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Authors: *Lacome M.[1], Avrillon S.[2], Cholley Y.[1], Simpson B.[1], Guilhem G.[2], Buchheit M.[1,2]*

1. Performance Department, Paris Saint Germain, Saint-Germain-En-Laye, France.
2. French Institute of Sport (INSEP), Research Department, Laboratory Sport, Expertise and Performance (EA 7370)

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Contacts details:

Mathieu Lacome
Performance Department, Paris Saint-Germain Football Club,
4a avenue du président Kennedy
78100 Saint-Germain-en-Laye, France
Tel : +33 1 61 07 10 77
Email : mlacome@psg.fr

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Abstract

Aim: To compare the effect of low- vs. high-volume of eccentric-biased hamstring training programs on knee-flexor strength and fascicle length changes in elite soccer players.

Methods: Nineteen elite youth soccer players took part in this study and were randomly assigned into two subgroups. For 6 weeks in-season, groups performed either a low (1 set per exercise; 10 reps in total) or a high (4 sets; 40 reps) volume eccentric training of their knee flexors. After 6 weeks (MID), players cross-overed and performed the alternate training regimen. Each training set consisted in 4 repetitions of the Nordic hamstring exercise and 6 repetitions of the bilateral stiff-leg deadlift. Eccentric knee-flexor strength (Nordbord) as well as biceps *femoris* long head (BFlh) and *semimembranosus* (SM) fascicle length (scanned with ultrasound scanner) were assessed during PRE, MID- and POST-training tests.

Results: Knee-flexor eccentric strength very likely increased from PRE to MID (+11.3±7.8% [low-volume] and 11.4±5.3% [high-volume]), with a possibly-to-likely increase in BFlh (+4.5±5.0% and 4.8±2.5%) and SM (+4.3±4.7% and 6.3±6.3%) fascicle length in both groups. There was no substantial changes between MID and POST. Overall, there was no clear between-group difference in the changes from PRE to MID and MID to POST for neither knee-flexor eccentric strength, BFlH nor SM fascicle length.

Conclusion: Low-volume knee-flexor eccentric training is as effective as a greater training dose to substantially improve knee-flexor strength and fascicle length in-season in young elite soccer players. Low-volume is however likely more appropriate to be used in an elite team facing congested schedules.

Title: Hamstring eccentric strengthening program: Does training volume matter?

Introduction.

Over the past 10 years, total sprint distance (~35%) and the number of sprints (~85%) have moderately-to-largely increased in the English Premier League, suggestive of an increased stress placed on the posterior chain muscle groups.[1] Together with this increased neuromuscular demand, hamstring is the muscle group that shows the greater injury incidence in soccer.[2,3] As such, practitioners spend a substantial amount of time trying to prevent injuries of this muscle group.[4]

Among many others[5], strength and fascicle length have been suggested as the most likely modifiable risk factors for hamstring muscle injuries. Several studies have reported that strength training could reduce the risk of hamstring injury.[6] Also, it has been suggested that professional soccer players with shorter biceps *femoris* long head (BFlh) fascicle (i.e., <10.5 cm) were 4.1 times more likely to sustain a future hamstring strain injury than those with longer fascicle length.[7] Although more evidences in a wide range of elite sport populations are still missing, these pioneer works demonstrated that both muscle strength and architecture might play a role in hamstring susceptibility to be injured. Although previous studies suggested distinct contributions of each hamstring head to global muscle torque[7] and energy absorption during running,[9] their respective adaptations to preventive programs remain however to be investigated.[10]

Six-to-ten weeks of Nordic hamstring or hip extension training resulted in large-to-very large increases in knee-flexor strength (13-78%) in recreational athletes.[11] Very large increases in BFlh fascicle length (~14%, range 5-34%) were also reported following eccentric training.[12] However, these protocols included high-volume training (2-3 times per week, 30-50 repetitions), which represents a challenge in terms of players' compliance.[13] Also, in elite soccer teams facing congested schedules when playing every 3 or 4 days, a high-volume, eccentric-biased hamstring training program[14] is very challenging to implement.[15]

Recently, Presland and colleagues[16] compared the effect of low- (8 repetitions per week) vs high-volume (100 repetitions per week) training on knee-flexor strength and structural adaptations. Interestingly, similar strength and architectural gains were observed following both training regimens. These data were the first to suggest that very low-volume, eccentric-biased hamstring exercises may be as effective as greater-volume programs for improving knee-flexor strength.[6] These findings open new opportunities for hamstring conditioning, i.e., low-volume program would likely be better adopted by players and in turn, help to implement more efficient injury prevention program. Caution is however required when interpreting those results as they were obtained in recreationally active males with a likely high trainability. Whether similar results could be observed in-season in highly-trained soccer players - accustomed to both high-levels of high-intensity running and eccentric-biased hamstring exercises - remains to be examined.

The aim of this study was to compare the effect of low- vs. high-volume of eccentric-biased hamstring training programs on knee-flexor strength and fascicle length adaptations in young elite soccer players.

Methods.

Subjects and study overview.

The players were the members of a U19's team belonging to an elite academy, former French Champions and qualified for the last stage of the Youth league competition. Anthropometrical and physical characteristics of the 19 young elite soccer players who took part in this study are presented in Table 1. The choice of the study population (i.e., young elite vs. professional adults) was motivated by the fact it's simply impossible to conduct randomized controlled studies in elite (soccer) players.[17] While care should always be taken when trying to generalize the results of a given study, we believe that both the high level and the training status of our U19 players was worth the experiment and may still help improving our understanding of the optimal training strategies to be implemented in elite populations.

