JOURNAL OF THEORY AND PRACTICE IN SPORT
MUĞLA SITKI KOÇMAN UNIVERSITY
FACULTY OF SPORT SCIENCES

A study of lower-limb bilateral and unilateral strength asymmetry in Maltese sprinters using the modified sphygmomanometer test

Kevin Hamza Magro[1]
Matthew Muscat-Inglott[1]

To cite this article: Magro, H. K., & Muscat-Inglott, M. (2022). A study of lower-limb bilateral and unilateral strength asymmetry in Maltese sprinters using the modified sphygmomanometer test. *Journal of Theory and Practice in Sport, 1*(1), 1-20.

Received: 29.08.2022

Accepted: 12.09.2022

Published: 25.12.2022

[1] Institute of Community Services, Malta College of Arts, Science & Technology, Paola, Malta
matthew.muscat.inglott@mcast.edu.mt, hamza.magro.e21975@mcast.edu.mt

A study of lower-limb bilateral and unilateral strength asymmetry in Maltese sprinters using the modified sphygmomanometer test

Abstract

In track and field athletics, sprint events require athletes to negotiate both straight as well as curved segments of the track. Athletes specializing in the longer sprints must thereby execute symmetrical as well as inherently asymmetrical movement patterns. Few studies have investigated lower-limb strength asymmetry in sprinters internationally, or indeed other factors related to the health and performance of sprinters in the specific case of Malta. This study aimed to explore the general state of affairs with regard to bilateral and unilateral strength asymmetries, specifically in Maltese sprinters, using the modified sphygmomanometer test as a convenient and low-cost method of assessment. We also tested a series of hypotheses investigating the effects on asymmetry of training age, running the curve and leg-dominance. The participants exhibited efficient hamstring to quadriceps strength ratios for sprinting, and generally stronger non-dominant hamstrings bilaterally. Running the curve and left- or right-leggedness did not have significant impacts on any form of lower-limb strength symmetry. There was some evidence to suggest that experienced sprinters may, to a limited degree, manage asymmetrical force production efficiently just where it matters the most. We also discuss the merits of sphygmomanometer testing in the context of purposive asymmetry-reducing neuromuscular control as a learned skill on the part of athletes and make recommendations for future research.

Keywords words: Lower-limb, Bilateral asymmetry, Unilateral asymmetry, Maltese sprinters, Modified sphygmomanometer test

Modifiye tansiyon aleti testi kullanılarak Maltalı kısa mesafe koşucularında alt ekstremite iki taraflı ve tek taraflı kuvvet asimetrisi üzerine bir çalışma

Özet

Atletizm atletizminde, sprint etkinlikleri, sporcuların pistin hem düz hem de kavisli kısımlarını aşmasını gerektirir. Daha uzun sprintlerde uzmanlaşan sporcular bu nedenle hem simetrik hem de doğası gereği asimetrik hareket kalıpları uygulamalıdır. Uluslararası düzeyde sprinterlerde alt ekstremite kuvveti asimetrisini veya Malta özelinde sprinterlerin sağlığı ve performansıyla ilgili diğer faktörleri araştıran çok az çalışma vardır. Bu çalışma, uygun ve düşük maliyetli bir değerlendirme yöntemi olarak modifiye tansiyon aleti testini kullanarak, özellikle Maltalı sprinterlerde iki taraflı ve tek taraflı kuvvet asimetrileri ile ilgili genel durumu araştırmayı amaçladı. Ayrıca antrenman yaşının asimetrisi, virajda koşma ve bacak hakimiyeti üzerindeki etkileri araştıran bir dizi hipotezi de test ettik. Katılımcılar, sprint için verimli hamstring - kuadriseps güç oranları ve genellikle iki taraflı olarak daha güçlü baskın olmayan hamstringler sergilediler. Eğriyi koşmak ve sol veya sağ bacaklı olmak, herhangi bir alt ekstremite kuvvet simetrisi üzerinde önemli bir etkiye sahip değildi. Deneyimli sprinterlerin, en önemli olduğu yerde, sınırlı bir dereceye kadar, asimetrik kuvvet üretimini verimli bir şekilde yönetebildiklerini gösteren bazı kanıtlar vardı. Ayrıca, atletler tarafından öğrenilmiş bir beceri olarak amaçlı asimetri azaltıcı nöromüsküler kontrol bağlamında tansiyon aleti testinin yararlarını tartışıyor ve gelecekteki araştırmalar için önerilerde bulunuyoruz.

Anahtar Kelimeler: Alt ekstremite, Bilateral asimetri, Unilateral asimetri, Malta sprinterleri, Modifiye tansiyon aleti testi

Introduction

Lower-limb asymmetry can be conceptualized either in terms of strength differences between legs (dominant versus non-dominant, or left versus right), or the hamstrings to quadriceps strength ratio in each leg. These are also referred to as inter- and intra-leg imbalances, respectively, or, bilateral and unilateral asymmetry. Where Q are the quadriceps and H the hamstrings, bilateral asymmetry would suggest an undesirable Q:Q or H:H discrepancy, while unilateral asymmetry would suggest an undesirable Q:H discrepancy (Maley et al., 2014). Based on the assumption that asymmetry is in fact undesirable, and is something to be minimized, some experts have recommended it not only be measured and identified, but also actively addressed using corrective training/conditioning programs (Zahálka et al., 2013; Maley et al., 2014; Girard et al., 2017; Tatlıcıoğlu et al., 2019; Pietraszewski et al., 2020).

