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Minimal Role of Hamstring Hypertrophy in Strength Transfer Between Nordic Hamstring and Stiff-Leg Deadlift: A Blinded Randomized Controlled Trial

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Abstract

Morin, T, Doguet, V, Nordez, A, Caillet, A, and Lacourpaille, L. Minimal role of hamstring hypertrophy in strength transfer between Nordic hamstring and stiff-leg deadlift: a blinded randomized controlled trial. *J Strength Cond Res* 39(9): 924–932, 2025—Strength transfer refers to the gain in strength in a nontrained exercise resulting from training another exercise. This study aims to determine whether whole and selective hamstring hypertrophy influences the magnitude of strength transfer between the Nordic hamstring exercise (NHE) and the stiff-leg deadlift (SDL). Using a blinded randomized controlled design, 36 resistance-untrained individuals were assigned to a control group (CON), an NHE group, or an SDL group. The 2 resistance training programs were performed 3 times per week for 9 weeks. Semimembranosus (SM), semitendinosus (ST), and biceps femoris (BF) hypertrophy was estimated from changes in the muscle volume using 3D ultrasound. Strength transfer was measured by changes in the 1RM of the nontrained exercise. After the resistance training programs, similar and significant whole hamstring hypertrophy was observed in both training groups (NHE: 11.4 ± 6.5%, and SDL: 7.0 ± 8.1%). The NHE group and SDL group presented a selective hypertrophy of ST (24.3 ± 10.8%) and SM (11.2 ± 12.7%), respectively. Conversely, no difference in strength transfer was observed between the NHE group (10.7 ± 8.5%) and the SDL group (20.7 ± 15.0%) ($p = 0.06$; 95% CI 0.3–20.4%, $d = 0.87$). Finally, nonsignificant correlations were found between strength transfer and both whole and selective hamstring hypertrophy ($r \leq 0.45$), except for the BF in SDL ($r = 0.60$). We conclude that hamstring hypertrophy has a minimal role in strength transfer in resistance-untrained individuals. These findings suggest that, even with hypertrophy, coaches and practitioners should include both Nordic hamstring and stiff-leg deadlift exercises in the same training program to enhance hamstring strength in knee flexion and hip extension tasks, benefiting both performance and injury prevention.

Key Words: resistance training, muscle volume, muscle activation

Introduction

The concept of strength transfer refers to the capacity of 1 exercise to improve strength in other, nontrained exercises or movement tasks (for review, see Mang et al. (24)). For instance, if a lifter performs kettlebell swings during a training block without performing a deadlift, yet their deadlift 1RM improves as a result of the kettlebell swings, this demonstrates strength transfer between the 2 exercises (25). Strength transfer becomes valuable as it allows strength and conditioning specialists to diversify their resistance training (RT) programs by incorporating exercises that yield additional and/or complementary effects.

Strength transfer magnitude seems to be influenced by several factors such as cross-task similarities in the external force vector direction (10,32), force-velocity constraints (21,34), and the number of degrees of freedom (e.g., monoarticular vs. biarticular; unilateral vs. bilateral). Additionally, a common practical strategy lies in the use of "accessory exercises" to induce strength gains via hypertrophic increases of agonist muscle groups while reducing stress on muscular and nonmuscular structures involved in the main exercise. This strategy is reasonable, as a hypertrophy-related increase in force-generating capacity of agonist muscles may lead to greater force production, even for nontrained exercises. However, little is known about the role of muscle hypertrophy in strength transfer. One recent study showed that strength transfer to a 3RM deadlift was not different between groups that performed hip thrust (15%) and back squat training (16%), while similar gluteus maximus hypertrophy (11%) was induced in both groups (29). However, Carmichael et al. (8) reported that a comparable 16% increase in hamstring hypertrophy, achieved through a 6-week protocol of either eccentric or isometric hip extension exercises, did not lead to strength transfer during isometric or eccentric knee flexion, respectively. Strength transfer to knee flexion performance was observed only when the contraction regimen during training matched that of the testing conditions, i.e., eccentric and isometric hip extension training increased about 10.2 and 10.3% eccentric and isometric maximal knee flexion, respectively. Therefore, it remains uncertain whether hypertrophy directly contributes to strength transfer mechanisms.

Biarticular hamstring muscle group, acting on both hip and knee joint, is an ideal model to understand the relationship between hypertrophy and strength transfer. This is because similar hypertrophy can be induced while using a monoarticular knee flexion-oriented and a hip extension-oriented movement training

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(5). Importantly, the distribution of hypertrophy among hamstring heads varies depending on the joint being mobilized. For instance, 10 weeks of Nordic hamstring training has been reported to induce preferential hypertrophy in the semitendinosus (ST) (5), whereas 10 weeks of stiff-leg deadlift training would rather induce a preferential hypertrophy in the semimembranosus (SM) (19). These 2 individual muscles exhibited large anatomical differences (20), with a larger physiological cross-sectional area for the SM leading to greater torque generating capacity in knee flexion (113.3 arbitrary units) compared with ST (60.2 arbitrary units) (4). Therefore, if strength transfer depends on hypertrophy, stiff-leg deadlift training that would rather hypertrophy a "stronger" muscle such as SM could exhibit greater strength transfer than Nordic hamstring training, more specific to a "weaker" ST muscle. However, this assumption holds true only if performance is not limited by other factors.