Players who may have suffered from a hamstring or anterior cruciate ligament injury within the 6 months preceding the study were not included (2 players). Players were all familiar with the strength exercises, which were previously included in their weekly lower-limb strength program (familiarisation, see below). The experimental protocol took place during the in-season period, between September and December. During this period, players trained/played ~9/10 h per week (6 training sessions + 1-2 games/week, weekly total distance: ~40000 m including ~300 m covered above 25.2 $km.h^{-1}$). The overall locomotor load (training + matches) was similar (or unclear differences) for both groups. Goalkeepers (2) were also excluded of this study as their training differ substantially from the group.

The overall study design is presented in Figure 1. Before the start of the experimental phase, players performed one weekly familiarisation session for 3 weeks, consisting in 1 set of 4 reps of submaximal Nordics and 1 set of 6 reps of varying exercises targeting hamstrings strength (e.g., hip extension, 1 leg stiff-leg deadlift, TRX supine single leg curl). Then, on week 1, pre-training (PRE) tests were carried out with eccentric knee-flexor strength assessed using a Nordbord (Vald Performance, Albion, Australia), while BFlh and *semimembranosus* (SM) fascicle length was measured with an ultrasound scanner. A block randomisation was used to separate players into two subgroups (Table 1). We separated players using a median split on their strength level (high or low), BFlh fascicle length (long or short), and potential participation in the youth league (Yes or No). Then, we performed a block randomisation to get the same numbers of high/low strength players, long/short fascicles length players and Yes/No youth league participation in the 2 groups. This allowed to get two well-balanced group before the start of the study.

For 6 weeks in-season, groups performed either a low- (1 set of 4 reps of NHE and 6 reps of modified stiff-leg deadlift (SLDL); 10 reps in total, n=9 players) or a high- (4 sets of each; 40 reps in total, n=10 players) volume eccentric training of their knee-flexor muscles. The intervention did not include any progressive intensity overload as no specific guidelines are available to date for eccentric-biased prevention exercises. We also wanted to implement a simple and easy-to-use protocol to improve the compliance and involvement of young athletes. We nevertheless acknowledge that this should be the focus of future research.

All exercises were performed on the pitch after the football session (48 to 72h after the last game and at least 72h before the next, often Tuesday). Similar assessments as PRE were conducted on week 7 (MID). After a one-week recovery phase, a cross-over occurred, and players performed the alternate training block for the 6 following weeks (Phase 2). Finally, post-training assessments (POST) were performed during week 15. Throughout the protocol, the load of soccer-specific and general upper-body strength sessions remained identical for both groups. No additional lower-body strength training was performed during this period – we believe therefore that the adaptations observed were likely the consequences of the additional eccentric training in this ecological context. As such, except for the eccentric training sequences, training components and exposure remained highly similar for both groups over the complete duration of the protocol. Note also that because of our randomization strategy, players' characteristics (Table 1) were similar between the 2 groups at baseline.

These data arose as a condition of player monitoring in which player activities are routinely measured over the course of the competitive season;[18] therefore, ethics committee clearance was not required. The study confirmed nevertheless to the recommendations of the Declaration of Helsinki and previous informed consent from all players was received before the start of the study.

Methodology.

Testing protocol.

Eccentric Knee-Flexor Strength Testing. The device used to determine eccentric knee-flexor strength during the Nordic hamstring exercise (NHE) (i.e., Nordbord) and its reliability have been described previously (typical error, TE: 24.7±6.8 N, 8.4±2.5%).[19] Eccentric knee-flexor strength testing was measured as previously described.[20] As between-leg differences were beyond the scope of the current study and since there was no clear between-leg differences at baseline (336±47 vs 330±55 N, ES=-

0.12±0.25), the average strength of both legs was used for analysis.[20] Data were expressed both in absolute values (N) and as the difference between players' actual (measured) and body-mass expected strength, as recommended.[20]

Fascicle length: BFlh and SM fascicle were imaged using a 42-mm linear probe (2–10 MHz, SL10-2) coupled with an ultrasound scanner (Aixplorer V11, Supersonic Imagine, Aix-en-Provence, France). Given that the field-of-view of the probe was too narrow to image an entire fascicle, we used a built-in panoramic mode of the ultrasound device. This mode uses an algorithm that fits series of images, allowing scanning of entire fascicles within one continuous scan. This technique enabled to avoid any extrapolation of non-visible parts of the muscle and improved the accuracy of the measurement.[21] Participants were prone with the hip and the knee at 0° (Figure 2). The first scan began with the probe placed in the transversal plane over the muscle of interest and progressed along the midline of the muscle belly to determine the best musculotendon path. Three scans were then completed longitudinally to the fascicle plane - from the popliteal fossa to ischial tuberosity - to image fascicles with superficial and distal aponeuroses fully visible at an approximate scan speed of 2 cm.s^{-1}. A segmented line (with a spline fit) was used to model and measure the length of two fascicles (one proximal, one distal, Figure 2) within each of the two muscles (ImageJ V1.48, National Institute for Health, USA). Given that muscle geometry may change after several weeks of training, it is difficult to ascertain that the same fascicle was measured at PRE and POST tests. Consequently, the two values of fascicle length were then averaged to get a representative value for each whole muscle. Test-retest reliability of fascicle length measurements performed on 12 participants with 24h between tests showed small and trivial variations in BFlh (typical error: 0.38 ± 0.15 cm, i.e. 4.9 ± 2.0%) and SM fascicle length (0.28 ± 0.11 cm, 4.4 ± 1.8%), respectively.