There is a general lack of peer-reviewed literature on Maltese sprinters or other track athletes, and studies about lower-limb strength asymmetries in sprinters of any nationality, are also as yet rare. Furthermore, the studies on lower-limb asymmetry that do exist, have not yielded much of a meaningful consensus on key issues. For instance, using a spring-mass model based on observed kinetic and kinematic factors, Girard et al. (2017) found acceptable degrees of lower-limb mechanical asymmetry among athletes performing repeated hill sprints on a treadmill. They also did not observe any significant fatigue-induced increases in asymmetry. On the other hand, using electromyography (EMG), Pietraszewski et al. (2020) found that soccer players exhibited asymmetrical motor activity in the hamstrings and gluteus muscles during maximal sprinting.

These studies were focused on performances of the sprinting action itself, and it should be noted that literature on lower-limb asymmetry tends to take on either of two perspectives, that of observing kinetic and kinematic factors in functional, integrated or in-action performances (like sprinting, jumping landing, throwing, etc.), or force-production in isolated tests of strength (like knee extension/flexion tests). The two approaches imply various types of contributing neuromuscular phenomena. In other words, functional movement tests necessarily involve a degree of coordinated and controlled (or partially "inhibited") motor performance, while all-out force production tests by definition involve as little neuromuscular inhibition as possible.

Based on tests of maximal force production, which is referred to here simply as *strength*, evidence supporting any potentially ill effects of asymmetrical results, meanwhile, has so far been mixed. Sannicardo et al. (2017) reported a correlation between explosive strength and balance performance, which would strongly suggest that greater symmetry would enhance, via improved balance, explosive capacity. Indeed, bilateral strength discrepancies have been linked with decreased performance in jumping or changing direction, particularly during maximal efforts (Bishop et al., 2016). However, Rutkowska-Kucharska (2020) conversely found no correlation between bilateral strength asymmetry and jump performance in athletes. While Coratella et al. (2018) similarly showed that in under-21 elite soccer players, short sprint performance was correlated with asymmetry in the hamstrings, they stressed that more research is needed, since the ability to produce maximal overall force was the more significant factor affecting performance in their study. Using a seven-test functional movement screen, Sannicandro et al. (2017) showed that while asymmetry may not have had a clear effect on the expression of maximal force, it nonetheless had an important role in submaximal actions like maintaining balance and performing safe movement patterns.

Looking at the link between asymmetry and performance from a different perspective, Beato et al. (2021) argued that among soccer players, bilateral and unilateral strength asymmetry may decrease in the professional ranks as opposed to non-professional. Fousekis et al. (2010) also specified that professional soccer players with more than 10 years of experience, expressed less bilateral asymmetry in their hamstrings. In track athletes, Mo et al. (2020) similarly found that bilateral asymmetry decreased as performance/experience level increased. So, despite relatively weak evidence supporting the link between performance and asymmetry, the findings of Beato et al. and Mo et al. imply that asymmetry nonetheless affects performance indirectly, since it ultimately differentiates higher- from lower-level performers. There are, however, likely additional extraneous factors mediating this relationship, reinforcing the need for further study in the area.

Apart from functional performance, some studies have investigated prospective links between various forms of asymmetry and injury. This evidence, however, also remains as yet unclear (Fousekis et al., 2010). Maulder et al. (2010) argued that increased risk of injury occurs when bilateral strength asymmetry exceeds 10%. Vaisman et al. (2017) similarly suggested that strength asymmetry should not exceed 15%, particularly if powerful movements are to be performed with the lower limbs during the rehabilitation process. In a systematic review of the literature, Helme et al. (2021) showed that out of 31 studies looking at strength asymmetry and its effects on injury risk, eight found no statistically significant association, 10 found only partial associations, and 10 actually reported significant findings. Given that positive findings are probably more likely to be published, these numbers do not present a particularly strong case for any prospective significant association between strength asymmetries and injury.

Based on some of these key themes in the literature, and the central notion that asymmetry may have real-world implications for athletes either in terms of performance or injury outcomes, we aimed to survey the general state of affairs in terms of lower-limb strength asymmetry in Maltese sprinters by asking, first:

Q_1: What is the status of Maltese sprinters in terms of bilateral and unilateral lower-limb strength asymmetries?

And, building on the assertions of Beato et al. (2021) and Mo et al. (2020) regarding measurable changes in such asymmetry over time:

Q_2: Do bilateral and unilateral lower-limb strength asymmetries vary among Maltese sprinters as they become more experienced or seasoned?