This study aimed to determine whether whole and selective hamstring hypertrophy influences the magnitude of strength transfer between 2 monoarticular movements: the knee flexion-oriented Nordic hamstring curl and the hip extension-oriented stiff-leg deadlift. First, we hypothesized that individuals involved in stiff-leg deadlift (SDL group) and Nordic hamstring (NHE group) resistance programs would demonstrate significant whole hamstring hypertrophy and strength transfer (5) compared with a control group (CON) not engaged in resistance training. Second, we hypothesized that SDL group would show greater selective hypertrophy in SM, while the NHE group would exhibit greater hypertrophy in ST (5,19). Based on the SM's higher torque generating capacity (4), we hypothesized that SM hypertrophy in the SDL group would result in a greater strength transfer (in Nordic hamstring exercise) than in the NHE group. For each group (NHE and SDL), we hypothesized that strength transfer would correlate significantly with both whole-hamstring and selective-hamstring hypertrophy.

To further investigate these mechanisms, surface electromyography (EMG) was used to measure individual hamstring muscle activation before and after training, providing insights to neural adaptations. These findings aim to enhance our understanding of the mechanisms underpinning strength transfer.

Methods

Experimental Approach to the Problem

A randomized controlled trial (RCT) investigated the impact of hamstring muscle hypertrophy and its distribution across hamstring muscles on strength transfer between 2 exercises: the Nordic hamstring exercise and the stiff-leg deadlift. This study was approved by ethics committee (n°2021-A02-993-38). The experimental protocol included 3 experimental sessions: a familiarization session and 2 testing sessions, which were conducted before (i.e., *pre*) and after (i.e., *post*) the resistance training program, which comprised 27 training sessions. Hamstring muscle volumes were measured during 1 session *pre* and *post* the resistance training program using freehand 3D ultrasound imaging to estimate muscle hypertrophy. 1RM was also measured during 1 dedicated session *pre* and *post* the resistance training program to estimate strength transfer between the 2 exercises.

Subjects

Thirty-six physically active (~9 h·wk^{-1}) sports science students participated in this study. The subjects were familiar with resistance training, while none were following a specific hamstring-strengthening program. Inclusion criteria required subjects to not be engaged in any specific lower limb training program and to have no history of lower limb injuries. Sample size calculations were based on the differences in strength transfer to maximal eccentric task between Hip Extension group (HE) and NHE from Bourne et al. (5). Each group required 11 subjects to demonstrate a significant difference between groups, with a power of 0.8, and a type 1 error rate of only 1%, as multiple comparisons were made between groups. The sample size of 12 conservatively allowed for 10% dropout. Before the first experimental session, subjects were randomly assigned to 1 of 3 groups: Control (CON, $n = 12$, age: 19.6 ± 1.1 years, height: 177.3 ± 7.7 cm, mass: 71.6 ± 10.6 kg), NHE (NHE, $n = 12$, age: 20.3 ± 1.5 years, height: 180.1 ± 9.1 cm, mass: 76.0 ± 11.1 kg), or Stiff-leg Deadlift (SDL, $n = 12$, age: 20.4 ± 1.4 years, height: 178.5 ± 7.1 cm, mass: 69.5 ± 9.3 kg). Flowchart graph and group differences are available in Supplementary Content (see Supplemental Content 1, http://links.lww.com/JSCR/A625). No subjects dropped out of the experimental protocol. Subjects were instructed to maintain their usual physical activities, but to continue to exclude any lower limb resistance training. During an initial meeting, subjects were informed about the nature, aims, and risks associated with the experimental and training procedures, and written informed consent was obtained. This trial (NCT06164249) was conducted in accordance with the Declaration of Helsinki and was approved by the ethics committee (No. 2021-A02993-38).

Dietary Supplementation. In line with recommendations for protein intake during resistance training focused on hypertrophy (27), subjects consumed a supplement on training days containing 22.0 g of protein and 2.0 g of carbohydrates (Whey Protein Bio, Alter Nutrition, France) under the examiner's supervision.

Procedures

Familiarization session. During the familiarization session, each subject was familiarized with both exercises. Since the Nordic hamstring often exceeds body mass as a supramaximal exercise, subjects used a specific machine (Westside inverse curl pro; Watson, United Kingdom) equipped with a counterweight system that allowed off-loading the subjects' body mass and precisely quantifying the load (Figure 1). After key execution criteria (detailed later) were presented and demonstrated by an experienced examiner, subjects spent 10 minutes per exercise to (a) experience the full range of motion with low resistance and (b) perform 8 to 10 contractions at a moderate resistance while adhering to the execution criteria. If execution was validated by the examiner (otherwise, an additional set was performed), a progressive increase in load was performed over 3–4 sets to determine the maximal load for 1 repetition at a rating of perceived effort (RPE) of about 8 (RPE 8). This maximal load performance was recorded and later used during the first 1RM assessment session (*pre*).

Nordic hamstring was performed from 90° knee flexion to full knee extension (thigh parallel to the floor) with a neutral spinal posture and complete hip extension (0°). Stiff-leg deadlift was performed with a shoulder width stance, no lower limb rotation, and movement from 0° to 90° of hip flexion. Only slight knee unlocking was permitted, and a neutral spinal posture was maintained (Figure 1). For both exercises, subjects were asked to perform the eccentric phase over 3