Nordic Hamstring exercise.

Players performed the NHE by pairs as previously described by Petersen et al.[22] (Figure 3). Consistent verbal encouragement was provided by the investigator to motivate the subjects to lower themselves as far as they could in a controlled manner.

Modified bilateral stiff-leg deadlift.

The hip-oriented SLDL was chosen since it selectively activates the BFlh and SM.[23] Players performed the exercise positioned slightly ahead of a wall (~10 cm) with a partner applying a pressure to the hip (Figure 3). As a deadlift exercise, and with a pelvis anteversion, players slowly leaned forward (i.e., flexing the hip) during the eccentric phase, maintaining trunk and hips help in a neutral position, until they reached a point ~90° from the starting position. Afterwards, players initiated hip extension during the concentric phase to return to the starting position. Players performed the exercise holding one circular 10-kg weighted plate with arms extended.

Statistical analysis

Data in the text and figures are presented as mean ± SD and 90% confidence limit/interval (CL/CI). All data were first log-transformed to reduce bias arising from nonuniformity error. Within-group changes in strength and fascicle length, as well as between-group differences in the changes between PRE and MID, and MID and POST tests were assessed using standardised differences, based on the Cohen effect-size principle. We then used magnitude-based inference (MBI) as an equivalent of Bayesian with a minimally informative prior.[24] Probabilities were used to make a qualitative probabilistic mechanistic inference about the true changes/differences in the changes within and between the groups, which were assessed in comparison to the smallest worthwhile change (0.2 x pre-tests between-subjects SDs).[25] The scale was as follows: 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain.[26] Thresholds values for standardized changes/differences in the changes were >0.2 (small), >0.6 (moderate), >1.2 (large) and >2 (very large).

Results

Pre-test.

Characteristics of the players, PRE knee-flexor strength and fascicles length are provided in Table 1. Except for SM fascicle length (likely small differences), there were no clear difference between the two groups before the start of the experiment.

Phase 1.

There was a very likely moderate increase in hamstring eccentric strength (+11.3±7.8 and 11.4±5.3% for low- and high-volume groups respectively) between PRE and MID as well as possible-to-likely small increase in BFhl (+4.5±5.0 and 4.8±2.5%) and SM (+4.3±4.7 and 6.3±6.3%) fascicle length in both groups (Table 2, Figure 4).
There was no clear difference in the changes from PRE to MID between the two groups for neither hamstring eccentric strength, BFlh or SM fascicle length (Figure 4).

Phase 2.

Overall, there was neither substantial changes in hamstring eccentric strength (1.2±2.9 and 0.9±7.5% for low- and high-volume groups respectively), BFlh (1.0±2.6 and 0.5±2.0%) nor SM (-1.6±2.6 and 1.8±4.7%) fascicle length between MID and POST in both groups (Table 2, Figure 5). There was no substantial difference in the changes from MID to POST between the two groups for hamstring eccentric strength and BFlh fascicle length (Figure 5). Changes in SM fascicle length were possible slightly greater in the high-volume group compared with the low-volume group between MID and POST.

Discussion:

To our knowledge, this is the first study to compare the effect of low- vs. high-volume of an eccentric training program on knee-flexors strength and the fascicle length of two hamstring heads in elite young soccer players. The main findings were that 1) an in-season 6-week low-volume eccentric-biased training program including NHE and SLDL exercises (10 reps/week) resulted in a very likely moderate increase in knee-flexor strength and possibly-to-likely small increased in BFlh and SM fascicle length, 2) the effects of this low-volume program were similar to those observed following a program including 4 times more repetitions and 3) after 6 weeks, the increase in training volume in the low-volume group did not result in further strength gain or fascicle lengthening, suggesting a likely ceiling effect.

Pre-training testing.

Before starting Phase 1, the knee-flexor strength values of our U19 players were slightly higher than those reported in A-league Australian adult soccer players (333.8±49.7 vs 309.5±73.4 N)[7], while similar (336±55 N) and very largely lower (411±65 N) than those measured in other players competing in the fourth and first French divisions, respectively.[20] However, when expressing knee-flexor strength in relation to body mass (difference between the measured vs. body-mass expected values)[19], our players (+13.4%) were moderately stronger than both the Australian players and the sub-elite French players (-5.8% and -1.6% respectively)[7,20]. They were however logically weaker than the elite French soccer players (+22.3%).[20] Taken together, these data suggest that the players involved in the present study had already a good level of strength before the start of the experimentation.

The BFlh fascicle length measured in this study was most likely very largely shorter (8.5±1.3 cm) than that observed in Australian soccer (11.20±1.2 cm)[7] or Australian Football Rules (10.92±0.76 cm) players.[27] Because of the non-uniform nature of hamstring architecture,[28] the use of a single B-mode image could provide a truncated representation of fascicle length.[29] In the present protocol we used an in-built panoramic mode, allowing to image the entire fascicle path, including localized variations in fascicle's orientation. The images were collected along the fascicle plane to avoid unreal muscle shape and architecture. The algorithm used to associate successive images could generate slight errors in the reconstruction, and thus requires further validation studies. Yet, the present fascicle length measurements were comprised in previously reported ranges (i.e. 6.9 cm for SM,[30] 7.8 to 9.8 cm for BFlh[31] on average) and showed a small TE. Finally, the younger age of the athletes in this study (~17 years vs. >21 years)[7,27] could also explain the discrepancies between studies, as muscles and fascicles generally tend to lengthen with growth.[31,32]

Changes in knee flexors strength and fascicles length following Phase 1

Following Phase 1, we observed a very likely moderate increase (+11%, Figure 4) in knee-flexor strength in both groups. Those changes were lower than those previously reported (+74% in 10 weeks ;[11] +27.5% in 6 weeks[16]). These differences can be explained by a likely reduced trainability of our players compared with previous studies: 1) our players already presented a good level of knee-flexor strength at the start of the study, 2) in contrast to the studies conducted in recreationally active men, the players in our study were highly trained (~9/10 h per week), and 3) our training protocol was performed in-season, following 2 months of pre-season and 3 weeks of familiarisation that likely already allowed players to improve their strength before the PRE tests.

