ORIGINAL ARTICLE

Nordic hamstring exercise asymmetries do not influence change of direction abilities

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ABSTRACT

Multidirectional demands in team sports emphasise eccentric hamstring strength, as the hamstrings play a critical role in modulating ground reaction forces during deceleration and change of direction (COD). A common method to assess limb asymmetry is the Nordic Hamstring Exercise (NHE), an eccentric movement which derives metrics such as maximum force and impulse which are associated with improved linear acceleration in team-sport athletes. The primary aim was to examine how NHE-derived symmetries and limb differences influence COD sprint performance metrics. Forty-six university-level athletes (28 males, 18 females; age 20.37 ± 1.47 years) underwent 30-m linear and COD sprints, alongside bilateral NHE on the VALD Nordbord measuring maximum force, average force, and impulse. Non-parametric data were analysed using ART followed by general linear models in SPSS, with fixed factors of symmetry grouping, limb, and direction (for directional metrics) and a significance of $p < .05$. No significant effects or interactions emerged for symmetry grouping across metrics including MDSA area, area percentage, acceleration, directional velocity and directional acceleration, and NHE forces and impulse. Limb grouping showed significant effects on area percentage ($p = .02$; left higher) and maximum force ($p = .05$; right higher), while directional grouping revealed highly significant effects ($p < .001$) with sharper angles yielding lower acceleration and velocity. These findings suggest NHE symmetries do not substantially influence COD performance in this cohort, whereas limb-specific differences influence area percentage and maximum force, and sharper turn angles substantially reduce acceleration and velocity.

Keywords: Performance analysis, Change of direction, Nordic hamstring exercise, Asymmetry.

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INTRODUCTION

Multidirectional sprinting in field- and court-based sporting codes plays a pivotal role in match performance due to the athletes being required to evade opponents, respond to dynamic game scenarios, and execute tactical manoeuvre effectively (Brughelli *et al.,* 2008; Sheppard & Young, 2006). These actions, including acceleration, deceleration and change of direction (COD), require an athlete to produce and absorb forces rapidly, particularly from lower extremities in which strength asymmetries as well as neuromuscular control can influence their multidirectional efficiency (Bishop *et al.,* 2019; Dos'Santos *et al.,* 2019). Athletes which undergo repetitive sport specific pivoting or unilateral loading may experience asymmetrical inter-limb differences exceeding 10-15% which may compromise specific tasks which require bilateral coordination (Bishop *et al.,* 2021; Kocak *et al.,* 2023; Loturco *et al.,* 2022).

Eccentric tasks during a deceleration are controlled by the hamstrings which moderate ground reaction forces (GRFs) in order to regulate momentum as well as facilitating re acceleration during a COD (Harper *et al.,* 2022; Morin *et al.,* 2015). To isolate and strengthen eccentric hamstring capabilities, the Nordic hamstring exercise (NHE) is commonly used with studies finding that team sport athletes that perform the NHE have found to have improved linear acceleration and reduced hamstring asymmetry (Freitas *et al.,* 2019; Kocak *et al.,* 2023; Loturco *et al.,* 2019; Opar *et al.,* 2015). Although the research is under explored when considering how NHE derived asymmetries may affect multidirectional sprints as these imbalances may not only impair functions slightly but also accumulate over time (Bishop *et al.,* 2022; Ličen & Kozinc, 2023).

A COD task will increase the demands required during sprinting as the athletes are required to, decelerate, redirect their path and re accelerate in that direction which can all be influenced by the turn angle, entry velocity as well as the limb dominance of the athlete (Dos'Santos *et al.,* 2018; Jones *et al.,* 2016). When performing a change of direction with a sharper angle, such as at 90° or 135°, greater braking impulses and eccentric control is required compared to that of narrower angles, which may lead to asymmetries in velocity and acceleration capabilities between limbs (Hader *et al.,* 2016; Arboix-Alió, Buscà *et al.,* 2024). Additionally, biomechanical research has found that COD sprints with larger turns will intensify braking impulses and additionally decrease momentum after the pivot, which negatively effects the reacceleration due to the increased demands for eccentric muscle regulation as well as GRF adjustments (Dos'Santos *et al.,* 2018; Dos'Santos *et al.,* 2021; Harper *et al.,* 2019).

