Received: 30 July 2020

Supplementary materials:
www.osf.io/hgsv8

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Interlimb Asymmetry Negatively Affects Combine-Related Performance in Collegiate American Football Players

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A peer-reviewed version of this article is now available at “Philipp et al., 2020”

ABSTRACT

The assessment of interlimb asymmetry has been of interest to researchers and practitioners who desire to maximize sport performance. The aim of this study was to explore the relationships between interlimb asymmetry and Combine-related performance testing in collegiate American Football players. Twenty-four skill position players (e.g., running backs, defensive backs, and wide receivers) from a Division II university completed all study-related procedures including unilateral countermovement (CMJ) and drop jumps on a force plate, 3-repetition maximum Bulgarian split squats with bar movement tracked by a 3D motion capture system, and their annual spring performance tests (L-drill, pro-agility, 40-yard dash, broad jump, and vertical jump). Using an alpha-level of 0.05, significant, positive Spearman’s correlations between change of direction (CoD) performance (in the L-drill test) and asymmetries in mean peak velocity (r_s = .491, n = 24, p = .015), mean peak power (r_s = .467, n = 24, p = .021), and mean average power (r_s = .455, n = 24, p = .026) were observed. Associations between interlimb asymmetries and the pro-agility test were not significant. Additionally, a significant, negative Pearson correlation between unilateral CMJ height asymmetry and vertical jump performance was observed (r = -.578, n = 24, p = .003). Asymmetry in mean peak velocity, mean peak power, and mean average power may negatively influence CoD ability within collegiate American Football players. Further, the L-drill may be a more sensitive assessment for testing the impact of interlimb asymmetry on CoD performance.

All authors have read and approved this version of the manuscript. This article was last modified on May 3rd, 2021.

INTRODUCTION

Successful performance in sports depends on specific skill-based proficiencies and physical attributes. In American Football, these proficiencies and attributes are routinely tested at the collegiate and professional level through Combine-related performance tests (i.e. L-drill, pro-agility, 40-yard [yd] dash, broad jump, and vertical jump). These tests rely on athletes' change of direction ability (CoD) and/or linear acceleration, as well as power production capacity in vertical and/or horizontal movements (Robbins, 2012). Physical attributes have been linked to outcomes in the noted performance tests. Specifically, lower extremity maximal strength (Peterson et al., 2006; Taber et al., 2016), rate of force development (RFD) (Taber et al., 2016), and reactive strength (Flanagan & Comyns, 2008) have well-documented associations with CoD, linear acceleration, and vertical and horizontal jump performance across various athletic populations. Understanding physical attributes that underlie success or failure in these skill-based performance tests is of great interest to coaches, athletes, strength and conditioning professionals, and sport scientists.

There is also considerable interest in how deficiencies in these physical attributes may detract from an athletes' proficiency when testing. For example, lower extremity interlimb asymmetry in maximal strength has been the target of specific investigation. Interlimb asymmetry is evaluated by comparing limb performance bilaterally. A 2018 systematic review by Bishop et al. (Bishop et al., 2018) revealed inconsistent findings with respect to maximal strength asymmetry among divergent athletic populations across a variety of performance test batteries. Nonetheless, recent studies indicate a negative relationship between interlimb asymmetries and CoD performance (Bishop, Read, et al., 2019; Bishop, Turner, et al., 2019; Madruga-Parera et al., 2019), sprint acceleration (Bishop, Read, et al., 2019; Bishop, Turner, et al., 2019; Madruga-Parera et al., 2019), and vertical power production (Bishop, Brashill, et al., 2019).

Only one study relating interlimb asymmetries to skill-based performance in American Football athletes could be found (Hoffman et al., 2007). The study indicated no correlation between differences in unilateral leg power (evaluated from a countermovement jump [CMJ] and CoD measured via the three-cone drill) (Hoffman et al., 2007). Contemporary investigations suggest there is a need to assess more than one metric of interlimb asymmetry in an effort to elucidate potential deficiencies. For example, Bishop et al. (Bishop, Read, et al., 2019) did not find a significant correlation between interlimb CMJ height asymmetry and CoD speed in professional soccer or cricket players. However, interlimb asymmetry assessed via a drop jump (DJ) task was significantly associated with CoD speed performance in the cricket athletes (Bishop, Read, et al., 2019). The discrepancy in significant association between DJ, but not the CMJ, and the performance task makes it clear that the use of a single task for assessment of interlimb asymmetry is possibly short-sighted and misleading.