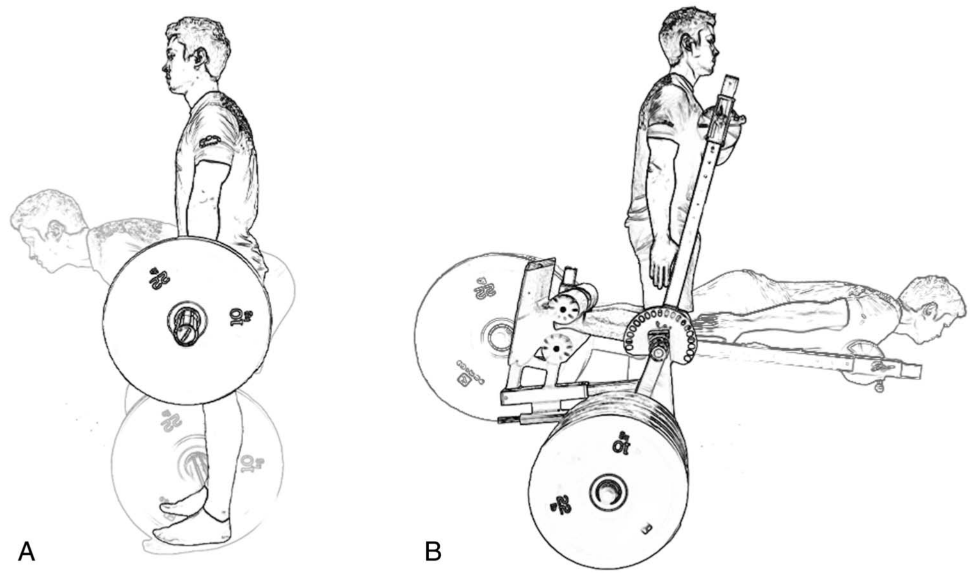

Figure 1. Representation of stiff-leg deadlift (A) and Nordic hamstring exercise (B).

seconds before executing the concentric phase with the intention of achieving maximal speed.

One-Repetition Maximum. The 1RM was assessed for both exercises 4–10 days before and 4–7 days after the 9-week training program. To support the training sessions, the 1RM was also reassessed at the start of the 10th and 19th training sessions. The 1RM evaluation session followed a standardized protocol to allow comparison across subjects: Subjects completed a standardized warm-up consisting of 2 rounds of 10 body-weight single-leg bridge reps and an 8 kg loaded good morning exercise, with progressively increasing effort levels. This was followed by a specific warm-up (either Nordic hamstring or stiff-leg deadlift) comprising 3 sets of 10, 6, and 1 repetitions performed at 30, 60, and 90% of the maximal load determined during the familiarization session, respectively. After the warm-up, a progressive load increase (minimum. 2.5 kg) was used to estimate the 1RM. If subjects failed, a second trial was attempted after 3 minutes of rest. A valid 1RM required (a) a controlled three-second eccentric phase and (b) compliance with the joint angles specified by the experimenter (see *Familiarization session*).

For Nordic hamstring, the lower the additional weight, the better the performance. Given the influence of individual biomechanics on Nordic hamstring force production, the 1RM torque (Nm) was calculated as follows:

$$1\text{RM (Nm)} = (\text{BM} \times \text{g} \times \text{COMposition}) - (\text{CW} \times \text{LA}) \quad (1)$$

where BM is the subject's body mass from Winter et al. (39), excluding (tibia and feet); g is the gravitational constant; COMposition is the estimated center of mass position of the system (body); CW is the additional counterweight; and LA is the lever arm of the machine counterweight.

For stiff-leg deadlift, the 1RM was the maximal load (kg) that could be lifted once over the range of motion (ROM). The 1RM for both the Nordic hamstring and stiff-leg deadlift were tested in randomized order.

Training Description. The training protocol took place at the "Movement—Interactions—Performance" laboratory of Nantes University (France) between February and April 2024. It consisted of 9 weeks of training for the NHE and SDL groups, with 3 sessions per week. The CON group continued their usual activities without any changes.

The NHE and SDL groups then began a progressive 27-session training protocol using a load set at 80% of their 1RM (35). As mentioned before, this load was adjusted every 3 weeks (5).

Progressive changes in training volume (i.e., number of sets and repetitions) followed a pyramid structure (5) and are reported in Table 1. Execution criteria and subject's safety were monitored by a certified coach. The coach was not involved in data collection or experimental data processing. Importantly, the training protocol was conducted using the exact same execution criteria as during the 1RM assessment.

Resistance Training Monitoring. Subjects monitoring during the 9-week training program was conducted using the HexFit application (Hexfit Inc, Quebec, Canada). This tool allowed subjects to schedule laboratory appointments for experimental sessions and to book training slots for the NHE and SDL groups. Two subjects (1 from the NHE group and 1 from the SDL group) were permitted to train simultaneously, ensuring proper supervision by the strength and conditioning coach.

Table 1
Training program for both the Nordic hamstring and stiff-leg deadlift exercises.*

Week	Sessions	Sets	Repetitions	Charge (%RM)
1	3	2	5	80
2	3	3	6	80
3	3	4	7	80
1RM reassessment				
4	3	4	7	80
5	3	5	7	80
6	3	6	8	80
1RM reassessment				
7	3	5	7	80
8	3	5	6	80
9	3	3	5	80

*1RM = 1-repetition maximum.

The application also enabled precise tracking of training loads throughout the 9 weeks. Additionally, it allowed the collection of data such as RPE, training-related comments, and fatigue levels.

Muscle Volume Assessment Using 3D Ultrasound and Hypertrophy Estimation. The freehand 3D ultrasound (3DUS) method used in the present study has been validated for the hamstrings (12). For instance, the present method shows a deviation of less than 0.8% compared with magnetic resonance imaging in estimating muscle volumes. Reproducibility tests show between-session coefficients of variation from 1.13 to 1.88% and intraclass correlation coefficients >0.99 for the hamstring muscles. Subjects laid prone on a massage table while ultrasound images of each hamstring head were captured using an ultrasound scanner (Aixplorer version 12.3, SuperSonic Imagine, Aix-en-Provence, France) with a 10-2 MHz transducer (40 mm field of view: Vermon, Tours, France). Image depth and brightness were individually adjusted for each subject.