Maltese sprinters are generally competitive at the GSSE (Games for the Small States of Europe), and less so at Commonwealth or Olympic level. For context in terms of standards, they could be classified outside Malta anywhere from the amateur level, up to a small number of competitors practicing at a semi-professional level. Nevertheless, asymmetry represents an important area of enquiry for sprinters, since they run either exclusively symmetrically on the straight portion of the track (as in the 100m), or both symmetrically and asymmetrically combined when the curved portions of the track are used (as in the 200m, 400m). As researchers have shown from their investigations of the specific biomechanics involved in running the curve (Chang & Kram, 2007; Alt et al., 2015), the action is inherently asymmetrical. Measurable lower-limb strength asymmetries can therefore reasonably be expected to result from repeated performances of such asymmetrical action. While Beukeboom (2000) found little evidence to clearly indicate that running tight curves on an indoor track had any effect on injury risk, it did tend to result in changes in the strength of various muscle groups. Ishimura and Sakurai (2016), meanwhile, reported that step length and frequency are asymmetrical when sprinting the curve, and that the outside leg plays a particularly important role in the action. These findings have at least two important implications, namely, that running the curve may produce measurable strength asymmetries, and second, that such asymmetry may systematically disadvantage left-legged sprinters, since the “important” role of the outside (necessarily *right*) leg, constitutes a special loading on the non-dominant side for these athletes. We also asked, therefore:

Q_3: Does running the curve have an effect on lower-limb strength bilateral or unilateral asymmetry in Maltese sprinters?

And:

Q_4: Does asymmetry vary across left- and right-leg dominant sprinters?

Bishop et al. (2016) called for more research on asymmetry to effectively measure and ultimately clarify its effects on performance as well as injury risk or other outcomes. In this sense, the present study looks to make an additional contribution through its choice of methodology. The study uses an alternative method for measuring strength asymmetry that could enhance convenience and long-term feasibility of such testing. Doing more research naturally depends on the availability of valid and reliable testing equipment, and many of the studies cited above were based on the use of isokinetic dynamometers. As elaborated below, we employed an alternative, more easily accessible and cost-effective type of equipment also capable of being used in the field.

Method

Rather than isokinetic testing, the Modified Sphygmomanometer Test (MST) (Helewa et al. 1981; Mondin et al., 2018), which can be performed either in the lab or in the field, was selected for use in the study. The generally widespread availability of standard manual sphygmomanometers used for blood pressure testing, means that track and field, and strength and conditioning, coaches can more easily carry out strength asymmetry testing without the need for more complex or expensive equipment. Naturally, the availability of more data collected in the field as a result of using more convenient methods may eventually lead to a better understanding of asymmetry and its effects over time. High test-retest validity has been reported for the MST (Mondin et al., 2018), and it has been used as a low-cost valid means of assessing hip strength (Toohey et al., 2017), as well as shoulder strength in Rugby players (Dow Morrison, 2020). While the MST has been used in a wide range of sports contexts for testing muscular strength, Souza et al. (2013) encourage researchers to more meticulously describe the precise methods followed when applying the test, if it is to gain more traction specifically in clinical settings. In the present study, the method of application of the MST followed that described in Mondin et al. (2018).

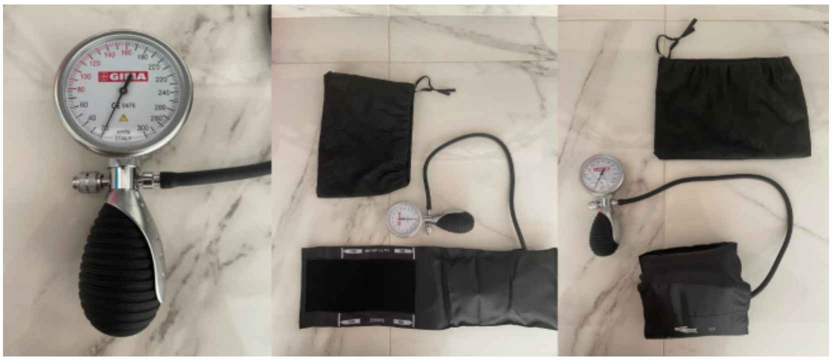

Figure 1. Preparation of the sphygmomanometer for the MST

The “Boston” sphygmomanometer used in the study (Figure 1) was acquired from a licensed medical equipment vendor, together with a spare cuff (of the same brand and design). After approximately 30 tests, the original cuff indeed began to lose pressure, and was immediately replaced, with affected tests redone. Further to the protocols discussed by Mondin et al., participants were instructed to apply maximal force to the cuff for a period of five seconds, followed by 15 seconds of rest, and a final five-second maximal attempt. The best of the two attempts was recorded for each participant. The test was performed on the hamstrings and quadriceps muscle groups in both the 30° and 90° positions of flexion, as illustrated in Figure 2.

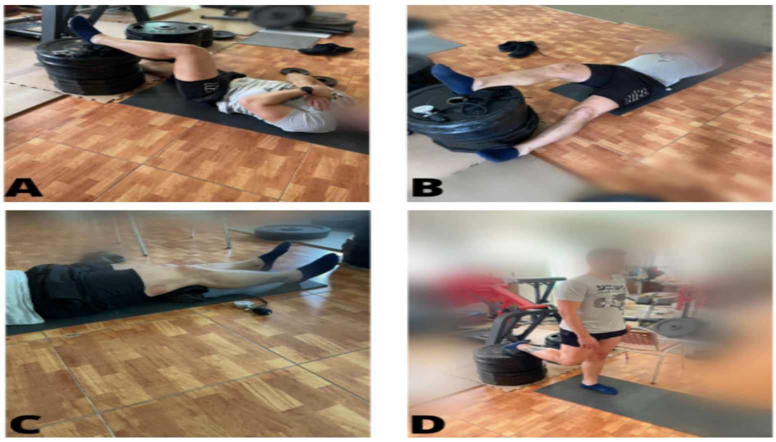

Figure 2. Hamstring and quadriceps test positions

Note: (A) Hamstrings at 90°, (B) Hamstrings at 30°, (C) Quadriceps at 30°, (D) Quadriceps at 90°