Possibly-to-likely small increases in fascicle length (~+0.5 cm; ~5%; Table 2) were observed following Phase 1. Those changes were in the lower margin of previous results showing no effect (Seymore et al. 2017) to very large increase in BFlh fascicle length (+1.6 cm to +2.5 cm)[12] after an eccentric-biased training program. This training-induced fascicle lengthening is thought to contribute to increase the capacity of fascicle to withstand active lengthening, putatively through the addition of in-series sarcomeres.[6] The rate of change (per session) in fascicle length observed here were in fact closer to those observed in the above-mentioned studies (0.07[33] to 0.11[11] vs 0.07 cm/ sessions in the present study). While the present changes are in the lower range of fascicle length adaptations, our results might be explained by both the lower trainability of our elite players and the period of the season when the intervention was planned. Another explanation may be that while strength sessions were conducted at the end of typical soccer sessions to reduce subsequent injury risk during the sessions,[33] this may have reduced the intensity of the training. Because mechanical load associated with fascicle stretch is one of the factors favouring changes in muscle architecture, this putative reduction in training intensity might have also influenced subsequent adaptations.[6,34] Another reason that could explain the lack of further adaptations during the Phase 2 could be the absence of progressive intensity overload, which may have reduced the potential training-induced muscle adaptations. Also, it is important to note that the observation of substantial changes in static relaxed muscle fascicle length may not fully reflect dynamic changes.[35] A recent study showed significant changes in muscle-tendon interactions after plyometric training of the plantar flexors, that in turn impacts fascicle length changes during contractions.[36] Such investigations are challenging to perform on a complex muscle architecture with 3D rotation during contractions - as the hamstrings - and are more time-consuming - as they require a careful probe positioning to obtain reliable measurements between sessions. Future methodological developments are needed to determine if these architectural adaptations actually translate into dynamic hamstring contractions.

Effect of training volume.

In this study, we showed for the first time in elite young soccer players, that knee-flexor eccentric strength and fascicles length adaptations following a low-volume eccentric training program were, in fact, similar to those observed following a 4-times greater training volume (Figure 4). These results confirm previous findings in recreationally active men, where similar adaptations in knee-flexor strength and BFlh fascicle length were reported after training programs consisting in 8 vs. 40 NHE repetitions per session.[16] This suggests that within-session training volume might not be a key factor for eccentric training-induced adaptations. These findings open new opportunities for hamstring conditioning in elite teams facing congested schedules or wanting to optimize their training schedule, to create more player-compliant programs and in turn, implement more efficient injury prevention programs.

During the second phase, changes in both knee-flexor eccentric strength and fascicle length were trivial in the two groups (Figure 5). Interestingly the plateau in fascicle lengthening after 6 weeks is in line with previous observations where there was no additional lengthening of the *vastus lateralis* after 5 weeks of isokinetic eccentric training.[37] This strongly suggests a ceiling effect in fascicle lengthening elicited by eccentric training. This result also suggests that a low-volume eccentric training allows muscle adaptations to be maintained, even for players previously performing greater volumes of knee-flexor eccentric training. Of note, the large increase in work volume in the group initially performing low-volumes of repetitions did not translate into any further adaptations. Again, this confirms that the number of repetitions per session may not be of primary importance when considering knee-flexor strength and fascicle length adaptations. Rather, the regular application of micro doses of high-intensity eccentric exercises could be favoured in injury prevention program.[38]

Strengths and limitations.

Players involved in this study were all elite young players, competing in the best U19's French division and for half of them, in the best European young soccer competition, the UEFA Youth League. While several studies have assessed the effect of knee-flexor eccentric training in recreationally active men, our study confirms that previous results are transferable to elite young populations.

One of the major limitations of the present study was our inability to use a clear control group (no eccentric training, only soccer typical sessions) to isolate the effect of the intervention programs per se. However, considering the evidence for the benefit of such eccentric training,[6] it would have been unethical (and likely counterproductive) not to offer a minimum of prevention work to our elite players. Secondly, providing a progressive intensity overload (especially during the modified SLDL) would have possibly increased training-induced changes, particularly during the second phase of the protocol. Finally, the concurrent use of the NHE and modified SLDL together likely limits the ability to determine which exercise was the more effective to promote muscle adaptations. However, we consider that the elite standard of the players' and the realistic training setting (eccentric sessions done after the typical soccer training sessions, group sessions) enhanced the ecological validity of the present investigation.

Practical applications

Programming high-volume of eccentric training during periods of congested schedules is likely not adapted for elite players.[15] The present results are therefore of importance for practitioners willing to implement preventive strategies in their regular training schedules. They can program low-volume (10 reps/week) of knee-flexor eccentric training and expect similar strength and fascicles length adaptations than those generally observed with greater number of repetitions. Also, in-season, knee-flexor strength and fascicle length can be maintained with 10 reps of knee-flexor eccentric training per week, even in players already accustomed to higher training volumes.

