Maximum isokinetic familiarization of the knee: Implication on bilateral assessment

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ABSTRACT
Purpose: Familiarization is necessary for an accurate strength assessment as it reduces confounding factors such as learning and training effects. However, the number of contractions required for familiarization and whether cross-limb transfer during familiarization could affect bilateral assessment are unknown. This study aimed at identifying the number of maximum contractions required for isokinetic knee extension and flexion familiarization in both dominant (D) and non-dominant limb (ND).

Methods: Twenty-eight right-limb dominant males (age: 22.64 ± 2.60 years, BMI: 23.82 ± 2.85 kg/m²) performed a total of 6 sets (each consisted of 5 continuous maximum contractions) at 60°/s for each limb.

Results: The number of sets required for familiarization is determined when the average peak torque achieved stabilization from the series of contractions of each limb. For knee extension, 3 sets (15 contractions) were required for familiarization, whereas 2 sets (10 contractions) for knee flexion in both limbs. Interestingly, for knee extension in ND, the number of sets required for familiarization was reduced to 2 following contralateral contractions in D, however, for knee extension in D, there was no difference in the number of sets required for familiarization following contralateral contractions in ND. While for knee flexion, no cross-limb transfer was observed. These observations suggest the presence of cross-limb transfer from D to ND during familiarization which implies the involvement of the central nervous system.

Conclusions: Practically, familiarization for bilateral isokinetic strength assessment for knee extension and flexion at 60°/s should begin with the dominant limb for 3 sets to obtain accurate and reliable measurements.

1. Introduction
Familiarization in strength generally refers to repeated contractions to optimize force production and reduce learning effect prior to a maximum strength testing. Lack of familiarization underestimates the results, while excessive familiarization may produce training effect and fatigue (Benton, Swan, & Peterson, 2009) as well as a waste of time. Therefore, an optimal number of familiarization is required for an accurate measurement during testing (Calder & Gabriel, 2007; do Nascimento et al., 2013; Green, Parro, & Gabriel, 2014; Ploutz-Snyder & Giamis, 2001; Ritti-Dias, Avelar, Salvador, & Cyrino, 2011).

Most studies report the number of familiarization sessions required for isotonic (1-RM) and isometric contractions, while for
isokinetic contraction, few studies used test-retest reliability which only provide indirect information on familiarization (Ritti-Dias et al., 2010; Sole, Hamren, Milosavljevic, Nicholson, & Sullivan, 2007). The number of familiarization sessions required for a 1-RM test ranges from 1 to 9 in a multiple-day setting (do Nascimento et al. et al., 2013; Phillips, Batterham, Valenzuela, & Burkett, 2004; Ploutz-Snyder & Giamis, 2001; Ritti-Dias et al., 2011; Ritti-Dias, Cyrino, Salvador, et al., 2005; Soares-Caldeira et al., 2009), while for isometric it is 2–3 sets (10–15 contractions) in a single-day session (Calder & Gabriel, 2007; Green et al., 2014). For isokinetic, although not the focus of their studies, Ritti-Dias et al. (2010) conducted 3 sets consisting of 3 maximum knee extension contraction and showed difference only between the first and second sessions which suggests 2 sessions (6 trials) are needed for familiarization. However, Sole et al. (2007) did not find any difference when comparing between the first two maximum sessions (plantar flexion), which means 1 session is sufficient. It is worth noting that in both studies, submaximal and maximal contractions were carried out as familiarization prior to the actual test re-test, hence may have also influenced their findings.