Positions A and B depict the 90° and 30° hamstrings strength tests using stacked weight plates to support the cuff and facilitate the desired angle of knee flexion. Positions C and D depict the 30° and 90° quadriceps tests using ankle weights and weight plates to support the cuff, respectively. In position C, the lower shin area was held in place by the tester, while the participant was instructed to flex the quadriceps, compressing the cuff. A consistent set of verbal cues was used to instruct the participants throughout the tests to avoid any changes in performance that might be attributable to different types of cues and/or encouragement. The cues used were, "Push as much as you can, but you have to hold it for five seconds", "Picture trying to bend your knee as much as possible", and "Keep your whole body touching the floor". The participants were tested in their own training environments and instructed to carry out their normal preferred warm-up routine prior to testing. Sprint coaches were instrumental in assisting with the recruitment process, promoting the study among their athletes within the respective clubs, and allowing time out of their normal training sessions to facilitate the testing procedure.

Ethical clearance was obtained from the institutional review board at the Malta College of Arts, Science and Technology in January 2021. A stratified convenience sampling strategy was used to recruit 20 Maltese (eligible for Malta national team duty), adult (18 years or over), track athletes with up to 400m as their specialty event. Participants had to be injury-free and in regular training at the time of the study. All participants completed a PAR-Q to help ensure their safe participation in the active test. The sample (N=20) eventually comprised 13 male and seven female sprinters, ranging from 18 to 30 years of age (M=22.50, SD=10.17). Their training age (years engaged in formal training) ranged from four to 20 years (M=11.20, SD=4.61). A majority (n=11) nominated the 100m as their main event, with remainder (n=9) nominating the 200m and 400m events as their specialty. In terms of leg dominance, the same distribution was noted across right-leg-dominance (n=11) and left-leg-dominance (n=9). All data resulting from the tests were eventually collated and organized using an open-source spreadsheet application (*LibreOffice Calc v7.2.2.2*).

Data analysis

Bishop et al. (2016) presented a number of different equations commonly used in the literature in the strength and conditioning context relating to lower-limb strength asymmetry. For the present study, we used the equations reported in Tatlıcıoğlu (2019). According to Bishop et al. (2016) the LSI equation used in Tatlıcıoğlu (2019) is the Bilateral Asymmetry Index (BSI) from Nunn and Mayhew (1988) and Impellizzeri et al. (2007), although they conceptualize it using stronger and weaker, rather than dominant and non-dominant. The equations were defined as:

$$LSI = \frac{DomLegForce - NonDomLegForce}{DomLegForce} \times 100$$

(Equation 1)

$$H{:}Q = \frac{HamForce}{QuadForce}$$

(Equation 2)

Since each muscle group was tested at both 30° and 90° degrees of flexion, using Equations 1 and 2 resulted in the operationalization of eight main variables of interest; LSI for quadriceps at 30° (LSI_{Quad30}), LSI for hamstrings at 30° (LSI_{Ham30}), LSI for quadriceps at 90° (LSI_{Quad90}), LSI for hamstrings at 90° (LSI_{Ham90}), H:Q for dominant leg at 30° ($H{:}Q_{Dom30}$), H:Q for non-dominant leg at 30°, ($H{:}Q_{NonDom30}$), H:Q for dominant leg at 90° ($H{:}Q_{Dom90}$), and H:Q for non-dominant leg at 90° ($H{:}Q_{NonDom90}$). The LSI and H:Q values were calculated in the spreadsheet software, and finally the updated dataset was imported into an open-source statistical analysis software package (*GNU PSPP v1.4.1*).

To address Q_1, basic descriptive statistics were run to explore the general state of affairs in terms of bilateral and unilateral asymmetry in our sample. For additional insight, 95% confidence intervals were generated with a view to comparing the MST values across different muscle groups and sides. To address Q_2, regarding prospective changes in asymmetry over time, Pearson's r was used to construct a correlation matric for comparing training age with each of the eight outcomes. To address Q_3 and Q_4 regarding the association between asymmetry and competitive running on the curve or not, and left- or right-side dominance, respectively, t tests were run with each of the eight outcomes as the dependent variable. An Alpha level of .05 was used to determine statistical significance when interpreting the results of all inferential statistical procedures.

Results and Discussion

Tables 1 and 2 below show the MST results for the quadriceps and hamstrings at 30° and 90°, for the dominant and non-dominant legs, respectively. The mean, standard deviation, standard error, and 95% confidence intervals are reported.

Table 1. Descriptive statistics for all tests on the dominant leg.

Test	*Mean*	*SD*	*SE*	*95% CI*
Hamstrings at 30°	174.30	36.78	8.22	157.09, 191.09
Quadriceps at 30°	223.50	46.94	10.49	201.53, 245.47
Hamstrings at 90°	179.55	44.34	9.92	158.80, 200.30
Quadriceps at 90°	201.40	47.58	10.64	150.31, 186.39

Table 2. Descriptive statistics for all tests on the non-dominant leg.