The aim of the present study was to determine if interlimb asymmetry in lower-extremity maximal power production capability, RFD, and other ground reaction force data were associated with Combine-related performance tests commonly utilized within American Football, but applicable across the sports spectrum. The inclusion of multiple tests offers a widespread coverage of potential asymmetries influencing Combine-related performance tests. Based on previous studies (2–5,22), we hypothesized that influential asymmetries may come from metrics extracted from (a) lower-extremity maximal power production capability assessed through the Bulgarian split squat (BSS) as well as (b) RFD and other ground reaction force data (e.g. peak eccentric force, reactive strength index) extracted from unilateral CMJ and DJ.

METHODS

Subjects and Eligibility

The University of Central Missouri's (UCM) Institutional Review Board approved all of the study procedures. All eligible participants had the opportunity to take as much time as desired to review the risks, ask questions, and receive an answer prior to signing the informed consent, and beginning the study procedures.

Study participants included running backs, defensive backs, and wide receivers (often referred to as skill position players) on the current roster. These positions were of interest as successful role execution is predicated, in part, on CoD and acceleration performance. Participants were instructed to refrain from vigorous lower-body resistance exercise in the 48 hours prior to testing, and all participants were cleared by athletic training staff to engage in football-related activities. Individuals experiencing acute illness or musculoskeletal injury were excluded from study participation.

Testing Procedures for Session One

Participants arrived to the UCM Kinesiology Human Performance Laboratory wearing comfortable athletic clothing. Supportive garments (e.g. knee wrap, ankle brace) and weightlifting belts were prohibited during testing procedures. After consent, anthropometric data (height, weight, and body composition) were collected in the Human Performance Laboratory. Participants were then taken to the UCM Biomechanics Laboratory for the warmup and collection of their unilateral ground reaction force and CMJ

DOI: 10.31236/osf.io/fm8z6

and DJ height data with the Kistler Force Plate (Kistler 9286A portable force plate, Kistler, Novi, MI) and Qualisys Motion Capture System (Qualisys AB, Göteborg, Sweden). Finally, participants returned to the Human Performance Laboratory for testing lower-extremity maximal power production capability via the BSS.

Anthropometric Data.

Height was measured barefoot using a Seca stadiometer (Seca®, Chino, CA) and recorded in centimeters (cm). Mass was measured using an electronic Befour PS 7700 scale (Befour®, Saukville, WI) and recorded in kilograms (kg). Body composition was estimated using the InBody® 570 (Cerritos, CA).

Warmup.

Prior to testing, each participant performed a dynamic warmup, using a 45-lb. plate. The warmup was a team-employed strategy to which all participants were accustomed. Participants progressed to a more specific warmup in which they were allowed two practice jumps on each limb with verbal guidance provided by researchers. After warmup, super-spherical markers were placed on the participant's left and right greater trochanter of the hip for delineation of the subphases of movement (e.g. eccentric, amortization, concentric).

Unilateral Countermovement Jump.

The best of two unilateral CMJ attempts (with respect to jump height) for each leg was used to assess the dependent variables. One minute of rest was completed after participants performed the unilateral CMJ. The unilateral CMJ procedure was adapted from McMahon et al. (McMahon et al., 2018). Participants were instructed to stand upright on the force plate, as still as possible, until given the command "jump," after which they dropped to their preferred depth as rapidly as possible and jumped up as fast and as high as possible. Upper-body involvement was minimized by a PVC pipe being held behind the head across the shoulders.

The Kistler Force Plate and Qualisys systems were used to acquire ground reaction force data that included peak eccentric force, overall peak force, average eccentric RFD, overall average RFD, and reactive strength index modified (RSImod). Peak eccentric force was defined as the peak force achieved throughout the eccentric portion of the CMJ. Peak overall force was defined as the peak force achieved throughout the entire CMJ. Average RFD was defined as the peak overall force achieved throughout the entire countermovement divided by the time it took to achieve that force (Haff et al., 2015). Average eccentric RFD was defined as the peak overall force achieved throughout the eccentric portion of the CMJ divided by the time it took to achieve that force (Laffaye & Wagner, 2013). The CMJ height was calculated as "$1/2g(t/2)^2$" (where g = gravity; 9.81 m/s^2 and t = time in air). RSImod was calculated by dividing the unilateral CMJ height in cm by time to take-off (Kipp et al., 2016). Each asymmetry was assessed as the percentage difference between limbs, using the following calculation [(max value – min value)/max value] x 100.