Conclusions

A low-volume (10 reps/week) of knee-flexor eccentric training is efficient to substantially improve knee-flexor strength and increase fascicle length in elite young soccer players. A low-volume is likely as effective as a high-volume training, but likely easier to implement in an elite team facing congested schedules and encountering already high workload. Further studies are now required to examine whether further gains would be made while increasing the frequency vs. the intensity of training.

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Tables & Figures:

Table 1: Characteristics of the players involved in the study.

Youth League.: number of game played in the Youth League during the period of the study. BFlh: B*iceps femoris* long head. SM: *Semimembranosus*.

Table 2: Changes in knee-flexor strength and fascicles length following the first (Pre-test to Mid-test) and second phase (Mid-test to Post-test) in low- and high-volume groups.

ES: Effect size. PRE, MID and POST refer to pre-, mid- and post-test respectively. BFlh: Biceps *femoris* long head, SM: *semimembranosis*.

Figure 1: Overview of the experimental design. PRE: Pre-training test, MID: Mid-training test, POST: Sets and reps for the training phase are given for each exercise (Bilateral stiff-leg deadlift and Nordics). Icon others than Nordic hamstring exercise during the familiarisation period represent the varying exercises targeting hamstrings strength (Hip extension, 1 Leg stiff-leg deadlift, TRX supine single leg curl) during this phase. For each exercise, and through all the training period, consistent verbal encouragements were provided by the investigators to motivate the players.

Figure 2: Representation of the fascicle length measurement. Participants were prone with the hip and the knee flexed at 0°.

Figure 3: Nordic hamstring exercise (A) and Bilateral stiff-leg deadlift (B) performed during the training protocol.

Figure 4: Individual changes in knee-flexor strength and fascicle length following the first phase (Pre-test to Mid-test) in low- and high-volume groups.

The inserts above each panel represent within-group standardised changes (triangle symbol). The graphs on the right-side show between-group standardised differences in the changes. Grey bars represent trivial changes/differences in the changes. *: possible change/difference in the change; ** likely, *** very likely. Pre- and Mid-test values are represented as individual values and mean with standard deviation. Standardised changes/difference in the changes are represented as mean and confidence interval.

Figure 5: Individual changes in knee-flexor strength and fascicle length following the second phase (Mid-test to Post-test) in low- and high-volume groups.

The inserts above each panel represent within-group standardised changes (triangle symbol). The graphs on the right-side show between-group standardised differences in the changes. Grey bars represent trivial changes/differences in the changes. *: possible change/difference in the change; ** likely, *** very likely. Pre- and Mid-test values are represented as individual values and mean with standard deviation. Standardised changes/difference in the changes are represented as mean and confidence interval.

Table 1: Characteristics of the players involved in the study.

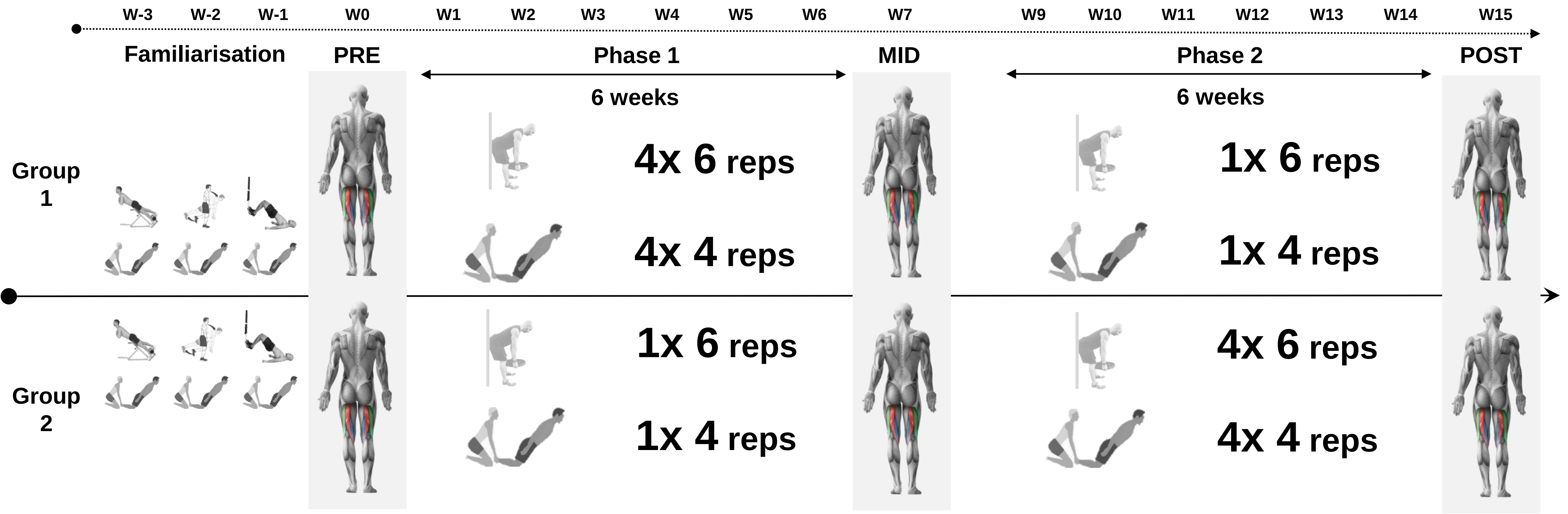
			High vs. Low			
Variables	**Starting with Low-volume (n=9)**	**Starting with High-volume (n=10)**	**Difference (%)**	**Standardised difference (ES)**	**Likehood**	**Rating**
Age (y)	17.5±0.7	17.2±0.7	-1.3±3.3	-0.32±0.80	13/26/61	unclear
Height (cm)	175.7±5.0	174.8±6.1	-0.6±2.7	-0.16±0.80	22/31/47	unclear
Body mass (kg)	64.7±4.9	64.1±5.7	-1.0±6.8	-0.12±0.80	25/32/43	unclear
Youth League (n)	2±2	2±2	+25.9±99.6	0.31±0.10	58/24/18	unclear
Knee-Flexors Eccentric Strength (N)	326.4±48.1	325.3±26.2	0.4±10.2	0.03±0.76	35/35/30	unclear
Expected Knee-Flexors Strength (N)	291.4±20.5	286.7±23.0	-1.7±6.3	-0.21±0.80	19/30/51	unclear
Δ Strength vs. Expected (%)	11.7±12.1	14.1±12.4	-1.4±46.2	-0.03±0.88	33/31/37	unclear
BFlh fascicle length (cm)	8.7±1.5	8.3±1	-3.9±11.6	-0.26±0.78	16/29/55	unclear
SM fascicle length (cm)	6.4±1.1	5.8±0.5	-8.2±10.2	-0.59±0.76	4/15/81	likely -