The transducer was fitted with a 3D-printed rigid body containing 4 reflective markers. An optoelectric motion capture system with 10 cameras (Optitrack Flex 13, NaturalPoint), recording at 120 Hz, tracked the transducer's position. Ultrasound images and transducer position data were recorded using the open-source software 3D Slicer (slicer.org; v.5.6.2; Perth, Australia). To ensure measurement reproducibility, the same examiner (T.M.) conducted all pretraininf and post-training volume recordings. Furthermore, for each measurement, the examiner was blinded to the subject group assignments. A gel pad was used to minimize compression effects, and no pressure was applied to the transducer during imaging (12,37).

Once data collection was complete, all muscle volumes were reconstructed and manually segmented using 3D Slicer by the same blinded examiner for consistency. Manual segmentations were conducted every 6.0 mm at the hamstring insertions and every 10.0 mm in the muscle belly regions, representing approximately 30–50 slices per muscle (see Supplementary Content 2, http://links.lww.com/JSCR/A626). Hypertrophy of each individual muscle was considered as the relative changes in muscle volume between *pre* and *post.* Whole hamstring hypertrophy was calculated as the averaged hypertrophy of the 3 hamstring heads (i.e., SM, ST, and biceps femoris [BF]).

Muscle Activation. Myoelectrical activity was recorded using surface EMG *pre* and *post* training during the 1RM. EMG electrodes were placed over the SM, ST, and BF muscles. Before electrode placement, the skin was shaved and cleaned with alcohol. Wireless surface electrodes (Cometa Pico, Cometa, Milan, Italy, interelectrode distance = 25 mm) were attached to the skin with double-sided tape (intersensor distance = 1 cm). Electrode placement was verified with B-mode ultrasound (6) to ensure alignment with the muscle fascicle plane and avoidance of neighboring muscle borders. To minimize crosstalk, EMG electrodes were placed on the midline of the most prominent superficial muscle belly of each hamstring head. Based on hamstring morphology (36), the electrode positions for BF and SM were slightly more distal than for ST. Given the regional variation in EMG amplitude (15,16), 2 electrodes were placed on each muscle: 1 at the proximal-middle and 1 at the distal-middle location. EMG signals were digitized at 2000 Hz and band-pass filtered (30–300 Hz) using a second-order Butterworth filter. The signals were then rectified and low-pass filtered at 6 Hz to generate individual EMG envelops (18). For EMG normalization, 2 maximal voluntary contractions (MVCs) were performed at 3 different knee flexion angles (20°, 45° and 80°; 0° = knee fully extended) with a fixed 90° of hip flexion (0° = full hip extension) (28). The peak value of each EMG envelops over the 6 MVCs was used as the maximal reference value for normalizing EMG signals to obtain an estimate of muscle activation. Kinematic data (MTw Awinda, Xsens North America Inc., Culver City, CA) were used to determine the onset and offset of each repetition of an eccentric contraction. Muscle activation was measured during the ROM as follows: from 90° to 0° of knee flexion for Nordic hamstring and from 0° to 90° of hip flexion for stiff-leg deadlift. Activation was expressed as percentage of the ROM for each exercise.

Statistical Analyses

The data distribution was assessed using the Shapiro-Wilk test. Outliers were detected using Grubbs' test (14), resulting in the exclusion of 1 subject of the CON group from the analyses. Absolute (kg and Nm) and relative (%) strength gains (1RM) were calculated for all subjects.

The effect of the 9-week training program on 1RM in the trained exercise (Nordic hamstring or stiff-leg deadlift) was evaluated using 2 independent Student's t tests to compare relative strength gains between control and trained groups (CON vs. NHE, CON vs. SDL). To assess differences in strength transfer between the NHE and SDL groups, a Student's t test was used to compare relative 1RM changes in the nontrained exercise.

A linear mixed-effects model was used to evaluate differences in muscle hypertrophy (%) between groups (CON, NHE, and SDL) and muscles (SM, ST, and BF). Group and Muscle were modeled as fixed effects, along with their interaction (Group × Muscle) to examine whether hypertrophy responses differed across muscles depending on the group. To account for inter-subject variability, subject was included as a random effect.

To compare EMG patterns with high temporal resolution, all statistical analyses were performed using Statistical Parametric Mapping (SPM 30, v0.4, www.spm1d.org) in Matlab (Matlab; The Mathworks, Nathick, MA). Family-wise type I error rate was set at 0.05. Two 3-way repeated-measures ANOVA were used to determine whether time (*pre* and *post*), muscle (SM, ST, and BF), group (NHE vs. CON; SDL vs. CON), and their interactions altered EMG signals recorded during the nontrained exercise. In case of an interaction at any timepoint across the range of motion, locations of the differences were tested using paired-sample *t* tests with Bonferroni correction. Statistical parametric mapping technical details are described elsewhere (1,11).

Finally, correlations were performed (by group) to determine the relationship between whole hamstring hypertrophy, selective hamstring hypertrophy and changes in 1RM for the nontrained exercise. Correlation coefficients were interpreted as negligible, small, moderate large, or very large at <0.10, 0.11–0.30, 0.31–0.50, 0.51–0.70, and >0.70, respectively (17).