However, even while considering these insights, tradition assessments will test linear sprint and COD capabilities separately, thus limiting the insight into an athlete's holistic multidirectional sprint ability (Nimphius *et al.,* 2018; Graham-Smith *et al.,* 2018). The multidirectional sprint area (MDSA) is a novel method in which the velocities from a linear sprint, deceleration and multiple COD sprints are used to create a holistic metric to determine an athlete's multidirectional sprint ability (Gordon & Green *et al.,* 2026). This method enables evaluation of proportional contributions, revealing how asymmetries in velocity or acceleration might stem from underlying strength disparities, as seen in comparisons between NHE and COD performance (Bishop *et al.,* 2021; Gordon & Green, 2026). Furthermore, athletes' training loads and recovery times vary, particularly in university athletes, while understanding these links could assist in informing interventions due to the paucity in comparing NHE symmetries with COD metrics across multiple angles in male and female groups (Freitas *et al.,* 2022; Loturco *et al.,* 2022).

In addition, due to the inconsistent relationship between COD speed and drop jumps as well as isokinetic tests, task specific evaluations are required to further understand the relationships for multidirectional ability (Bishop *et al.,* 2022; Dos'Santos *et al.,* 2019). While previous research has shown that hamstring demands will increase as the angle in a COD increases, it remains unclear how NHE metrics different when comparing the specific angles, particularly when including the MDSA method for the athletes (Gordon & Green, 2026; Harper *et al.,* 2022). This may assist coaches and practitioners with profiling their athletes, where early detection of their imbalances could support their development of their multidirectional sprint ability (O'Cain *et al.,* 2025; Arboix-Alió *et al.,* 2024).

The primary aim of this study is to investigate the relationships between NHE symmetries, limb differences, and COD sprint performance metrics—including MDSA areas, accelerations, and velocities—across 45°, 90°, and 135° turns in university-level athletes.

METHODOLOGY

Research design and participants

This study followed an observational cross-sectional approach in order to compare the NHE symmetry/ asymmetry classifications of the athletes and their sprint and COD metrics. The assessments were conducted over two sessions, conducted on separate days interspersed by a minimum of 48 hours, to limit fatigue accumulation. Sprint and COD tests were performed on grass surface to mimic competition setting. The testing procedure was varied between individuals within the groups to mitigate sequencing bias, however the athletes followed a fixed schedule for consistency in measurement.

A sample of 46 university-level athletes (age: 20.37 ± 1.47 years; mass: 65.14 ± 8.22 kg; height: 169.15 ± 8.67 cm) who volunteered from team sports including football, rugby, and hockey. The sample comprised 28 males (age: 20.86 ± 1.62 years; mass: 67.38 ± 8.03 kg; height: 173.21 ± 8.53 cm) and 18 females (age: 19.61 ± 0.7 years; mass: 61.66 ± 7.7 kg; height: 162.83 ± 4.2 cm). All athletes completed written informed consent forms prior to participation, and the study received institutional ethical approval (REC-1359-2022).

Linear maximal sprint

The velocity of a 30 m maximal straight-line sprint was captured using a Stalker ATS II radar device (Stalker Pro, Radar Sales Inc., Richardson, TX, USA). Each sprint was split into the first 15 m and the second 15 m to reach the overall 30 m distance performed. Acceleration was subsequently calculated from the velocity measurements from the sprints. Athletes were instructed to use a split start stance, with their lead foot placed 30 cm behind the start line to ensure they started at the correct position and were encouraged to continue running at maximal effort past the end point. Three attempts were performed by each athlete with a minimum of 2-minute intervals between attempts to allow for optimal performance during each attempt. Data processing was conducted through Stalker ATS 5.0 software (Stalker Pro, Radar Sales Inc., Minneapolis, MN, USA) (Cronin & Templeton, 2008).

Comentado [AG1]: To continue running at maximal effort past the end point

Change of direction

COD capabilities were measured through 30-m sprints incorporating pivots at the midpoint (15 m) with turn angles of 45°, 90°, and 135° executed bilaterally, yielding six variant conditions. Interval timings at 15 m and 30 m were obtained using Fusion Smartspeed timing gates (Fusion Sports, Coopers Plains, Queensland, Australia) accurate to 0.01 s. Commencing from a static split stance akin to the sprint test, athletes propelled maximally to the pivot point, braked optimally for redirection, and accelerated to completion. Each variant allowed three repetitions separated by no less than 3-minutes of recovery. The attempt with the fastest 15-30 m interval was used to for the velocity and acceleration data.