Test	*Mean*	*SD*	*SE*	*95% CI*
Hamstrings at 30°	168.35	38.54	8.62	150.31, 186.39
Quadriceps at 30°	212.25	46.01	10.29	190.72, 233.78
Hamstrings at 90°	183.10	32.81	7.34	167.75, 198.45
Quadriceps at 90°	196.55	44.99	10.06	175.50, 217.60

In varsity American football players, Tatlıcıoğlu et al. (2019) reported evidence supporting increased strength in the quadriceps of the dominant, as opposed to non-dominant, leg. Table 1 shows that at both 30° and 90°, the overlapping 95% confidence intervals do not suggest any such difference was evident in this study. However, the quadriceps of the dominant leg were significantly stronger at 30° (*95% CI* = 201.53, 245.47) than at 90° (*95% CI* = 150.31, 186.39), showing that more pronounced increases in force production were possible specifically in the dominant leg. The raw data help establish some context for coaches and/or researchers intent on making use of the MST for the purpose of comparison, at least in the context of sprinters. Tables 3 and 4 present the MST scores further differentiated by sex.

Table 3*:* Descriptive statistics for all tests on the dominant leg, by sex.

Test	*Female*		*Male*	
	Mean	*95% CI*	*Mean*	*95% CI*
Hamstrings at 30°	140.00	123.11, 156.89	192.77	174.45, 211.09
Quadriceps at 30°	217.14	188.04, 246.25	226.92	194.07, 259.78
Hamstrings at 90°	137.29	117.71, 156.87	202.31	180.64, 223.98
Quadriceps at 90°	175.00	166.15, 183.85	215.62	183.00, 248.23

Table 4. Descriptive statistics for all tests on the non-dominant leg, by sex.

Test	*Female*		*Male*	
	Mean	*95% CI*	*Mean*	*95% CI*
Hamstrings at 30°	134.00	118.38, 149.62	186.85	166.35, 207.34
Quadriceps at 30°	190.71	144.59, 236.84	223.85	198.99, 248.71
Hamstrings at 90°	158.57	133.85, 183.29	196.31	179.14, 213.48
Quadriceps at 90°	174.00	147.40, 200.40	208.69	179.46, 237.93

Bilateral and unilateral symmetry in Maltese sprinters

Building on the above data, Tables 5 and 6 present the results for the eight main asymmetry variables of interest, derived using Equations 1 and 2 for LSI and H:Q values, respectively. Together, they provide insight for addressing Q_1, and ascertaining the general status of Maltese sprinters in terms of bilateral and unilateral asymmetry.

Table 5: Descriptive statistics for the LSI measurements.

Outcome	*Mean*	*SD*	*SE*	*95% CI*
LSI_{Ham30}	2.84	13.24	2.96	-3.35, 9.04
LSI_{Quad30}	4.18	14.77	3.30	-2.73, 11.09
LSI_{Ham90}	-4.87	18.95	4.24	-13.74, 4
LSI_{Quad90}	1.38	14.32	3.20	-5.32, 8.08

Taking into account Maulder et al.'s (2010) cut-off of 10% for bilateral asymmetry as reflected in the LSI scores, the mean values for the sample (-4.87 to 4.18) were well within the 10% threshold. However, taking the sample as representative of the larger population of Maltese sprinters, and considering the 95% confidence intervals reported, the claim cannot be generalized that there is any systematic trend towards symmetry. The confidence intervals surrounding LSI_{Quad30} (*95% CI* = -2.73, 11.09) and LSI_{Ham90} (*95% CI* = -13.74, 4) indicate possible population parameters exceeding ±10% (11.09, -13.74). We cannot, therefore, conclude that Maltese sprinters do *not* exhibit bilateral asymmetry. For those accepting the assumption that asymmetry is something to be remedied via corrective training (Zahálka et al., 2013; Maley et al., 2014; Tatlıcıoğlu et al., 2019; Pietraszewski et al., 2020), Maltese sprint coaches are advised to exercise caution, and endeavor to more closely monitor their athletes for signs of bilateral asymmetry, based on these findings. The MST, in this sense, represents a valuable opportunity for coaches to carry out their own regular asymmetry testing over the long-term.

Table 6. Descriptive statistics for the H:Q measurements.

Outcome	*Mean*	*SD*	*SE*	*95% CI*
$H{:}Q_{Dom30}$	0.81	0.22	0.05	0.70, 0.91
$H{:}Q_{NonDom30}$	0.82	0.23	0.05	0.72, 0.93
$H{:}Q_{Dom90}$	0.94	0.41	0.09	0.75, 1.14
$H{:}Q_{NonDom90}$	1.00	0.42	0.09	0.80, 1.19

A slightly larger discrepancy between hamstrings and quadriceps was observed at 30° (0.81, 0.82) as opposed to 90° (0.94, 1.00). The 95% confidence intervals, however, suggest that, ultimately, no significant differences in the H:Q ratio were evident in any of the muscle groups tested, between the dominant and non-dominant legs. Tatlıcıoğlu et al. (2019) cited two cut-offs commonly used in the literature for H:Q ratio testing, namely >.47 and >.60. Similarly, Coombs and Garbutt (2002) discussed widespread "general acceptance" of .66 as the optimal ratio for concentric strength, with the broader range ideally spanning anywhere from .43 to .90. There does not appear to be a strong consensus on what precisely constitutes a valid threshold for the H:Q ratio. Regardless of which threshold was used to interpret our data, however, none of the 95% confidence intervals incorporated any of the cut-offs stated above (.47, .60, .66), suggesting a satisfactory H:Q ratio in Maltese sprinters. Two of the values ($H{:}Q_{Dom30}$ and $H{:}Q_{NonDom30}$) just exceeded the maximal limit of .90 established by Coombs and Garbutt (2002). This suggests that at least at 30°, Maltese sprinters demonstrate comparatively strong hamstrings in relation to their quadriceps. This relatively high capacity for force production in the hamstrings, specifically, is not surprising when considering that the hamstrings are known to play a dominant role in the sprinting action (Morin et al., 2015; Pandy et al., 2021).