Unilateral Drop Jump.

A total of three minutes was allotted between the unilateral CMJ and DJ procedures. The best of two unilateral DJ attempts (with respect to jump height) for each leg was used to assess the dependent variables. One minute of rest was completed between the completion of unilateral DJ attempts. Upper-body involvement was again minimized by a PVC pipe held behind the head across the shoulders. Dropping from a 30-cm platform, participants landed on the force plate and attempted to jump as fast and as high as possible, attempting to minimize time on the ground. Researchers acquired ground reaction force data to calculate reactive strength index (RSI). RSI was calculated by dividing unilateral DJ height by time on the ground (Flanagan & Comyns, 2008). Unilateral DJ height was calculated as previously described [$1/2g(t/2)^2$]. The asymmetry calculation was noted previously. Following the jump procedures, the super-spherical markers were removed.

Bulgarian Split Squat.

Participants returned to the Human Performance Laboratory for the BSS. A total of five minutes was given between the completion of the unilateral DJ procedures and the start of the warmup for the BSS. The procedures for testing the BSS were adapted from McCurdy et al., (McCurdy et al., 2004) and Lockie et al., (Lockie et al., 2017) and were performed within a power rack. A single leg squat roller was used to elevate and support the rear foot. The warmup consisted of participants performing ten repetitions with a load approximating 40% of their respective estimated 1-RM for the lift. For the second set, participants performed five repetitions after researchers added approximately 10-20% more weight (Lockie et al., 2017). For the third set onward, three repetitions were performed with an increased weight until the 3-RM was achieved. A successful repetition necessitated the femur of the working leg to be parallel to the floor before commencement of the concentric phase of the lift. This technique is in line with recommendations by McCurdy et al. (McCurdy et al., 2004) and Lockie et al. (Lockie et al., 2017). Visual assessment by members of the research team and verbal cues were provided to participants to ensure proper technique during all sets. Participants were asked to perform the concentric portion of the movement as explosive as possible. Standardized, three-minute rest periods were utilized between sequential attempts. After completion of the first leg, the second leg was tested in accordance. Spotter bars were positioned for safety.

Mechanical power and velocity applied to the bar were measured using the EliteForm® 3D motion capturing system, a valid and reliable tool (EliteForm®, Lincoln, Nebraska) (Bradford, 2017). The EliteForm® captured data at 30 Hz via dual 3D cameras and provided a digital readout from which researchers recorded mean peak velocity (mPV) and mean average velocity (mAV), as well as mean peak power (mPP) and mean average power (mAP) for the final successful 3-RM lift for each leg (for the concentric portion of the lift).

DOI: 10.31236/osf.io/fm8z6

Computations for mPV, mAV, mPP, and mAP are calculated based on proprietary algorithms. The asymmetry was calculated as noted previously.

Testing Procedures for Session Two

Session two occurred at the Audrey J. Walton stadium during spring football testing and included a standardized warmup and Combine-related performance testing. Participants arrived wearing comfortable athletic clothing and football cleats. All participants performed the L-drill, pro-agility, 40-yd dash, broad jump, and vertical jump. Testing occurred by position group, so the order was not controlled by the research team (i.e. testing occurred orderly but was not randomized). Three people were responsible for hand-capturing times for the L-drill, pro-agility, or 40-yd dash. The same person captured times for all participants on their respective Combine-related performance test.

The L-Drill.

The L-drill, also called the three-cone drill, was one measure of CoD. The method was derived from its usage within the NFL Combine. The three cones were placed five yds apart. The distance covered totaled 30 yds and consisted of six short sprints. Participants started in a three-point stance. The best of three attempts was used in analysis. A successful attempt involved the participant completing the drill from start cone to the finish cone (same cone) without contacting any cone.

Pro-Agility Drill.