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Multidirectional Sprint Area (MDSA)
The MDSA method is a novel method which is used to quantify a holistic multi directional sprint performance of an athlete by measuring linear sprint, deceleration and COD velocities across eight equidistant directions (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) (Gordon & Green, 2026). The MDSA method can present an athlete's MDSA in directional sections, including forward, backward, right and left. The protocol established for this method used velocity data from the 15-30 m interval of the various tests which forms an octagonal polygon on a graph (Gordon & Green, 2026). A shoelace formula, defined as $0.5 \mid \sum(x_i y_{i+1} - x_{i+1} y_i) \mid$, was used to calculate the total area as well as the segmented areas derived from the velocity data captured (Gordon & Green, 2026). Furthermore, the segmented areas of the right and left direction can be used to assess the athlete's directional dominance with both a relative percentage value as well as the actual value calculated from the segmented area.

Nordic curls
A Nordic hamstring curl was used to evaluate the hamstring eccentric capacity of the athletes using a VALD Nordbord (VALD Performance, Newstead, Australia). The athletes were instructed to set themselves in a knelling position on the VALD Nordbord with their lower legs fixed with restraints that are positioned onto the ankle joints, with each attempt having a 30 second rest interval. Each athlete attempted the NHE three times and were instructed to have a controlled forward descent against the resistance while also ensuring their hips and torso stay aligned as well as their arms folded across their torso. The attempts were considered acceptable if a clear and distinct force apex was succeeded by an abrupt reduction during the assessment. The metrics recorded for this test included peak force (N), mean force (N) and peak impulse (N·s) for each leg.

Identification of asymmetry
Symmetry and asymmetry were evaluated bilaterally for NHE metrics (right and left limbs) and directionally for COD accelerations and velocities. For NHE, symmetry was determined by comparing absolute differences using maximum force, with asymmetry defined as a difference exceeding 10% of the stronger limb's value (Kocak *et al.,* 2023). Data were grouped into symmetry (symmetrical vs. asymmetrical) and limb (right vs. left) categories, with directional added for COD-specific analyses to capture turn-side effects.

Statistical analysis
Participants were grouped by a symmetrical grouping, which was examined by the symmetry and asymmetry metrics from their max force outputs of their NHE for comparative analysis. Additionally, the limb groupings were made according to the directional (left and right) tests as well as directional grouping which were grouped by the different angles of the COD tests (45°, 90° and 135°).

Shapiro-Wilk tests confirmed non-parametric data distribution, necessitating aligned rank transformation (ART) for ANOVA-type analyses using the ARTool. ART-transformed data were analysed in SPSS (Version 30, IBM Corp., Armonk, NY, USA) using general linear models (GLM) and univariate procedures. Fixed factors included symmetry grouping and limb grouping for all metrics, with direction added as a third factor for directional acceleration and velocity datasets. Dependent variables comprised ART-transformed MDSA area, MDSA area percentage, acceleration, directional velocity, directional acceleration, NHE maximum force, NHE average force, and NHE maximum impulse. Significance was set at $p < .05$, with post-hoc tests adjusted for multiple comparisons where applicable. Multiple comparisons (n = 18) resulted in an adjusted p-value of .00278.

RESULTS

When comparing the directional acceleration and velocity of the athletes during each change of direction sprint, the data indicates that CODs with greater angles of change exhibit lower acceleration and velocity than those with lesser angles, consistent with biomechanical demands of sharper turns (Table 1). For the MDSA method, minor differences between left and right segments were revealed (Table 2). Finally, the Nordic hamstring curl metrics, the median average force, maximum force and maximum impulse showed differences between the symmetrical and directional groupings (Table 2).

Table 1. Descriptive data (median and interquartile range (IQR)) for the COD tests for 46 field team-sport athletes, based on allocated groups.

	Asymmetrical (n = 21)	**Symmetrical (n = 25)**	**Left (n = 46)**	**Right (n = 46)**	**45 (n = 92)**	**90 (n = 92)**	**135 (n = 92)**
Velocity†	5.84 (1.932)	5.94 (1.98)	5.94 (2.01)	5.87 (1.94)	7.52 (2.04)	6.47 (1.72)	5.12 (1.19)
Acceleration†	2.27 (1.59)	2.43 (1.69)	2.36 (1.70)	2.30 (1.63)	3.94 (1.93)	2.80 (1.40)	1.76 (0.80)

Note. †p < .00278.