Few studies have suggested that neural adaptations involved during early stages of resistance training could also contribute to familiarization (Benton et al., 2009; Calder & Gabriel, 2007; do Nascimento et al. et al., 2013; Ritti-Dias et al., 2005; Ritti-Dias et al., 2011). These include increases in recruitment, firing rates and synchronicity of the motor units in the agonist muscle (Kamen & Knight, 2004; Knight & Kamen, 2001; Semmler, 2002), and reduction in antagonist muscles activation (Carolan & Cafarelli, 1992). Another phenomenon that could also be involved is cross-limb transfer, whereby the gain in strength is generally observed in the opposite untrained limb after longer-term interventions (Carroll, Herbert, & Munn J Lee, M Gandevia SC., 2006; Scripture, Smith, & Brown, 1894; Zhou, 2000). Furthermore, this transfer could also be applied in an acute setting, where a contralateral drop in force due to cross-over fatigue has been reported (Halperin, Copithorne, & Behm, 2014), however, a positive cross-over effect is also probable. In the context of limb dominance, studies have shown that the transfer of strength is comparatively more pronounced from dominant to non-dominant limb (Farthing, 2009; Farthing, Chilibeck, & Binsted, 2005; Manca, Pisanu, Ortu, et al., 2015).

Since isokinetic knee strength is most commonly assessed, this study aimed to identify the number of sets required for familiarization for maximum isokinetic knee extension and flexion at 60°/s for both dominant and non-dominant limbs. It is hypothesized that 2–3 sets (10–15 contractions) are required for familiarization since few studies have indicated that “low” sets or trials are needed. This information is important, due to the lack of i) available data on the contribution of maximum isokinetic contractions during familiarization and ii) standardized isokinetic familiarization protocol prior to strength testing. In addition, this study also aimed to provide information on the presence of cross-limb transfer during familiarization, which is a novelty in this research to future cross-limb transfer studies.

2. Methods

2.1. Experimental design

This study design allows the dissociation of limb dominance (dominant and non-dominant) and contractions (knee extension and flexion) during familiarization. In addition, the interactions between the two limbs provide information on the presence of cross-limb transfer. All participants performed a total of twelve sets; six sets in each limb (each set consisted of 5 maximal contractions of knee extension and flexion in a continuous manner at 60°/s). This speed was chosen to capture the strength-speed component during isokinetic contraction as well as safety reason (Biodex System 3 Pro, Biodex Medical Systems, Inc., Shirley, New York, USA). A three-minute rest was given between each set (including while changing between each limb). Group A started the first set with the non-dominant (left) limb, then switched to the dominant limb for the next five sets, and then backed to the non-dominant limb for another five sets and ended with one set in the dominant limb, as shown in Fig. 1. As for group B, each subject performed the test in the opposite manner; where they started the first set with the dominant (right) limb.

2.2. Participants

Twenty-eight (n = 28) young healthy sedentary males who reported that they had no resistance training experience for more than six months, no experience using an isokinetic device, right footed, and free from lower limb injury at pre-screening were recruited. The subjects were randomly selected and divided into two experimental groups; A (age: 22.07 ± 2.46 years; height: 1.72 ± 0.05 m; weight: 68.65 ± 8.64 kg; body mass index (BMI): 23.28 ± 2.24 kg/m²) and B (age: 23.21 ± 2.67 years; height: 1.70 ± 0.07 m; weight: 71.12 ± 12.58 kg; body mass index (BMI): 24.37 ± 3.35 kg/m²). Each subject underwent an isokinetic familiarization for maximum isokinetic knee extension and flexion (quadriceps and hamstrings respectively). The study was approved by the University of Malaya research ethics committee (UM.TNC2/RCH/UMREC) and conducted according to the Declaration of Helsinki.

2.3. Procedures

Subjects were initially screened for homogeneity based on anthropometric measures such as height, weight, and body mass index (BMI). Their footedness (preferred and non-preferred limb) were determined using the lateral preferred inventory (Coren, 1993). A score of 4/4 is considered as right limb dominance. The selected subjects then signed the informed consent.