The pro-agility drill, also called the 5-10-5 drill, was another measure of CoD. The method was derived from established professional procedures and is a popular test to measure CoD performance within this population (Haff & Tripplet, 2016). The test is set up with two lines set 10 yds apart and a third line directly in the middle, five yds from each end. The participants started in a three-point stance, with one foot on either side of the center line. On a signal, the participant turned and sprinted five yds to their left, touched the line, turned 180°, and sprinted ten yds in the other direction, before turning 180° a final time, and sprinted for five yds through the line at which they started (Haff & Tripplet, 2016). The best of three attempts was used in analysis. The timer was started upon the first movement of the participant. A successful attempt involved the participant contacting the line at which they were turning, with their hand.

40-Yard Dash.

The 40-yd dash was conducted with participants beginning in a three-point stance and running as fast as possible for 40-yd (Kuzmits & Adams, 2008). The best of three attempts was used in analysis.

Broad Jump.

For the broad jump, participants began from a standing position and jumped as far as possible horizontally (from the starting line to the rearmost heel strike)(Koch et al., 2003). Participants were allowed three attempts with the best being used in analysis. A successful attempt involved a jump from the starting line and the participants landing without falling back.

Vertical Jump.

The vertical jump data was recorded using the Just Jump System (Probotics, Inc., Huntsville, AL). Participants stepped onto the mat, dropped forcefully to their preferred depth, and jumped as high as possible. The task was performed bilaterally with use of an arm swing. Participants were allowed three attempts with the best being used in analysis. A successful attempt involved the participants jumping from and landing back on the measuring mat.

Statistical Analyses

All data were assessed for normality using a Shapiro-Wilk statistic and screened for influential outliers (step of 1.5 x interquartile range) prior to all inferential tests. No outliers were identified. Both non-parametric (Spearman's Rho; r_s) and parametric (Pearson; r) analyses were used to assess relationships between participant's physical attributes and skill-based performance tests. All analyses were run in SPSS version 24.0 (IBM, Inc., Armonk, NY), and statistical inferences were made using an α level of 0.05. All data are presented as means (M) ± standard deviations (SD).

Results

A convenience sample comprised of 26 participants was recruited. Two participants who sustained non-study related injuries did not participate in the Combine-related performance testing. Accordingly, 24 participants engaged in the study (age = 19.8 ± 0.9 years, height = 179.0 ± 3.4 cm, and mass = 83.2 ± 5.7 kg; n = 19 for body fat = 9.9 ± 3.1% and lean mass = 43.6 ± 2.9 kg). Training age of the 24 participants (years in the UCM collegiate strength and conditioning program) was 1.9 ± 0.9 years.

Combine-Related Performance Test Descriptive Statistics

Table 1 presents the descriptive data for the Combine-related performance tests, as well as comparative values from recognized, collegiate American Football designations.

Table 1. Descriptive characteristics for the Combine-related performance tests

Combine-related performance tests	Sample (n = 24)	Non-Power 5 (n = 503)	Power 5 (n = 1156)
L-drill (s)	6.95 ± 0.22	7.04 ± 0.26	7.03 ± 0.25
Pro-agility (s)	4.25 ± 0.13	4.20 ± 0.16	4.19 ± 0.15
40-yard dash (s)	4.52 ± 0.14	4.55 ± 0.11	4.54 ± 0.11
Broad jump (m)	2.89 ± 0.2	3.03 ± 0.2	3.02 ± 0.1
Vertical jump (cm)	86.2 ± 5.8	89.7 ± 7.6	89.6 ± 7.5

Note. Non-Power 5 and Power 5 data retrieved from publicly available information (https://www.pro-football-reference.com/play-index/nfl-combine-results.cgi) from 1997-2018.

Asymmetry Metrics Descriptive Statistics

Table 2 presents the descriptive data for all asymmetry metrics, including the mean and standard deviations for the higher (maximal value) and lower (minimum value) performing limbs.