Fousekis et al. (2010), meanwhile, made the argument that optimal ratios are more important in the dominant leg, but this was not evident in our findings. Both the mean values as well as the 95% confidence intervals indicated that the H:Q ratio did not differ significantly across the dominant and non-dominant sides. The findings indicate, overall, that Maltese sprinters exhibit generally low degrees of asymmetry, particularly unilaterally. Bilaterally, athletes in the study generally scored inside the 10% asymmetry threshold, but caution should be exercised in generalizing this finding to the general population of Maltese sprinters. In the case of the hamstrings at 90°, the LSI score was expressed in a negative number. This suggests that Maltese sprinters tend towards increased hamstring strength in their non-dominant side. Accordingly, it is worth noting that in any consideration of bilateral asymmetry, the dominant and non-dominant sides are not necessarily equivalent to stronger and weaker sides. Fort-Vanmeerhaeghe (2016) showed that in a sample of volley-ball players, self-reported leg dominance was not a reliable indicator of comparative limb strength.

Change in asymmetry over time

Changes in asymmetry as a function of training age were initially explored by surveying the Pearson correlation coefficients and significance values. Table 7 shows the resulting non-significant findings in all instances except for $H{:}Q_{NonDom90}$.

Table 7. Pearson's correlations for training age with all eight outcomes

Outcome	*Pearson's r*	*p value (two tailed)*
LSI_{Ham30}	-.35	.13
LSI_{Quad30}	.12	.60
LSI_{Ham90}	-.11	.66
LSI_{Quad90}	-.33	.16
$H{:}Q_{Dom30}$	-.26	.27
$H{:}Q_{NonDom30}$	-.04	.86
$H{:}Q_{Dom90}$	-.39	.09
$H{:}Q_{NonDom90}$	-.46	.04*

For $H{:}Q_{NonDom90}$ the null hypothesis of no relationship between training age and unilateral asymmetry in the non-dominant leg could be rejected. In other words, there appeared to be a relationship between training age and unilateral symmetry in the non-dominant leg. Overall, the evidence did not lend considerable support to the overarching alternative hypothesis that training age was significantly related to asymmetry in Maltese sprinters. Older players generally tend to exhibit a more optimal ratio at least in their *dominant* leg, according to Fousekis et al. (2010). The fact that only one in four measures of unilateral asymmetry in our analysis returned a significant result, and that this occurred on the *non-dominant* side, indicates that, according to the MST, asymmetry does not generally appear to decrease to any significant degree as sprinters become more experienced.

Further research, however, is warranted. Taking into account the prior LSI scores (in particular LSI_{Quad30} and LSI_{Ham90}, which exceeded the 10% by virtue of their 95% confidence intervals), the significant result is interesting, since bilateral hamstring strength appeared to favor the non-dominant side. This means that the non-dominant hamstrings were a key muscle group, and it was precisely in this muscle group exclusively that improvements in symmetry over time were evident. This indicates that whatever small degree of adjustment appeared to be taking place by the more seasoned sprinters, seemed to occur where it was most needed.

Effects of running the curve and leg-dominance

A series of *t* tests were run to test for variations in LSI and H:Q outcomes across curve-running and leg-dominance as the independent variables. Tables 8 and 9 report the *t*, and *r* values denoting effect size, as well as the significance levels.

Table 8. *t* tests for competing on the curve or not, across all eight outcomes ($df = 18$)

Outcome	*t*	*Effect size (r)*	*p value (two tailed)*
LSI_{Ham30}	.55	-.13	.59
LSI_{Quad30}	-.18	.04	.86
LSI_{Ham90}	-.90	.21	.38
LSI_{Quad90}	-.08	.02	.94
$H{:}Q_{Dom30}$	-.29	.07	.78
$H{:}Q_{NonDom30}$	-.24	.06	.82
$H{:}Q_{Dom90}$	-1.28	.29	.22
$H{:}Q_{NonDom90}$	-.83	.19	.42

It was clear that no form of asymmetry in Maltese sprinters appeared to vary according to whether or not athletes' main event involved sprinting on the curve (200m, or 400m). Despite the inherently asymmetrical biomechanics involved in sprinting on the curve (Chang & Kram, 2007; Alt et al., 2015; Ishimura & Sakurai, 2016), Beukeboom (2000) argued that curve running did not increase injury-risk, but could produce measurable differences in the strength of different muscle groups. The results of the MST, however, at least in the case of Maltese sprinters, do not support the notion that significant strength asymmetries result from running the curve.

Further to the focus on the non-dominant hamstrings reflected in the trend towards negative values for LSI_{Ham90}, it was interesting to note that this strength asymmetry was not affected by the inherent asymmetrical mechanics of competing on the curve. If increased power expression in the non-dominant hamstring, regardless of left- or right-footedness, was not affected by increased curve sprinting, then it would appear that having a stronger non-dominant side is likely instead a response to simply sprinting straight, perhaps as some form of counter-balancing action in coordination with the dominant side.