Table 2. Descriptive data (median and interquartile range (IQR)) values for the symmetry and directional data

	Asymmetrical (n = 21)	**Symmetrical (n = 25)**	**Left (n = 46)**	**Right (n = 46)**
Area	55.26 (25.05)	59.72 (25.68)	58.51 (26.96)	58.91 (24.77)
Area percentage*	50.00 (2.77)	50.00 (2.38)	49.57 (3.99)	50.44 (3.99)
Max force*	294.63 (121.25)	336.00 (133.19)	299.88 (112.88)	338.63 (147.81)
Avg. force	284.71 (103.72)	313.28 (111.75)	284.71 (105.57)	314.91 (123.40)
Max impulse	3055.03 (3522.30)	3242.66 (3113.25)	2906.83 (2944.98)	3644.33 (3581.14)

*Note. *p < .05.*

Symmetrical grouping

The ART, followed by GLM analyses for symmetrical grouping, revealed no significance or interactions across most metrics. Specifically, no significant effects of symmetrical grouping were observed on acceleration, area, area percentage, average force, maximum force, or maximum impulse.

Limb grouping

ART-GLM analyses for limb grouping indicated limited significant effects, with no significant interactions across metrics (Table 2). No significant effects of limb grouping were found on acceleration, area, average force, or maximum impulse. However, a significant effect of limb grouping was observed on area percentage (p = .02), with the left limb contributing to a higher proportional area compared to the right. In addition, a significant difference was observed on the maximum force (p = .05), in which the right limb exhibited greater peak values when compared to the left.

Directional grouping

The directional grouping analysis was only conducted for the directional acceleration and velocity metrics. The results observed revealed highly significant difference for directional however no significant interactions were found (Table 1). Additionally, for the directional acceleration, a significant difference was found (p < .001) while the directional velocity also showed a significant difference with the direction (p < .001) where lower acceleration occurred at sharper angles compared to that at smaller angles. No significant differences were found in both the directional acceleration and velocity for direction by symmetrical grouping interaction, direction by limb interaction, or direction by symmetrical grouping by limb interaction.

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DISCUSSION

The primary aim of the study was to investigate the NHE symmetry and limb specific differences exerted on COD sprint performance among university athletes, with no significant effects or interactions observed for symmetrical grouping across all metrics. Furthermore, limb grouping yielded significant effects limited to area percentage (greater left limb contribution) and maximum force (higher right limb peaks). In contrast, directional grouping demonstrated significant main effects specific to acceleration and velocity, with sharper angles imposing progressively greater biomechanical demands, independent of symmetry or limb factors.

The findings from the symmetrical grouping analyses indicate that there were no significant effects or interactions on any of the COD and NHE metrics. These suggest that asymmetry in NHE metrics, as assessed via the VALD Nordbord, does not substantially differentiate COD sprint performance in university level athletes performing 30 m sprints with turns at 15 m. Similar observations have been reported in studies examining asymmetries in COD tasks, where inter limb differences in strength related metrics do not consistently impair overall performance, potentially because athletes can compensate through technical adjustments or bilateral contributions during multi directional movements (Bishop *et al.,* 2021; Dos'Santos *et al.,* 2019). Additionally, the lack of significance may stem from the relatively homogeneous sample of university athletes, who may not exhibit the extreme asymmetries seen in elite populations, thereby reducing the detectable impact of symmetrical grouping on COD outcomes (Loturco *et al.,* 2019). Although performing the NHE primarily targets eccentric hamstring strength of an individual, which could be seen as vital in the deceleration phase of the COD, this may not necessarily translate to their maximal sprinting velocity (Harper *et al.,* 2022; Morin *et al.,* 2015). The method of using the ART GLM may indicate the inability to subtle symmetrical differences within a non-parametric distribution due to the non-significant findings (Bishop *et al.,* 2021). Subsequently, these limitations may be even greater with regards to asymmetry from high intensity actions derived from COD protocols (Dos'Santos *et al.,* 2019). The results from this research reveal that aiming for perfect symmetry in the NHE may not assist in improving the athletes COD performance within this sample, which aligns with previous research which signify that moderate asymmetries can be present in athletes with strong COD ability (Bishop *et al.,* 2022; Loturco *et al.,* 2022).