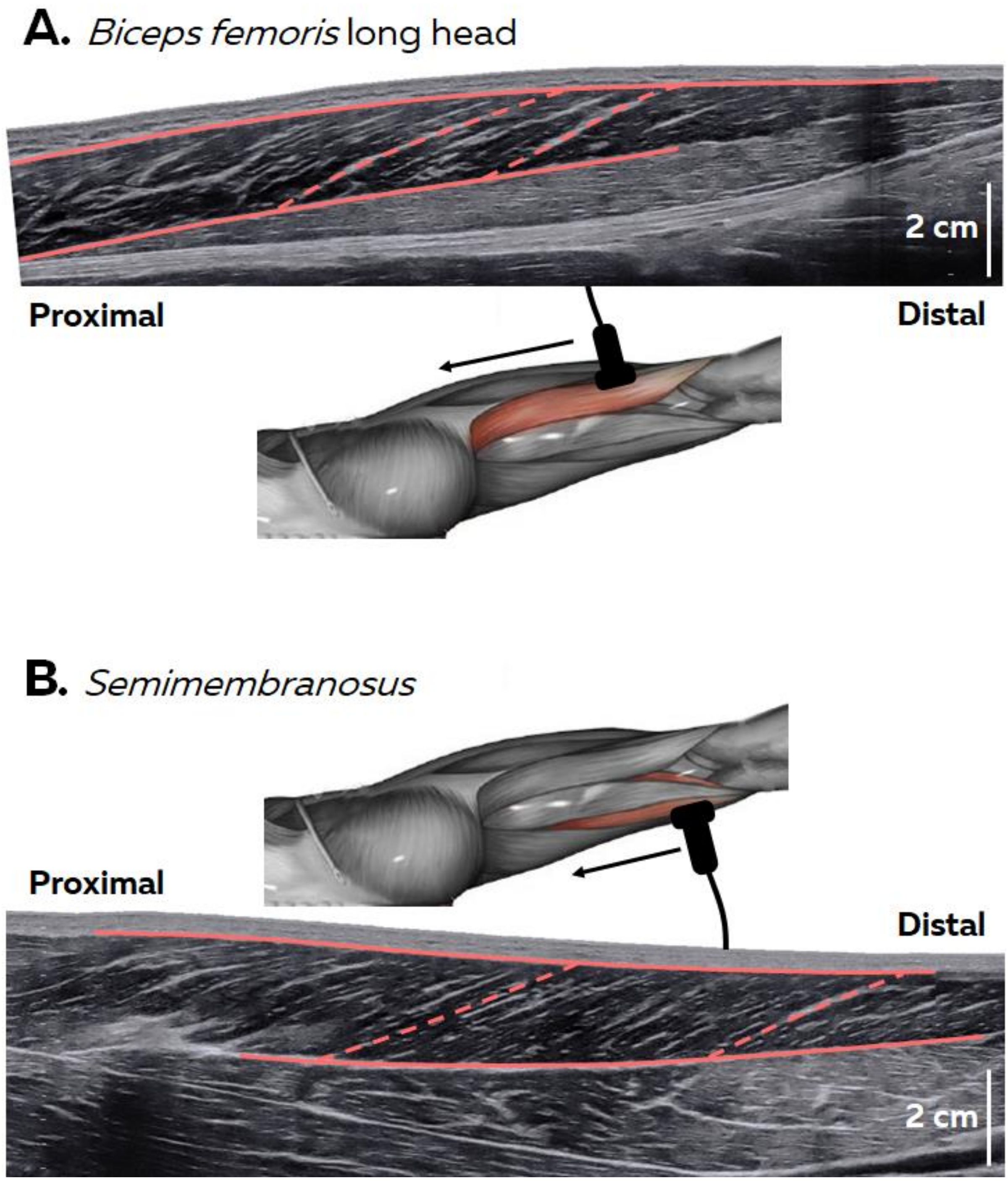
Youth League.: number of game played in the Youth League during the period of the study. BFlh: B*iceps femoris* long head. SM: *Semimembranosus*.