Table 9. *t* tests for leg-dominance across all eight outcomes (*df* = 18)

Outcome	*t*	*Effect size (r)*	*p value (two tailed)*
LSI_{Ham30}	1.64	-.36	.12
LSI_{Quad30}	-.93	.21	.37
LSI_{Ham90}	.65	-.15	.53
LSI_{Quad90}	1.27	-.28	.22
$H{:}Q_{Dom30}$	-.67	.16	.51
$H{:}Q_{NonDom30}$	-1.81	.39	.09
$H{:}Q_{Dom90}$	.47	-.11	.65
$H{:}Q_{NonDom90}$	.67	-.16	.51

As was the case with running the curve, Table 9 indicates that leg-dominance had no significant effects on any form of asymmetry. In other words, asymmetry did not differ significantly between left- and right-leg dominant athletes. Despite Ishimura and Sakurai's (2016) observation that the "outside" leg plays a particularly important role in running the curve, the fact that this is necessarily the *right* leg during competitive sprinting on the curve, does not appear to disproportionately affect left-leg dominant athletes in terms of their strength symmetry.

Conclusion and Recommendations

Zahálka et al. (2013) showed that the best performances of elite soccer goalkeepers involved the most asymmetrical functional muscle recruitment patterns. The assumption that measures of strength asymmetry decrease in elite performers appears to be at odds with this observation. Beato et al. (2021) argued, in this sense, that rather than strength asymmetry itself, the key factor remains how athletes actively manage available force-production from participating muscle groups in a given performance, a capacity which experienced athletes appear to hone as they progress throughout their careers. Given that some sports techniques are inherently asymmetrical in nature, like running the curve, it seems reasonable that the ability to recruit muscular force efficiently in response to external conditions be considered the more important factor, regardless of the maximal force individual muscle groups are capable of exerting in test conditions. It is an important consideration, therefore, when testing strength asymmetry, to what degree such an element of control is in fact also being tested.

Earlier it was pointed out that research on asymmetry tends to involve measurement of either functionally integrated sporting actions, on the one hand, or force-production in isolated tests of strength on the other. The former necessarily involves a degree of neuromuscular coordination or control, while that latter depends on decreasing neuromuscular inhibition as much as possible. The MST, in this sense, represents an interesting interplay between these poles. The test is not a truly maximal test of strength because subjects are told to, "Push as much as [they] can, *but* […] to hold it for five seconds." A degree of inhibition or "management" is thereby introduced, rendering the MST an assessment of controlled application of near-maximal muscular force. The results of the present study and the application of existing asymmetry thresholds/cut-offs should therefore by interpreted with this nuance in mind. Further research using the MST test in conjunction with EMG monitoring could yield some valuable insights in this regard, particularly if compared to additional measures like dynamometry, or other tests involving maximal force production.

It should also be noted in any discussion of curve running, that athletes who only compete in the 100m will still typically engage in a degree of curve running during training, although likely at a significantly lower intensity than 200m or 400m sprinters. Sample size was a limitation in this study, yet the general population of Maltese sprinters is similarly rather small. Malta is classified as a European micro-state with a population of around half a million people, and track and field athletics can be considered a relatively minor sport even within this setting. More research both in terms of studying sprinters specifically, as well as use of the MST, would enable more contextualization of the findings and consolidation of research efforts in the future. More studies based on MST data will facilitate comparisons between athletes, and more longitudinal studies in the club context may lead to more effective screening of asymmetry over time.

In conclusion, we are in a position to report that our sample exhibited relatively symmetrical performances according to the MST, particularly in the case of unilateral intra-leg symmetry. There was sufficient variation in the between-leg dimension, however, to challenge any broader claims that the larger population of Maltese sprinters do systematically possess optimum bilateral symmetry. It was interesting to note that Maltese sprinters appear to exhibit a strength bias in the hamstrings in favor of their non-dominant side. In terms of H:Q ratio, it was clear that Maltese sprinters fit the expectation of having relatively strong hamstrings, given the known importance of this muscle group for the sprinting action. The sprinters did not show a great deal of asymmetry adaptation over time, however the minimal adaptation recorded among the more experience sprinters, given the emerging prominence of the non-dominant hamstring, appeared to occur just where it most counted. Running the curve and leg-dominance had no effect on any form of asymmetry in the participants.

Author Contribution

Magro, K. H. (Conceptual framework, data collection), Muscat-Inglott, M. (Data Analysis)

Conflict of Interest

All authors must declare that there is no conflict of interest.

Ethical Statement

Ethical review was provided by the institutional review board at the Malta College of Arts, Science & Technology.

References

Alt, T., Heinrich, K., Funken, J., & Potthast, W. (2015). Lower extremity kinematics of athletics curve sprinting. *Journal of Sports Sciences*, *33*(6), 552-560.

Beato, M., Young, D., Stiff, A. and Coratella, G. (2021) Lower-limb muscle strength, anterior-posterior and inter-limb asymmetry in professional, elite academy and amateur soccer players. *Journal of Human Kinetics, 77*(21) 135-146.

Beukeboom, C., Birmingham, T. B., Forwell, L., & Ohrling, D. (2000). Asymmetrical strength changes and injuries in athletes training on a small radius curve indoor track. *Clinical Journal of Sport Medicine*, *10*(4), 245-250.