On test day, all subject were provided with the same pre-experimental instructions; checked for daily nutritional requirement and sleeping pattern. Prior to the test, a general cardiovascular warm-up was carried out for five minutes on a cycle ergometer (55–60 rpm and 50 W load). This was followed by dynamic exercises to prepare the prime movers of the muscles involved (Daneshjoo, Rahnama, Mokhtar, & Yusof, 2013). After completing the warm-up, subjects were introduced to the Biodex System 3 Pro
and the movements for knee extension and flexion were demonstrated. Instructions to “push” and “pull” as hard and as fast as possible were given before the trials. The Biodex System 3 Pro has a high intraclass correlation coefficient (ICC ≥ 0.99; Drouin, Valovich-mcLeod, Shultz, Gansneder, & Perrin, 2004). During familiarization, verbal encouragement and visual feedback were given to all subjects to ensure maximal effort was exerted. No prior submaximal contractions were carried out since this may confound the number of sets required for familiarization and to attribute any changes solely to the maximum contractions. The experiment was conducted at approximately 1000 (AM), over a period of 6 months form July–December 2016.

2.4. Isokinetic familiarization

All subjects underwent the maximum concentric isokinetic knee extension and flexion at 60°/s (angular velocity). Before each session, the dynamometer was gravitationally corrected in accordance with the manufacturer's recommendations. The range of movement was from 0° (anatomic 0) to 90° of knee flexion. Each subject was seated on the Biodex chair in an optimal position based on the manufacturer's guidelines, and strapped across the chest, pelvic and thigh to limit excessive movement (Daneshjoo et al., 2013). A knee attachment and the cuff of the dynamometer's lever arm were attached proximal to the medial malleoli of the ankle. The dynamometer and chair orientations were fixed at 90°, while the chair-back tilted at 75–85°. All seating positions and the fixtures of the subjects were consistent throughout the experiment. Five contractions were performed in each set during the isokinetic familiarization at 60°/s (Brown & Whitehurst, 2003; Gonzalez-Rave et al., 2014). To minimize measurement errors, all procedures were carried out by the same tester. Peak torque data were recorded and average peak torque (PTa) defined as the mean of the peak torque values achieved during each of the five maximal contractions was used as denominator for force in each set. The values were retrieved from the isokinetic device for the period of knee extension and flexion at 60°/s.

2.5. Statistical analysis

Average peak torque data were analyzed and presented using the SPSS version 23 software since there were no comparable difference with peak torque observed. Normality was checked by Shapiro-Wilk test and the data met all the assumptions for linear statistics. Data are presented as mean ± SD. Furthermore, the Levene's test was used to assess the homogeneity of variance between groups. To determine the number of sets required to familiarize for the dominant limb in group A, R2-R6 (5 sets) were considered for analysis and named FD, likewise, for the non-dominant limb in group B, L2-L6 (5 sets) were considered (FND). To determine the evidence of cross-limb transfer on familiarization to non-dominant limb in A, L1, L7-L11 (6 sets) were utilized and named FNDcross. Similarly, cross-limb transfer to dominant limb in B, R1, R7-R11 (6 sets) were used (FDcross).

One-way repeated measure analysis of variance (one-way ANOVA) was applied separately. Significance level was set at
To determine the number of sets required for familiarization, the immediate set that was not significantly different from subsequent sets was identified as the number required (do Nascimento et al., 2013; Ritti-Dias et al., 2005). In addition, an independent t-test between the first two contractions (R1 vs L2; L1 vs R2) was applied to determine if there was an order effect that could have contributed to the results.

3. Results

To recap, in determining the number of sets required to familiarize for the dominant limb in A; R2-R6 (5 sets) were utilized for analysis (FD), likewise, for the non-dominant limb in B; L2-L6 (5 sets) were used (FND). To examine the effect of cross-limb transfer on familiarization in A; L1, L7-L11 (6 sets) were utilized for analysis (FNDcross). Similarly, in B; R1, R7-R11 (6 sets) were used (FDCross). Importantly, there was no difference in strength at baseline (between L1 and R2 or R1 and L2).