Effect sizes were also calculated using Cohen's *d* (9) and interpreted as *trivial*, *small*, *moderate*, and *large* at <0.35, 0.35–0.80, 0.80–1.50, and >1.50, respectively (33). All statistical analyses and data visualizations in this study were performed using R (R Foundation for Statistical Computing, v.4.4.0, Vienna, Austria) and Prism (GraphPad Prism, v.10.1.1, Boston, MA) software. Data tables and statistical results are available as supplementary materials, http://links.lww.com/JSCR/A625, http://links.lww.com/JSCR/A626, http://links.lww.com/JSCR/A627.

Results

Training session attendance was 96.6 ± 3.7% for the NHE group and 94.8 ± 4.0% for the SDL group. Table 2 shows the 1RM results for each group in both trained and nontrained (strength transfer) exercises. Individual progressions in Nordic hamstring and stiff-leg deadlift exercises for the NHE, SDL, and CON groups are presented in Figure 2.

Muscle Hypertrophy

The linear mixed-effects model revealed a significant group × muscle interaction effect on changes in muscle hypertrophy ($p <$ 0.001) as well as a significant group effect ($p = 0.004$). Post hoc tests showed that both the NHE and SDL groups experienced significant overall hamstring hypertrophy compared with the control group ($p < 0.001$ and $p = 0.044$, respectively). No significant difference in overall hypertrophy was observed between the NHE and SDL groups ($p > 0.05$).

Regarding muscle-specific hypertrophy, the NHE group exhibited significant hypertrophy of the ST (24.4 ± 10.8%) compared with both the CON group (1.0 ± 6.2%; $p < 0.001$, $d =$ 2.83) and the SDL group (5.5 ± 9.3%; $p < 0.001$, $d = 1.96$). The SDL group, in contrast, showed significant hypertrophy of the SM (11.2 ± 12.7%) compared with the CON group (1.9 ± 4.3%; $p = 0.02$, $d = 0.92$), but not compared with the NHE group (4.6 ± 5.8%; $p = 0.24$, $d = 0.69$). For the BF, no significant differences in hypertrophy were observed between any of the groups ($p \geq 0.39$, $d \leq 0.58$).

Relative Strength Gains in the Trained Exercise

In the Nordic hamstring exercise, the NHE group showed a significantly larger increase in 1RM compared with the CON group (mean difference = 15.5%, 95% confidence interval [CI]: 3.0–34.5%, $p = 0.02$, $d = 0.94$). On average, subjects in the NHE group exhibited a 37.4 ± 13.8% increase on 1RM after 9 weeks of training (Figure 2). In the stiff-leg deadlift exercise, the SDL group showed a significantly larger increase in 1RM compared with the CON group (mean difference = 21.6%, 95% CI: 7.2–36.1%, $p = 0.01$, $d = 1.36$). On average, subjects in the SDL group exhibited a 34.0 ± 21.2% increase in 1RM.

Relative Strength Gains in the Nontrained Exercise (Strength Transfer)

The relative increase in 1RM in the nontrained exercise was 10.7 ± 8.5% and 20.7 ± 15.0% in the NHE group and the SDL group, respectively (Figure 2). Additionally, no significant difference was found between the CON group and the respective progressions of the NHE group in stiff-leg deadlift (mean difference = 1.7%, 95% CI −9.5 to 6.1%, $p = 0.65$, $d = 0.20$) and the SDL group in Nordic hamstring (mean difference = −1.2%, 95% CI −14.1 to 16.5%, $p = 0.87$, $d = 0.07$). No significant difference in strength gains in the nontrained exercise was observed between the NHE and SDL groups (mean difference = 10.1%, 95% CI 0.3–20.4%, $p = 0.06$, $d = 0.87$).

Muscle Activations in the Nontrained Exercise

The muscle activation patterns are depicted in Figure 3. Statistical parametric mapping analyses revealed neither a time, group, nor a time×muscle×group (all $p \geq 0.05$) effect on muscle activations during the nontrained exercises. A main effect of muscle was observed for both Nordic hamstring ($p < 0.001$) and stiff-leg deadlift exercises ($p < 0.001$).

Correlation Between Strength Transfer and Muscle Hypertrophy. For both the NHE and SDL groups, a nonsignificant correlation was observed between the increase in whole hamstring hypertrophy and the strength transfer to nontrained exercise ($r \leq 0.23$; $p = 0.52$). The relationships between selective hypertrophy of the SM, ST, and BF and strength transfer to the nontrained exercise, depicted in Figure 4, yielded similar results. For the SDL group, *negligible* to *small* and nonsignificant correlations ($r \leq 0.27$; $p \geq$ 0.39) were found between SM, ST, and BF hypertrophy and strength transfer to Nordic hamstring exercise (bottom panels in Figure 4). For the NHE group, *small* and *moderate* nonsignificant correlations ($r \leq 0.40$; $p \geq 0.19$) were found for SM and ST (top panels in Figure 4), while a *large* and significant positive correlation was observed between BF hypertrophy and strength transfer to stiff-leg deadlift exercise ($r = 0.60$; $p = 0.04$).

Discussion

We conducted a blinded randomized controlled trial over 9 weeks to examine the effects of Nordic hamstring and stiff-leg deadlift exercises on strength gains in nontrained exercises, and (a) whole and (b) selective hamstring hypertrophy, and conclude on the possible correlation between muscle hypertrophy and strength transfer. In presence of a significant whole hamstring hypertrophy in NHE (11.4 ± 6.5%) and SDL (7.0 ± 8.1%) groups, they did not exhibit larger strength transfer compared with CON. According to our hypothesis, NHE group exhibited a selective hypertrophy of the ST (24.4 ± 10.8%) while SDL group exhibited a selective hypertrophy of the SM (11.2 ± 12.7%). However, no difference in strength transfer was observed between NHE and SDL groups. Finally, no significant correlations were found between both whole and selective hamstring hypertrophy and strength transfer. We concluded a minimal role of hamstring hypertrophy in strength transfer between Nordic hamstring and stiff-leg deadlift in resistance-untrained individuals.