Table 2. Descriptive characteristics for asymmetry metrics (*n* = 24 unless specified)

Asymmetry metrics	Higher Performing Limb (M ± SD)	Lower Performing Limb (M ± SD)	% Difference
mPV (m/s)	0.66 ± 0.12	0.53 ± 0.12	18.0 ± 12.8
mAV (m/s)	0.42 ± 0.07	0.36 ± 0.07	14.5 ± 9.1
mPP (W)	740.92 ± 183.3	599.77 ± 196.4	18.0 ± 12.8
mAP (W)	660.58 ± 174.0	538.15 ± 168.4	16.0 ± 11.8
CMJ height (cm)	29.0 ± 0.03	26.0 ± 0.03	9.3 ± 6.5
Peak Eccentric Force (N) (*n* = 23)	1534.0 ± 224.3	1436.3 ± 209.6	5.2 ± 4.3
Peak Overall Force (N)	1814.6 ± 171.6	1741.4 ± 160.2	4.3 ± 2.5
Avg RFD ($N \cdot s^{-1}$)	4397.7 ± 1776.8	3631.7 ± 1356.1	15.9 ± 12.1
Avg Eccentric RFD ($N \cdot s_{-1}$) (*n* = 23)	5661.4 ± 1963.2	4752.5 ± 1732.9	14.6 ± 10.8
DJ height (cm)	26.0 ± 0.04	25.38 ± 0.04	6.2 ± 6.5
Reactive Strength Index	0.69 ± 0.14	0.59 ± 0.11	13.8 ± 8.8
RSImod	0.42 ± 0.09	0.38 ± 0.08	10.1 ± 9.6

mPV = mean peak velocity; mAV = mean average velocity; mPP = mean peak power; mAP = mean average power; CMJ = countermovement jump; Avg = average; Avg RFD = average rate of force development; DJ = drop jump; RSImod = reactive strength index modified

Relationships between Combine-Related Performance Tests and Asymmetry Metrics

For the L-drill test, several asymmetry metrics demonstrated significant relationships with participant's performance. Extracted from the BSS test, there were moderate, positive correlations between asymmetry in mPV (r_s = .491, n = 24, p = .015), MPP (r_s = .467, n = 24, p = .021), and mAP (r_s = .455, n = 24, p = .026) and L-drill performance.

For the vertical jump test, there was a moderate, negative correlation between CMJ height asymmetry (r = -.578, n = 24, p = .003) and vertical jump performance.

Discussion

The present study investigated the effect of interlimb asymmetry on Combine-related performance tests within Division II collegiate American Football players. We hypothesized that larger interlimb asymmetry would negatively influence performance on selected Combine-related performance tests. These data reveal that interlimb asymmetries in mPV, mPP, and mAP negatively influence performance in the L-drill test, while interlimb asymmetry in CMJ height negatively influences performance in the vertical jump test. There were no significant correlations revealed between other measures of asymmetry and performance (pro-agility drill, 40-yd dash, or broad jump).

Within the present study, asymmetry in mPV, mPP, and mAP were negatively related to CoD performance assessed via the L-drill. Lockie et al. (Lockie et al., 2017) similarly used this assessment task to identify asymmetry to assess effect on sprint acceleration performance. A large, negative relationship (n = 8, p = .015) between unilateral mean force asymmetry in the BSS and 0-5-meter velocity split in a 20 meter sprint was found (Lockie et al., 2017). The indication was that a faster initial acceleration was associated with a lower unilateral asymmetry in mean force production capability between legs. Our study also revealed that asymmetry in CMJ height negatively influences performance in the vertical jump test. This corroborates recent findings that asymmetry in CMJ height can have a negative impact on vertical jump performance (Bishop et al., 2018). By looking at multiple Combine-related performance tests, our data speak to the limitation of solely focusing on linear sprint acceleration and sprint performance. As sport performance most typically relies on CoD and lower extremity power production capability, knowing that asymmetry impacts this outcome is useful for athletes and practitioners.

Beyond the primary questions of interest, there are two additional findings worthy of discussion. First, even though performance in the L-drill and pro-agility tests were significantly related (r = 0.75), the L-drill showed greater sensitivity to interlimb asymmetry. We believe this may be due to the fact that, in the pro-agility drill, athletes can choose which leg to utilize to change direction. Conversely, within the L-drill, athletes are forced to change direction as each leg is forced to plant and serve as the base for reacceleration. This would suggest that, between the L-drill and pro-agility tests, the L-drill may be a better fit for practitioners wanting to assess the effects of interlimb asymmetry on CoD performance due to its ability to control for potential limb preference bias in athletes' execution of the pro-agility test. Second, based on recent evidence from Bishop et al. (Bishop, Read, et al., 2019; Bishop, Turner, et al., 2019), we anticipated that the unilateral DJ test would produce asymmetry metrics significantly related to our CoD performance measures. We did not find significant correlations between DJ height asymmetry and the Combine-related performance tests. Bishop et al. (Bishop, Read, et al., 2019) had athletes drop from a box height of 18 cm, whereas participant's in our study dropped from 30 cm. Future research could investigate if a particular DJ height shows greater sensitivity toward highlighting interlimb asymmetry as this may influence landing kinematics (Hobara et al., 2011).