Fig. 2 illustrates the PTa in each set while Table 1 provides the actual value of PTa and coefficient of variance (CV) in each set. For knee extension in FD, significance differences were found between R2 vs R4 ($P = .0019$), R5 ($P = .0027$) and vs R6 ($P = .0032$), and between R3 vs R6 ($P = .0341$). ICC for this group was 0.91. While in FND, significance differences were observed between L2 vs L3 ($P = .0007$), L4 ($P = .0002$), L5 ($P = .0001$) and vs L6 ($P = .0001$) and between L3 vs L5 ($P = .013$) and vs L6 ($P = .0018$). In addition, ICC for this group was 0.92. Hence, the number of sets required to familiarize for both FD and FND knee extension (quadriceps) were 3 (15 contractions). For knee flexion, FD showed significance differences between R2 vs R5 ($P = .0091$), and vs R6 ($P = .0048$). ICC for this group was 0.96. While in FND, significance differences between L2 vs L3 ($P = .0016$), L4 ($P = .0094$), L5 ($P = .0023$), and vs L6 ($P = .0118$). In addition, ICC for this group was 0.91. Hence, the number of sets required to familiarize for both FD and FND knee flexion (hamstrings) were 2 (10 contractions).

Following 5 consecutive sets of knee extension (R2-R6), the non-dominant limb (FNDcross) showed significant difference between
Table 1

Average peak torque (P_{\text{ta}}) and Coefficient of Variance (CV) measurements of knee extension and flexion (mean ± SD; n = 14) on familiarize for the dominant limb (FD), non-dominant limb (FND), cross-limb transfer to dominant limb (FDcross) and cross-limb transfer to non-dominant limb (FNDcross). * signifies difference from first set of each limb, while † from the second set of each limb, and ‡ signifies from third set of each limb, and ‡‡ signifies from fourth set of each limb (P < .05).