Consistent with prior research, Nordic hamstring curl-based resistance training effectively improved maximal knee flexion

Table 2

Changes in 1RM in both exercises for the NHE, SDL, and CON groups.*†

Group	Stiff-leg deadlift		Nordic hamstring exercise	
	Pre	Post	Pre	Post
NHE ($n = 12$)	125.4 ± 30.0 kg	138.1 ± 30.6 kg	201.0 ± 60.2 Nm	274.6 ± 81.6 Nm
SDL ($n = 12$)	103.5 ± 22.9 kg	136.0 ± 23.0 kg	198.2 ± 80.5 Nm	232.0 ± 85.3 Nm
CON ($n = 11$)	115.5 ± 26.5 kg	128.2 ± 22.9 kg	183.6 ± 53.2 Nm	221.3 ± 61.4 Nm

*1RM = 1-repetition maximum; NHE = Nordic hamstring exercise; SDL = stiff-leg deadlift; CON = control group; Pre = 1RM before the training program; post = 1RM after the training program.
†Data are presented as mean ± *SD*.

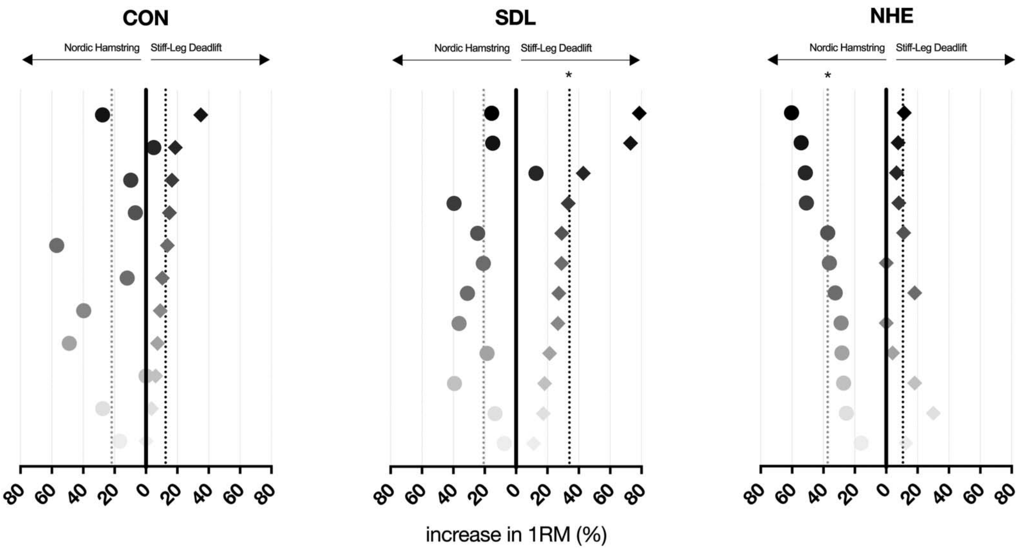

Figure 2. Relative increases in 1RM for each group (i.e., CON, SDL, and NHE), for each exercise and subject. The data for the Nordic hamstring exercise trend to the left, while the data for the stiff-leg deadlift exercise trend to the right. The mean increases for the Nordic hamstring exercise are indicated by gray vertical dotted lines, whereas the mean increases for the stiff-leg deadlift exercise are marked by black vertical dotted lines. *Significantly different from the CON group. 1RM = 1-repetition maximum; NHE = Nordic hamstring exercise; SDL = stiff-leg deadlift; CON = control group.

strength (2,3,5,7,23). Previous studies, such as Andrews et al. (3), reported a ~40% increase in eccentric knee flexion torque after 9 weeks of Nordic hamstring training, which is in line with the 37.4 ± 13.8% increase in 1RM observed here for the NHE group after 27 training sessions. In contrast, stiff-leg deadlift training has been less explored, although Kawama et al. (19) reported 20–26%