Conversely, this research found that limited significant differences within the limb-grouping indicates that the asymmetries in the NHE may not directly influence the overall performance of left and right COD directions. When considering the MDSA area percentage of the athletes, it was found that the left segment contributed to more to the overall multidirectional sprint ability. This finding suggests the athletes' sprinting ability was impacted more from the left proportion of the MDSA in addition to the force distribution towards to the left CODs, particularly the deceleration and reacceleration during these tasks. This may be the case due to limb specific adaptations in sport in which the non-dominant limb will act as a stabilising or braking mean when turning (Dos'Santos *et al.,* 2021; Jones *et al.,* 2016). The contribution of the left segment of the MDSA aligns with previous literature where the inner leg, which is usually the left, generates larger braking forces during the COD turn by ensuring efficient deceleration and minimising the turn radius and therefore enhancing the task efficiency (Arboix-Alió *et al.,* 2024). These adaptations underscore the functional utility of moderate left-limb emphasis in force contributions; however, they may also signal a need for bilateral monitoring to prevent compensatory overload. Maximal force also was revealed to be significantly larger with the right limb compared to the left during the peak values of the task. This may be an indication that the right limb is the dominant limb in force production during the NHE, which is similar to previous findings in movements such as sprinting or pivoting (Bishop *et al.,* 2019; Loturco *et al.,* 2022). Acceleration and impulse did not have significant results, and this may be a result of compensatory mechanisms between limbs. Furthermore, this may allow athletes to maintain their performance despite these asymmetries, which can also be found when strength asymmetries do not correlate with their speed deficits (Freitas *et al.,* 2019; Morin *et al.,* 2015). The limb grouping also showed non-significant results for directional metrics, suggesting that these unilateral tasks may not alter the acceleration or velocity of the athlete's turning performance due to its bilateral nature (Bishop *et al.,* 2019; Dos'Santos *et al.,* 2020).

Moreover, the directional grouping analyses, applied specifically to directional acceleration and velocity, demonstrated highly significant effects of direction. In contrast, no significant interactions involving symmetrical or limb groupings were found with these metrics. When performing sharper angles, lower acceleration and velocity was present compared to that of shallower angles. This further demonstrates the demands of acute COD necessitating a greater need for deceleration and reacceleration by the athlete. Additionally, the greater requirement of amplified braking forces, extended ground contact times, reduced post-turn momentum and velocities, and compromised reacceleration via enhanced eccentric control and GRF modulation is essential for the ability of an efficient COD performance (Dos'Santos *et al.,* 2018; Harper *et al.,* 2019; Dos'Santos *et al.,* 2021). Due to the needs of these demands, deceleration reliance on hamstring efficiency increases, and furthermore the comparisons of NHE confirm the critical role of eccentric strength in the turn of a COD task (Harper *et al.,* 2022; Morin *et al.,* 2015). In addition, greater posterior chain energy expenditure is required by the athlete when turning shaper angles and thus have elevated metabolic costs (Hader *et al.,* 2016). The lack of interactions in this research indicates that the directional results are consistent across symmetrical and limb groupings, suggesting that angle specific challenges in COD are not controlled by baseline NHE symmetry or limb preferences of the athletes. Thus, the 15 m entry distance performed in this research may not reach the approach velocities which may significantly reveal differential impacts as COD biomechanics have been known to influence under greater variable sprint conditions (Dos'Santos *et al.,* 2018; Dos'Santos *et al.,* 2021).

Regarding the non-significant findings for symmetrical grouping, it is pertinent to consider that symmetries in athletic performance are inherently test specific. Previous research has found this by indicating how bilateral asymmetries in one metric or task do not necessarily correlate with those in another (Bishop *et al.,* 2022). Such as the asymmetries observed in the eccentric hamstring strength from the NHE may not directly relate to the dynamic COD task or the MDSA method. This emphasises the task dependency of inter-limb balance as well as the potential limitation of generalising symmetry from isolated tests to multi-planar movements (Virgile & Bishop, 2021). This is consistent with the results of this study, where NHE-derived symmetries failed to influence COD outcomes, suggesting that practitioners should assess symmetries across multiple modalities to capture a comprehensive profile rather than assuming transferability. University athletes with less experience as compared to elite athletes, may have greater masked interaction effects in which asymmetries impair angle-related deficits (Bishop *et al.,* 2022; Loturco *et al.,* 2022). The findings in this study emphasise the importance of angle specific training in COD programs, which particularly should focus on sharper turns that demand superior deceleration capabilities. Moreover, this is consistent with recommendations for incorporating high-intensity braking drills to mitigate performance losses (Harper *et al.,* 2019; Jones *et al.,* 2016).