<table>
<thead>
<tr>
<th>Group (Condition)</th>
<th>Sets</th>
<th>Extension</th>
<th>%CV</th>
<th>Flexion</th>
<th>% CV</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (FN)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>R2</td>
<td>174.99 ± 53.60</td>
<td>11.22 ± 3.26</td>
<td>95.49 ± 35.84</td>
<td>6.11 ± 3.99</td>
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<tr>
<td>R3</td>
<td>182.21 ± 53.99</td>
<td>9.98 ± 5.39</td>
<td>100.35 ± 32.18</td>
<td>5.85 ± 2.40</td>
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<tr>
<td>R4</td>
<td>193.60 ± 47.46*</td>
<td>7.55 ± 3.17</td>
<td>103.86 ± 30.04</td>
<td>6.47 ± 3.49</td>
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<tr>
<td>R5</td>
<td>195.52 ± 51.56*</td>
<td>7.96 ± 5.37</td>
<td>104.40 ± 32.77*</td>
<td>6.04 ± 3.61</td>
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<tr>
<td>R6</td>
<td>203.09 ± 46.83†</td>
<td>7.26 ± 4.95</td>
<td>104.73 ± 32.33†</td>
<td>5.44 ± 3.81</td>
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<tr>
<td>R12</td>
<td>208.17 ± 49.77*</td>
<td>7.98 ± 5.08</td>
<td>100.45 ± 34.32</td>
<td>6.78 ± 3.45</td>
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<tr>
<td>B (FND)</td>
<td></td>
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</tr>
<tr>
<td>L2</td>
<td>156.67 ± 34.18</td>
<td>13.34 ± 6.92</td>
<td>83.17 ± 19.08</td>
<td>8.13 ± 5.01</td>
<td></td>
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<tr>
<td>L3</td>
<td>178.53 ± 37.42*</td>
<td>10.38 ± 3.99</td>
<td>93.46 ± 19.58*</td>
<td>5.98 ± 4.38</td>
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</tr>
<tr>
<td>L4</td>
<td>186.40 ± 37.56*</td>
<td>10.41 ± 4.83</td>
<td>95.22 ± 20.99*</td>
<td>5.92 ± 2.18</td>
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</tr>
<tr>
<td>L12</td>
<td>192.07 ± 34.81†</td>
<td>7.65 ± 3.79</td>
<td>96.36 ± 19.30†</td>
<td>5.55 ± 2.53</td>
<td></td>
</tr>
<tr>
<td>L6</td>
<td>196.37 ± 34.10†</td>
<td>8.14 ± 4.36</td>
<td>94.47 ± 19.51†</td>
<td>7.18 ± 3.06</td>
<td></td>
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<tr>
<td>B (FDcross)</td>
<td></td>
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</tr>
<tr>
<td>R1</td>
<td>199.67 ± 34.78*</td>
<td>6.75 ± 3.89</td>
<td>88.56 ± 17.52*d</td>
<td>7.93 ± 3.70</td>
<td></td>
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<tr>
<td>R7</td>
<td>186.51 ± 37.42*</td>
<td>14.93 ± 6.42</td>
<td>75.63 ± 14.34</td>
<td>7.53 ± 4.55</td>
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<tr>
<td>R8</td>
<td>196.86 ± 37.56*</td>
<td>7.84 ± 4.17</td>
<td>90.78 ± 18.62</td>
<td>7.08 ± 3.12</td>
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<tr>
<td>R9</td>
<td>199.94 ± 34.81*</td>
<td>7.95 ± 4.11</td>
<td>95.75 ± 18.20*</td>
<td>6.21 ± 2.13</td>
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<tr>
<td>R11</td>
<td>205.88 ± 34.78*</td>
<td>7.05 ± 4.36</td>
<td>93.22 ± 20.55*</td>
<td>6.61 ± 2.35</td>
<td></td>
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<tr>
<td>A (FNDcross)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>156.86 ± 50.71</td>
<td>13.78 ± 10.48</td>
<td>78.36 ± 33.02</td>
<td>10.55 ± 6.89</td>
<td></td>
</tr>
<tr>
<td>L7</td>
<td>184.37 ± 45.40*</td>
<td>7.78 ± 3.18</td>
<td>95.92 ± 28.01*</td>
<td>5.68 ± 1.99</td>
<td></td>
</tr>
<tr>
<td>L8</td>
<td>188.66 ± 44.85*</td>
<td>7.00 ± 3.57</td>
<td>98.17 ± 25.81*</td>
<td>6.24 ± 2.86</td>
<td></td>
</tr>
<tr>
<td>L9</td>
<td>190.20 ± 42.71*</td>
<td>6.84 ± 2.68</td>
<td>99.05 ± 26.24*</td>
<td>6.17 ± 3.33</td>
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<tr>
<td>L10</td>
<td>187.64 ± 43.28*</td>
<td>8.54 ± 2.87</td>
<td>96.62 ± 24.29</td>
<td>7.03 ± 3.76</td>
<td></td>
</tr>
<tr>
<td>L11</td>
<td>195.80 ± 42.00*</td>
<td>8.26 ± 3.30</td>
<td>100.93 ± 24.75*</td>
<td>7.30 ± 4.63</td>
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</table>

L1 vs L7 (P = .0011), L8 (P = .0024), L9 (P = .0119), L10 (P = .0449) and vs L11 (P = .0061) with an ICC of 0.90 for this group, hence only 2 sets (10 contractions) were sufficient for familiarization. However, following 5 consecutive sets of knee extension (L2-L6) in FDbcross, the dominant limb showed significance difference between R1 vs R7 (P = .0268), R8 (P = .0234), R9 (P = .005), R10 (P = .0056) and vs R11 (P = .0047), and between R7 and R11 (P = .0113) with an ICC of 0.81 for this group, hence, 3 sets (15 contractions) were still required for familiarization. While for knee flexion, following 5 consecutive sets (R2-R6 or L2-L6), 2 sets were still required for familiarization since significant differences were only found between R1 vs R7 (P = .0267), R8 (P = .0253), R9 (P = .0302), and R10 (P = .0491), and between L1 vs L7 (P = .0051), L8 (P = .0131), L9 (P = .0105), and L11 (P = .0079) in both FDbcross and FNDcross respectively. ICC was 0.78 and 0.90 for these groups respectively.

