight (i.e., non-significant) difference in EO activation and lower contralateral RA activation when compared to the plank. Finally, the SH was defined by significantly greater muscle activation in the contralateral LT and MF, in addition to a slight difference in EO activation and lower contralateral RA activation when compared to the plank.

There are some results from the present study that may have implications for the strength and conditioning field. To start, we observed significantly greater muscle activation in the RA during the plank (54.1±5.5% left, 48.8±4.6% right) compared to all other carries and holds. Activation of the RA during the SC and SH was closest to the plank, eliciting 18.9±2.9% and 15.2±1.6% on the contralateral sides respectively. Therefore, out of the strength training exercises examined in this study, individuals looking to activate the RA should utilize the plank compared to a unilateral carry or hold. Further, the contralateral EO during the SC (33.0±4.2%) and SH (31.4±4.2 %) experienced similar EO muscle activation compared to the plank (34.5±4.8%). A potential application of this observation may apply to individuals who struggle to get up and down from the floor, where a plank may be unrealistic. In this instance, the SC or SH both provide similar EO muscle activation without the need to get into a prone position.

Finally, greater bilateral low back muscle activation (LT and MF) was observed during the FC when compared to the FH (LT, +9.2% left, +10.8% right) (MF, +9.6% left, +11.2 right) and plank (LT, +8.7% left, +10.9% right) (MF, +10.8% left, +11.4% right). In examining the differences of these strength training exercises, it appears that the addition of locomotion in the FC leads to increased activation of the low back musculature examined in the present study. Taking this one step further, greater muscle activation was observed on the contralateral side of the unilateral SC when compared to the left side during the FC (LT, +15.4%) (MF, +6.1%). With these observations in mind, it appears that a unilaterally loaded strength training exercise with locomotion stimulates the greatest muscle activation in the LT and MF. A potential application of these findings lies in the progression of strength training exercises. If looking to gradually increase EMG activation of the low back muscles, one could progress from the FH, to FC, to SC.

Our study was not without limitations. The findings presented in this study are limited to a young, healthy population. While this limits our external application, the findings certainly help to establish a baseline of understanding. Future research groups may find great value in examining muscle activation during these essential movements in other populations such as resistance-trained individuals and older cohorts. Electrode adherence in this protocol was exacerbated by sweat. Anecdotally, it was likely the thorough warmup protocol and ambient room conditions (which were consistent, though fairly warm) that led to our issues of electrode adherence in some participants. Participant effort should not have been a contributing factor based on the standardized load application and very short time periods of the carries with five-minute rests in-between. Finally, we had one individual in the study who was not able to maintain the grip strength necessary (and not load carriage per se) for the required carries. This individual's findings are excluded. Future researchers may consider the use of supportive straps to better control for the variable of grip strength. Finally, this study was limited to a surface EMG investigation of four muscles, which represents a small number relative to the total number of muscles involved in the conditions of this study. Future studies can further illuminate the plank, FC, FH, SC, SH through examination of additional musculature as well as other relevant kinematic (e.g., joint kinematics) and kinetic (e.g., ground reaction forces) variables.

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