Finally, the findings in this study emphasise the efficiency and proficiency of using the ART-GLM method for examining skewed athletic performance datasets. The ART preprocessing step aligns and ranks data to facilitate factorial ANOVA-like analyses on non-parametric distributions. Previous research has used a similar approach in order to evaluate relationships in non-normal data, particularly within factorial designs for repeated measures (Elkin *et al.,* 2021; Wobbrock *et al.,* 2011). This method was vital to identify the man effects and relationships across the non-parametric data. Moreover, this ensured this research was able to bypass any restrictive requirements of traditional parametric assumptions.

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Practical implications

The current study further emphasises that training protocols should prioritise functional output rather than the attempt to achieve absolute bilateral symmetry (Bishop *et al.,* 2021; Dos'Santos *et al.,* 2019). Furthermore, moderate eccentric strength imbalances appear entirely compatible with refined COD ability. Practitioners and coaches should use COD drills which involve smaller angles to maximise deceleration abilities in order to mimic match requirements as well as emphasise eccentric posterior chain strength (Dos'Santos *et al.,* 2021; Harper *et al.,* 2019; Jones *et al.,* 2016). In addition, the limb-specific variances examined in this study, suggest using individual monitoring technologies such as the VALD Nordbord allow for identifying functional adaptations and mitigating compensatory overload (Bishop *et al.,* 2019; Loturco *et al.,* 2022; Arboix-Alió *et al.,* 2024). Moreover, by using a holistic method such as the MDSA along with the NHE assessments provides valuable evaluations to optimise training efficiency as well as evidence-based training for the athletes.

Limitations

Although the use of the ART preprocessing provides a robust framework for evaluating non-parametric data, the relatively small sample size of this study may lack the statistical power to successfully identify the subtle relationships in the groupings. In addition, university populations have been found to have moderate asymmetries when compared to more elite populations, in which more definite imbalances are known to degrade COD abilities (Bishop *et al.,* 2022). By utilising isolated NHE metrics, the contributions of the hamstrings and cognitive load of unanticipated turns may may not be fully encompassed, which can lead to the role of limb symmetry being amplified (Dos'Santos *et al.,* 2020; Morin *et al.,* 2015). Lastly, physiological sex differences and differing sports participation experience within this mixed-gender group may have influenced the outcomes. Future studies may incorporate stratified sampling techniques to improve real-world application of the MDSA metric.

CONCLUSION

The primary objective of this study was to examine the relationships between NHE symmetry, limb-specific variances and COD sprint performance in university athletes. This research observed that limb-specific groupings yielded isolated significant differences such as higher left limb contributions to area percentage and higher peak maximum force in the right limb. This suggests that functional adaptations in force distribution may not fundamentally change an athlete's overall multidirectional ability. However, the directional grouping results showed significant differences in both acceleration and velocity, which propose increased mechanical demands are required to change direction at sharper angles. This effect seems to be independent of the athlete's symmetry profile as well as limb dominance. While a lack of significant differences in the symmetrical grouping may indicate that for university-level athletes, the bilateral symmetry in their eccentric hamstring strength may not be a primary determinant of MDSA performance.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. G.G. and A.G. were responsible for the conceptualisation of the project. Data collection was conducted by G.G., while data analysis and interpretation were carried out by both G.G. and A.G. The manuscript draft was completed by G.G. Both authors contributed to the review and incorporation of comments. Supervision of the project was provided by A.G. All authors have read and agreed to the published version of the manuscript. All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, during the preparation of this work the author(s) used Google Gemini in order to assist with finding redundancies and refining sections. After using this tool/service, the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

INSTITUTIONAL REVIEW BOARD STATEMENT

The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board (or Faculty of Health Sciences, Research Ethics Committee) of The University of Johannesburg (REC-1359-2022, 26 January 2022).

INFORMED CONSENT STATEMENT

Informed consent was obtained from all subjects involved in the study.

DATA AVAILABILITY STATEMENT

The original contributions presented in this study are included in the article. Data are available upon reasonable request from the corresponding author.

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