Baseline strength for the first two contractions (R1 vs L2; L1 vs R2) showed no significant difference (between dominant and non-dominant limb).

4. Discussion

The main finding of this study showed that the optimal number of sets required for familiarization of isokinetic knee extension and flexion were 3 (15 contractions) and 2 (10 contractions) for FD and FND respectively. Interestingly, for the non-dominant limb (FNDcross) knee extension, only 2 sets (10 contractions) were required to familiarize following contralateral limb maximum contractions. This positive effect is however, only observed from the dominant to non-dominant limb. Since lesser sets are required following contralateral contractions, it is deduced that this reduction may be due to cross-limb transfer.

The main findings of this study corroborate with published literature which show that few number of sessions/sets are required for familiarization, where 2–3 sessions/sets had been reported for both isotonic and isometric contractions. For isotonic contraction, 2 sessions are needed for leg extension (do Nascimento et al., 2013), and 2–3 sessions for squat (Ritti-Dias et al., 2005; Ritti-Dias et al., 2011; Soares-Caldeira et al., 2009), while for isometric contraction, 2 sets (10 contractions) are required for dorsiflexion (Green et al., 2014). Though the ranges observed for these modes are similar, direct comparisons between them is not possible due to the different nature of contraction, resting period administered and muscle group tested. Typically, a 1-RM (isotonic) test requires a multiple-day session (48–72 h) for familiarization. Meanwhile, for isometric contraction, a single day session with 10–15 contractions and 2–3 min rest interval is sufficient (Calder & Gabriel, 2007; Green et al., 2014). Notably, the present study also shows that familiarization for isokinetic contraction can be achieved in a single-day.

4.1. Number of contractions required for isokinetic familiarization

This is the first study that familiarizes two opposing maximum contractions (extension and flexion) in one sitting, where both contractions were reciprocally acting as agonist and antagonist in continuous fashion. It seems that the larger (quadriceps) muscle
group compared to smaller (hamstrings) requires more sets for familiarization. This may not be a surprise due to the morphological differences between them; the quadriceps has greater proportion of fast twitch fiber compared to hamstrings (Johnson, Polgar, Weightman, & Appleton, 1973). Therefore, a longer time is required to achieve maximum force generation. It is also worth noting that the hamstrings have a higher activation ratio during its antagonist phase compared to quadriceps (Croce, Miller, Confessore, & Vallas, 1998), which suggests that hamstrings reach their maximum force generation relatively sooner, thus contributing to an earlier familiarization. The differences between the number of sets required for familiarization in different muscle groups are also supported by Ritti-Dias et al. (2005) where a larger muscle group (chest press) is seen to require more sessions to familiarize compared to a smaller group (arm curl). These suggest that the rate of adaptations is dependent on muscle size.