Table 2: Changes in knee-flexor strength and fascicles length following the first (Pre-test to Mid-test) and second phase (Mid-test to Post-test) in low- and high-volume groups.

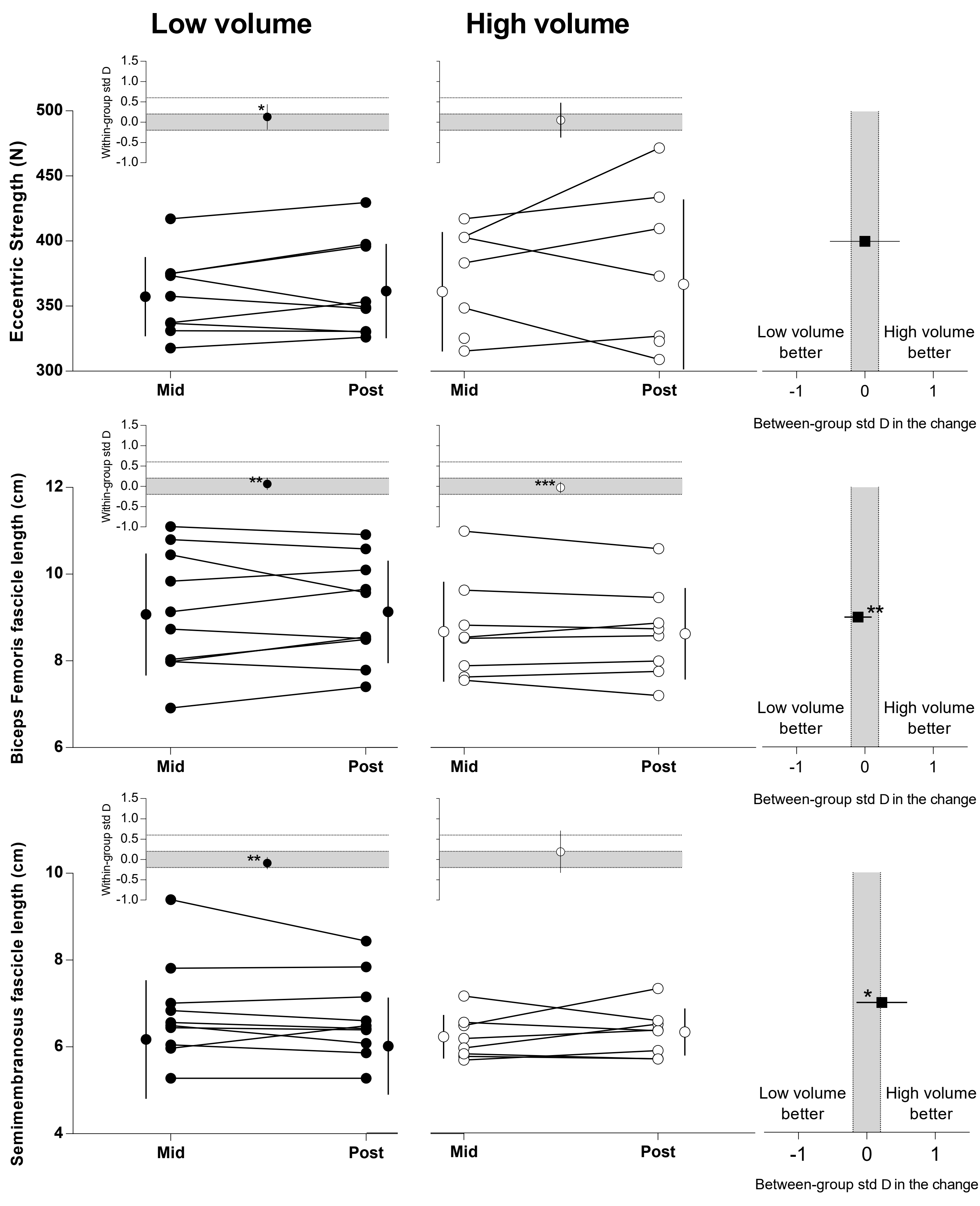
		Phase 1					
		MID vs. PRE					
		PRE	MID	Diff (%)	Standardised change (ES)	Likelihood	Rating
Knee-flexor eccentric strength (N)	Low-volume	325±26	362±46	11.3±7.8	1.18±0.77	97/2/1	very likely +
	High-volume	326±48	361±30	11.4±5.3	0.63±0.28	99/1/0	most likely +
BFlh fascicle length (cm)	Low-volume	8.3±1.0	8.7±1.2	4.5±5.0	0.33±0.35	74/24/1	possibly +
	High-volume	8.7±1.5	9.1±1.2	4.8±2.5	0.25±0.13	75/25/0	likely +
SM fascicle length (cm)	Low-volume	5.8±0.6	6.2±0.5	4.3±4.7	0.39±0.42	80/19/2	likely +
	High-volume	6.4±1.1	6.8±1.1	6.3±6.3	0.33±0.32	76/23/1	likely +
		Phase 2					
		POST vs. MID					
		MID	POST	Diff (%)	Standardised change (ES)	Likelihood	Rating
Knee-flexor eccentric strength (N)	Low-volume	358±31	362±37	1.2±2.9	0.12±0.31	32/63/4	possibly =
	High-volume	362±46	367±66	0.9±7.5	0.05±0.43	26/59/15	unclear
BFlh fascicle length (cm)	Low-volume	9.1±1.4	9.2±1.2	1.0±2.6	0.06±0.15	6/93/1	very likely =
	High-volume	8.7±1.2	8.7±1.1	-0.5±2.0	-0.03+-0.14	1/96/3	very likely =
SM fascicle length (cm)	Low-volume	6.8±1.1	6.7±0.9	-1.6±2.6	-0.09±0.15	0/88/11	likely =
	High-volume	6.2±0.5	6.3±0.5	1.8±4.7	0.19±0.52	49/41/10	unclear

ES: Effect size. PRE, MID and POST refer to pre-, mid- and post-test respectively. BFlh: Biceps *femoris* long head, SM: *semimembranosis*.