To our knowledge, only one other study has investigated asymmetry effects on physical performance tests in American Football players. In their study, Hoffmann et al. (Hoffman et al., 2007) had collegiate players perform a unilateral CMJ testing prior to performing the L-drill. The correlation (r = 0.11) between differences in unilateral leg power and CoD performance was weak and not significant (Hoffman et al., 2007). Hoffman et al. (Hoffman et al., 2007) singularly looked at power in relationship to the L-drill. Our study sought to investigate the potential role asymmetry more comprehensively might play by investigating multiple CoD tasks in this population. This concept was recently supported by Bishop et al. (Bishop, Read, et al., 2019) who found that interlimb asymmetry in DJ height, but not CMJ height, predicted CoD speed performance in professional cricket athletes. Different testing methods may reveal divergent findings. A wider scope of investigation may ultimately reveal the most sensitive asymmetry metrics relating to Combine-related performance tests, and the most sensitive assessment tools applicable for a wide range of sport performance.

We understand that performance tests are not a true representation of sport performance. Nevertheless, recent evidence does highlight the relationship between performance within Combine-related performance testing and actual on-field performance within American Football (LaPlaca & McCullick, 2020). The results may be valuably extended beyond American Football athletes, by assessing multiple metrics of asymmetry in athletes across the sports spectrum.

Expanding further, future research may investigate the magnitude at which asymmetries begin to impact athletic performance. For example, Lockie et al. (Lockie et al., 2017) have suggested that a meaningful threshold of 15% asymmetry may be the point at which physical attributes are negatively affected. Practitioners would benefit from knowing established asymmetry thresholds (given a specific assessment method and performance test of interest) to discriminate high- and low-performance.

The present study is not without its limitations. Although the BSS 3-RM is a valid and reliable means of assessing unilateral strength, it has recently been suggested that using a 5-RM for assessing interlimb asymmetries is also a valid and reliable means to conducting the test (Helme et al., 2019; McCurdy et al., 2004). A 5-RM testing method would have reduced the absolute loads during the submaximal and maximal attempts. Our participants were trained and skilled on the movement, but they were still challenged by a need to focus on stabilization and maintaining balance while producing maximal unilateral concentric force. It was expected that our participants would demonstrate above average levels of lower body strength (mean unilateral 3-RM: 113 ± 19.9 kg). Some individuals squatted over 120 kg on a single leg during our testing. Yet, by working up to such a large load, some of our participants experienced difficulty remaining balanced. It is unknown whether difficulty balancing influenced our data. Using a 5-RM, instead of a 3-RM, would reduce the absolute loads lifted and may reduce potential balance concerns in studies

DOI: 10.31236/osf.io/fm8z6

wishing to mimic these procedures. Arguably, the greatest limitation of this study is the fact that interlimb asymmetry was analyzed from a single testing session. Recent evidence from Bishop et al., has shown that interlimb asymmetry may not track consistently over time (Bishop et al., 2020). Future research should include test-retest data.

The present study demonstrates that interlimb asymmetries negatively associate with CoD performance in Division II collegiate American Football players. These findings, as well as the procedures used, may benefit practitioners wanting to assess the effects that interlimb asymmetry have on their athletes. Additionally, our findings indicate that particular assessments may be more sensitive at detecting underlying asymmetry. We suggest that more than one metric of assessment be used when testing for potential interlimb asymmetry in athletes. Lastly, researchers will want to investigate intervention strategies, and the time course of effective interventions, to effectively address the asymmetry concerns.

Conclusion

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Contributions

Contributed to conception and design: NMP, MJG, DAC
Contributed to acquisition of data: NMP, MJG, DAC, DWD, JAH
Contributed to analysis and interpretation of data: NMP, MJG, DAC
Drafted and or revised the article: NMP, MJG, DAC
Approved the submitted version for publication: NMP, MJG, DAC, DWD, JAH

Acknowledgements

None.

Funding information

None.

Data and Supplementary Material Accessibility

Data and analyses are available at the OSF project website identified on title page.

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