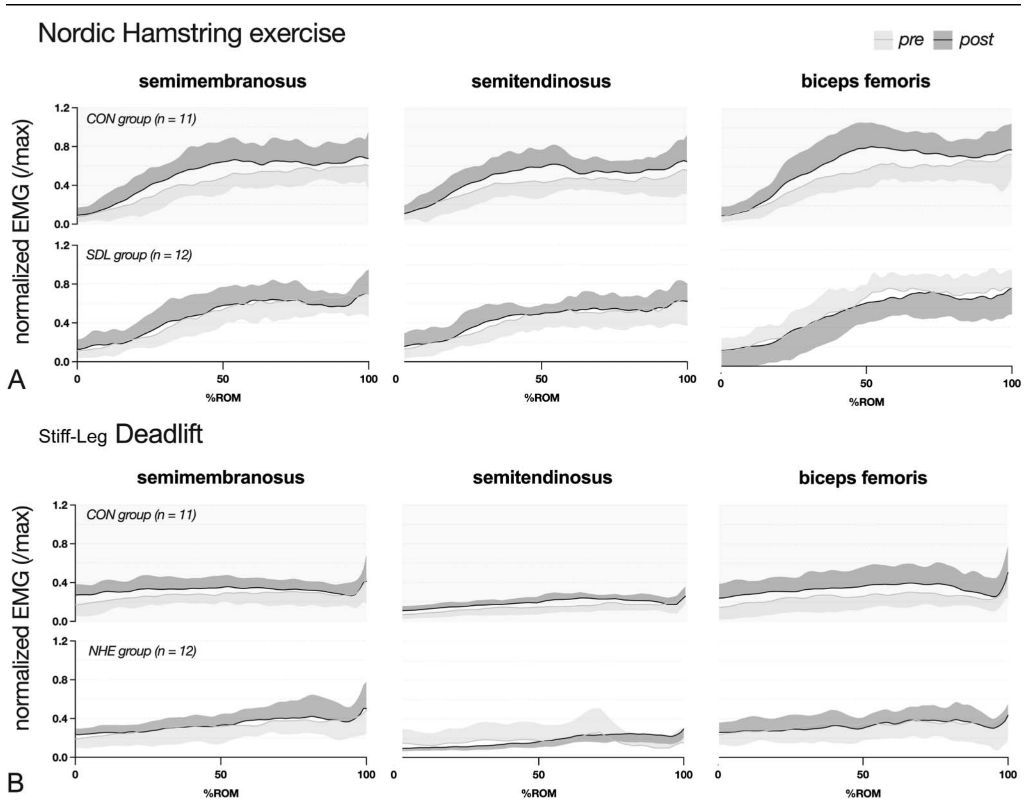

Figure 3. Normalized EMG for each hamstring head pretraining and post-training measurements for nontrained exercise and for both exercises for CON group. Pretraining are represented by gray lines and areas, while post-training EMG data are represented by black lines and areas. The data are presented as a function of the range of motion (from 0 to 100%) during the eccentric phase of the movement. Panel (A): data for the SDL and CON groups in Nordic hamstring. Panel (B): data for the NHE and CON groups in stiff-leg deadlift. CON = control group; NHE = Nordic hamstring exercise; SDL = stiff-leg deadlift.

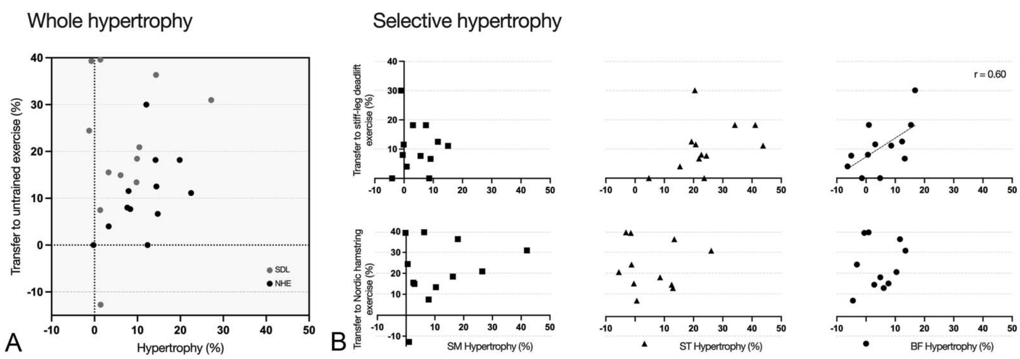

Figure 4. Relationship between strength transfer and hypertrophy. The panel (A) represents the relationship between whole hamstring hypertrophy and strength transfer in the untrained exercise for every subject. Data for the SDL group are represented by gray dots while data for the NHE group are represented by black dots. The panel (B) represents the relationship between selective hamstring hypertrophy and strength transfer in untrained exercise for the NHE and SLD groups. Data of NHE group are presented in the top panel. Data of SDL are presented in the bottom panel. NHE = Nordic hamstring exercise; SDL = stiff-leg deadlift.

increases in maximal isometric knee flexion torque. However, this study used lower loads (60% of body mass), maximal range of motion to focus on flexibility, and hamstring structural adaptations and did not report results in terms of 1RM. Our study, which employed different loads (~80% 1RM), also observed a large increase in strength in the trained stiff-leg deadlift exercise (34.0 ± 21.2% increase in 1RM for the SDL group; Figure 2).

Both the NHE and SDL groups exhibited significant and similar whole hamstring hypertrophy compared with the CON group (11.4 ± 6.5% and 7.0 ± 8.1%, respectively, vs. 1.2 ± 3.6%). Albeit no existing Nordic hamstring-stiff-leg deadlift comparison in the literature, these results align with Bourne et al. (5), who reported 15–16% hamstring hypertrophy for the Nordic hamstring, with no difference compared with a 45° hip extension exercise. The similar subjects training status (non–resistance-trained) combined with the similar sets and repetitions range (Table 1) likely explain the accordance with our study. According to our second hypothesis, the NHE and SDL groups exhibited significantly greater selective ST and SM hypertrophy, respectively. Although this is the first study comparing directly these 2 exercises, this result is in accordance with the literature (5,19). Interindividual variability of the distribution of hypertrophy was notable, with some subjects from the NHE group notably showing 80–100% of the total hamstring hypertrophy in ST, while another from the same group showed only 44%. Similar results were observed in the SDL group, as 1 subject showed 76% of the total hamstring hypertrophy in SM, while it represents 24% for another subject from the same group. The interindividual difference in the distribution of the hamstring hypertrophy has been already reported in Frouin et al. (13). The identification of the origin and the consequences of this phenomenon requires further investigations.