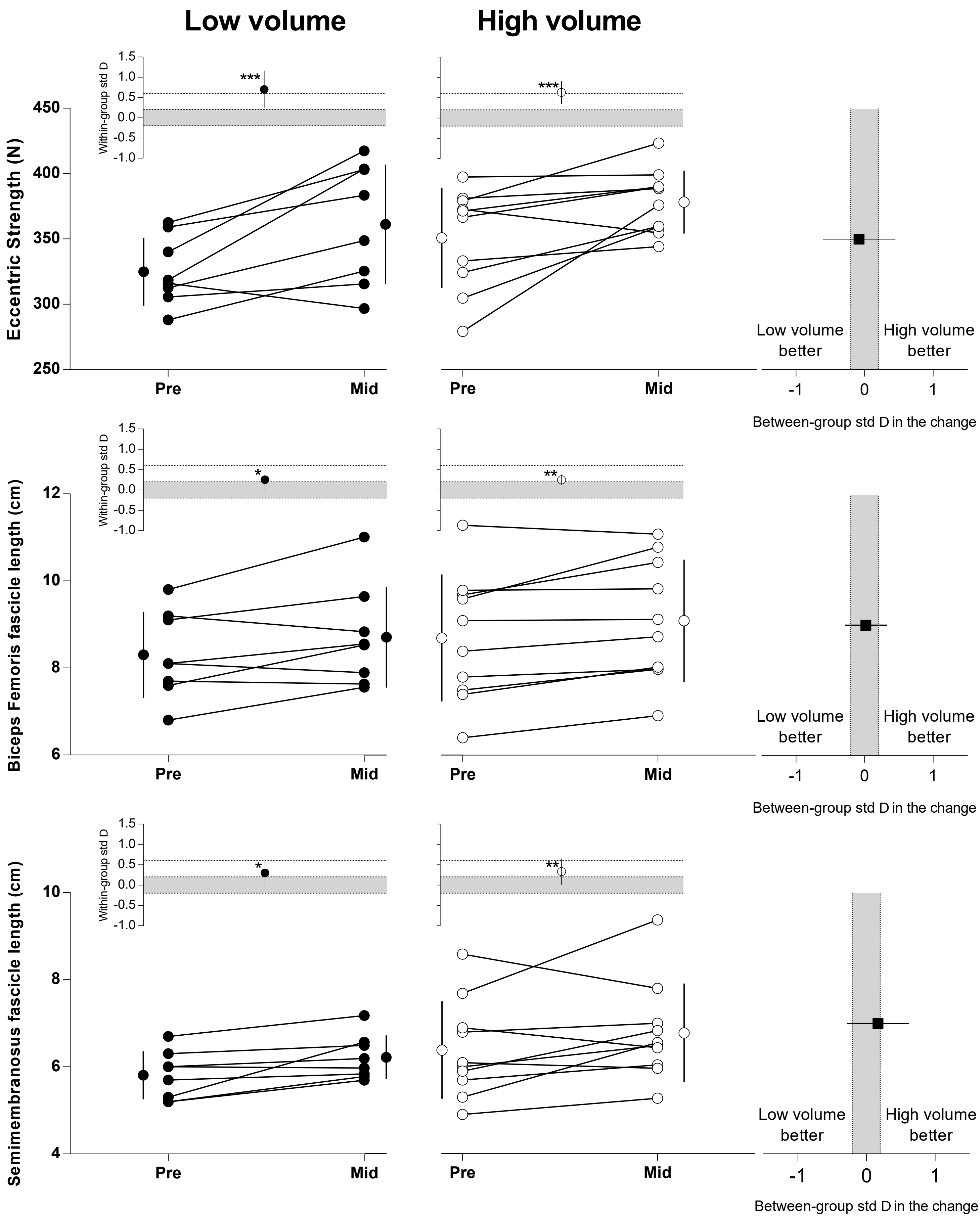

W-3
W-2
W-1
W0
W1
W2
W3
W4
W5
W6
W7
W9
W10
W11
W12
W13
W14
W15
Familiarisation
PRE
Phase 1
6 weeks
MID
Phase 2
6 weeks
POST
Group 1
4x 6 reps
4x 4 reps
1x 6 reps
1x 4 reps
Group 2
1x 6 reps
1x 4 reps
4x 6 reps
4x 4 reps


A. Biceps femoris long head
2 cm
Proximal
Distal
B. Semimembranosus
Proximal
Distal
2 cm


A1
A2
B1
B2



Low volume
High volume
Eccentric Strength (N)
Within-group std D
Mid
Post
Low volume better
High volume better
Between-group std D in the change
Biceps Femoris fascicle length (cm)
Semimembranosus fascicle length (cm)



Low volume
High volume
Within-group std D
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*
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Eccentric Strength (N)
Biceps Femoris fascicle length (cm)
Semimembranosus fascicle length (cm)
Pre
Mid
Low volume better
High volume better
Between-group std D in the change