Bishop, C., Read, P., Chavda, S., & Turner, A. (2016). Asymmetries of the Lower Limb. *Strength and Conditioning Journal, 38(6), 27–32.*

Chang, Y. H., & Kram, R. (2007). Limitations to maximum running speed on flat curves. *Journal of Experimental Biology*, *210*(6), 971-982.

Coombs, R., & Garbutt, G. (2002). Developments in the use of the hamstring/quadriceps ratio for the assessment of muscle balance. *Journal of Sports Science & Medicine*, *1*(3), 56.

Coratella, G., Beato, M., & Schena, F. (2018). Correlation between quadriceps and hamstrings inter-limb strength asymmetry with change of direction and sprint in U21 elite soccer-players. *Human Movement Science, 59,* 81–87.

Dow Morrison, F. N., Ashworth, B., & Kaveney, T. T. (2020). The validity of the sphygmomanometer for shoulder strength assessment in amateur rugby union players. *Physical Therapy in Sport.*

Fort-Vanmeerhaeghe, A., Gual, G., Romero-Rodriguez, D., & Unnitha, V. (2016). Lower limb neuromuscular asymmetry in volleyball and basketball players. *Journal of Human Kinetics*, *50*(1), 135-143.

Fousekis, K., Tsepis, E., & Vagenas, G. (2010). Lower limb strength in professional soccer players: profile, asymmetry, and training age. *Journal of Sports Science & Medicine*, *9*(3), 364.

Girard, O., Brocherie, F., Morin, J. B., & Millet, G. P. (2017). Lower limb mechanical asymmetry during repeated treadmill sprints. *Human movement science*, *52*, 203-214.

Helewa, A., Goldsmith, C. H., & Smythe, H. A. (1981). The modified sphygmomanometer—An instrument to measure muscle strength: A validation study. *Journal of Chronic Diseases, 34*(7), 353–361.

Helme, M., Tee, J., Emmonds, S., & Low, C. (2021). Does lower-limb asymmetry increase injury risk in sport? A systematic review. *Physical Therapy in Sport, 49,* 204–213.

Impellizzeri, F. M., Rampinini, E., Maffiuletti, N. & Marcora, S. M. (2007). A vertical jump force test for assessing bilateral strength asymmetry in athletes. *Med Sci Sports Ex, 39,* 2044–2050.

Ishimura, K., & Sakurai, S. (2016). Asymmetry in Determinants of Running Speed During Curved Sprinting. *Journal of Applied Biomechanics, 32*(4), 394–400.

Mondin, D., Owen, J. A., Negro, M., & D'Antona, G. (2018). Validity and reliability of a non-invasive test to assess quadriceps and hamstrings strength in athletes. *Frontiers in Physiology*, *9*, 1702.

Morin, J. B., Gimenez, P., Edouard, P., Arnal, P., Jiménez-Reyes, P., Samozino, P., Brughelli, M. & Mendiguchia, J. (2015). Sprint acceleration mechanics: the major role of hamstrings in horizontal force production. *Frontiers in Physiology*, *6*, 404.

Nunn, K. D. & Mayhew, J. L. (1988). Comparison of three methods of assessing strength imbalances at the knee. *J Orthop Sports Phys Ther, 6*, 134–137.

Pandy, M. G., Lai, A. K., Schache, A. G., & Lin, Y. C. (2021). How muscles maximize performance in accelerated sprinting. *Scandinavian Journal of Medicine & Science in Sports*, *31*(10), 1882-1896.

Pietraszewski, P., Gołaś, A., Matusiński, A., Mrzygłód, S., Mostowik, A., & Maszczyk, A. (2020). Muscle activity asymmetry of the lower limbs during sprinting in elite soccer players. *Journal of Human Kinetics*, *75*(1), 239-245.

Rutkowska-Kucharska, A. (2020). Asymmetry of lower limb strength and jumping ability of young soccer players. *Acta of Bioengineering and Biomechanics*, *22*(1).

Sannicandro, I., Piccinno, A., Rosa, R. A., & De Pascalis, S. (2011). Functional asymmetry in the lower limb professional soccer players*. British Journal of Sports Medicine, 45*(4), 370–370.

Sannicandro, I., Cofano, G., Rosa, A. R., Traficante, P., & Piccinno, A. (2017). Functional movement screen and lower limb strength asymmetry in professional soccer players. *British Journal of Sports Medicine*, *51*(4), 381-382.

Souza, L. A. C. e, Martins, J. C., Teixeira-Salmela, L. F., Godoy, M. R., Aguiar, L. T., & Faria, C. D. C. de M. (2013). Avaliação da força muscular pelo teste do esfigmomanômetro modificado: uma revisão da literatura*. Fisioterapia Em Movimento, 26*(2), 437–452.

Tatlıcıoğlu, E., Atalağ, O., Kırmızıgil, B., Kurt, C., & Acar, M. F. (2019). Side-to-side asymmetry in lower limb strength and hamstring-quadriceps strength ratio among collegiate American football players*. Journal of Physical Therapy Science, 31*(11), 884–888.

Zahálka, F., Malý, T., Malá, L., Gryc, T., & Hráský, P. (2013). Power assessment of lower limbs and strength asymmetry of soccer goalkeepers. *Acta Gymnica*, *43*(2), 31-38.