Carmichael et al. (8) reported that a 6-week eccentric and isometric hip extension exercise intervention induced whole hamstring hypertrophy of about 10 and 8.5%, respectively. Strength transfer to knee flexion performance followed specificity principle with significant gains in eccentric condition (12.0 and 8.4% at moderate and fast speed, respectively) and nonsignificant gains in isometric condition for the eccentric group, with reciprocal results for the isometric group (10.3% in maximal isometric knee flexion strength). This is a crucial result, as it suggests that 10 and 8.5% of hypertrophy of both groups do not enhance the maximal strength in the knee flexion performance in the nontrained contraction regimen. Although we reported substantial increases in 1RM in the nontrained exercise (10.7 and 20.7% for NHE and SDL group, respectively), these changes were not different compared with CON (Figure 2). This means that the significant increase in hamstring volume in both the SDL (7.0 ± 8.1%) and NHE (11.4 ± 6.5%) groups did not contribute to enhance strength transfer. Also, the greater selective SM hypertrophy induced in SDL group, which exhibit large torque generating capacities (4), did not lead to a larger strength transfer to Nordic hamstring (nontrained exercise), which was counterintuitive to our initial hypothesis. Overall, no significant relationship was found between strength transfer and whole hamstring hypertrophy (all r values ≤ 0.32) and selective hypertrophy of each hamstring head (all r values ≤ 0.39), except for the BF in stiff-leg deadlift (r = 0.60; Figure 4). This latter *large* correlation needs to be interpreted with caution as the magnitude of hypertrophy on BF was about 6.3% on average, with 7/12 subjects exhibiting less than 8% of hypertrophy. This provides the first impetus that hypertrophy plays a minimal role in strength transfer in non–resistance-trained individuals. Together with the absence of changes in muscle activation between *pre* and *post* resistance training for any group (Figure 3), this helps us conclude about the major role of technical factor (i.e., the subject's ability to produce efficient force) in the strength transfer observed in NHE and SDL groups, as well as the strength gains in the CON group.

Three main hypotheses may be formulated to explain the minor role of hypertrophy in strength transfer. First, the present study has shown that hamstring muscle activation is submaximal during the 1RM of Nordic hamstring and stiff-leg deadlift exercise (Figure 2). It is likely that the fibers exhibiting hypertrophy were not all recruited during 1RM reducing the hypertrophy-related strength transfer. Second, Hegyi et al. (15) showed a region-dependent hamstring electrical activity in Nordic hamstring exercise and stiff-leg deadlift with proximo-distal patterns depending on muscle and exercises. If the Nordic hamstring exercise induced hypertrophy to the distal region of the ST (22), the low activation of this region during stiff-leg deadlift would limit the strength transfer. In a similar manner, musculoskeletal modelling revealed that the contribution in total force was limited for ST and SM in stiff-leg deadlift and Nordic hamstring exercises, respectively (38). This limits the role of selective hypertrophy in strength transfer between these 2 specific exercises. Third, the strength transfer associated with muscle hypertrophy requires that hamstring strength represent a limiting factor of exercise performance. This assumption holds true for Nordic hamstring exercise but not for stiff-leg deadlift, where various nontechnical factors—such as maximal strength of the grip (30), the spinal extensors (31), and gluteal muscles (29) can constrain performance. This is particularly true when the stiff-leg deadlift is performed in bilateral condition at a high relative load. In other words, when multiple factors limit the performance, as in the stiff-leg deadlift, it is unlikely that muscle hypertrophy significantly contributes to strength transfer. Supporting this hypothesis, we found a *moderately* but nonsignificant ($d = -0.82$) smaller strength transfer from NHE group to stiff-leg deadlift exercise, despite a *moderately* ($d = 0.64$) greater hypertrophic response. This suggests that the role of muscle hypertrophy in strength transfer between Nordic hamstring and stiff-leg deadlift exercise is mediated by other performance-limiting factors, the magnitude of which varies between exercise.

The interpretation of statistical results in this study should consider certain limitations. The small sample size (36 subjects across 3 groups) likely reduced the statistical power to detect subtle relationships between hypertrophy and strength transfer, increasing the likelihood of Type II errors (e.g., concluding $p > 0.05$ and incorrectly interpreting absence of significant correlation while a moderate linear relationship of $r = 0.41$ between hypertrophy and strength transfer could exist). This issue is compounded by large intersubject variability observed in both hypertrophy and strength transfer responses and captured by the mixed-effect model in the hypertrophy versus group-muscle analysis. Such variability increases noise in the data, widening confidence intervals and making it difficult to detect consistent trends. Together, these factors underscore that larger sample sizes are needed to account for individual differences, improve the reliability of the statistical estimates, and consolidate the conclusions drawn in this study.

Future studies should explore whether hypertrophy accelerates strength gains during a subsequent training block focused on the previously untrained exercise from the first block. In line with the microdosing principle, it would be valuable to design a mixed program combining a high training volume for 1 exercise (designated as the trained exercise) with a minimal effective dose for another (designated as the untrained exercise). This approach could help us to determine whether muscle hypertrophy has a greater impact on strength transfer when the technical dimension is minimized. This question should also be examined in resistance-trained individuals. Such an approach would offer deeper insights into the role of muscle hypertrophy in performance (26) and its broader implications for rehabilitation and training strategies.

Practical Applications

From the results of our study, both whole and selective hamstring hypertrophy induced by Nordic hamstring and stiff-leg deadlift exercises did not affect the magnitude of strength transfer in resistance-untrained subjects. Coaches and practitioners should include both Nordic hamstring curl and stiff-leg deadlift exercises in training programs to maximize strength gains in both knee flexion-oriented and hip extension-oriented tasks. This study suggests that the role of muscle hypertrophy in strength transfer between Nordic hamstring and stiff-leg deadlift exercise is mediated by other performance-limiting factors, the magnitude of which varies between exercise. Future research needs to determine the influence of resistance training status on hypertrophy-induced strength transfer and its putative optimization through minimal effective dose during a block periodization.

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