In this study, it is shown that both dominant and non-dominant limbs (FD and FND) required a similar number of sets (3) for familiarization (unilateral assessment). Therefore, it can be deduced that the dominance control system of the lower limb (factors affecting footedness) does not play a role during familiarization and therefore similar underlying mechanisms are likely involved for familiarization in both limbs. The rapid changes in strength are possibly due to increases in neural drive originating from adaptation within the central nervous system to changes occurring in the motor units. It is proposed that the mechanisms involved in neural adaptation to strength gains play a role in familiarization. The mechanisms include increases in motor unit recruitment, firing rates and synchronicity of the agonist muscle and inhibition of the antagonist muscles (Kamen & Knight, 2004; Knight & Kamen, 2001; Semmler, 2002). At central level, changes in excitability have been identified at multiple sites including cortical and spinal levels (Carroll, Riek, & Carson, 2002; Carroll, Selvanayagam, Riek, & Semmler, 2011; Kidgell, Bonanno, Frazer, Howatson, & Pearce, 2017; Nuzzo, Barry, Gandevia, & Taylor, 2016). Involvement of inhibitory interneurons and the strengthening of neural network have also been implicated (Mason, Frazer, Pearce, et al., 2019; Selvanayagam, Riek, & Carroll, 2011; Selvanayagam, Riek, De Ruygu, & Carroll, 2016; Weier, Pearce, & Kidgell, 2012). Future familiarization studies should assess these adaptations using neurophysiological techniques, i.e. fine-wire electromyography, nerve and magnetic stimulation.

4.2. Evidence of cross-limb transfer during familiarization

A meta-analysis by Munn, Herbert, and Gandevia (2004) shows that approximately 8% of strength gain in the untrained limb is attributable to the transfer from short term contralateral training. Few researchers have reported relatively higher strength gain (17.9 to 39.2%) and the transfer occurs from dominant to non-dominant limbs (Farthing et al., 2005; Manca et al., 2015). In addition, a study by Hendy and Kidgell (2014) has also demonstrated that muscle strength can be improved following a single session of strength training when performed with anodal-tDCS. In this study, it was observed that the number of sets required for familiarization of the quadriceps was two (10 contractions) in the non-dominant limb following five sets of contractions in the dominant limb (FNDcross), compared to three sets during unilateral contractions in ND. Evidently, there was no change in the number of sets required to familiarize in the dominant limb following contralateral contractions of the non-dominant limb (FDcross) (Fig. 2. C and D). This indicates the positive effect of cross-limb transfer exclusively from dominant to non-dominant limb. The findings reveal that the phenomenon which is generally seen after a few weeks of strength training (Farthing, 2009; Manca et al., 2015) can also be observed in single day session. Since the magnitude of force transfer in the untrained limb is normally expressed relative to the increase observed in the trained limb (Rudy, Rudolf, Kalkman, et al., 2016), the findings of this study are of no surprise as indicated by the large increase in force during familiarization. Furthermore, cross-limb transfer has also been observed in a single day session in studies related to intermanual and interlateral skill transfer (Lee, Hinder, Gandevia, & Carroll, 2010). In this context, in a single day familiarization, the changes observed between sets in the trained limb is large similar to studies where training leads to an increase in force generated, where cross-limb transfer is observed (Ruddy et al., 2016). Hence, the evidence of cross-limb transfer reported in this study is consistent with a typical cross-limb phenomenon following an intervention regime.

Adaptations of cross-limb transfer is known to occur at multiple sites of the central nervous system (Carroll et al., 2006; Frazer et al., 2018; Lee et al., 2010; Ruddy & Carson, 2013). Two hypotheses on how the transfer of strength could occur are cross-activation and bilateral access (Lee & Carroll, 2007). The cross-activation hypothesis suggests that adaptation occurs directly at neural circuits that control the untrained homologous muscle group following unilateral training. While, bilateral access suggests that adaptation occurs at supraspinal areas that are involved in the control of movements of the trained limb, where the modifications of neural circuits may be accessed by the untrained limb. Evidently, in this study, cross-limb transfer was also observed during familiarization which suggests these distinct adaptations of the central nervous system could be involved. This information could be of importance to maximise the potential cross-limb contribution for an accurate bilateral strength assessments. Meanwhile, the effect of cross-limb transfer was not observed in the hamstrings, since only one set is required for familiarization. However, there was a trend of increase in force following contralateral maximum contractions.

There are few limitations of this study worth mentioning. While we are aware that most cross-limb studies have a control group to compare the intervention effect, this study allows familiarization to be assessed whilst accounting for contribution from the contralateral contractions. Secondly, the study design only allows for a single speed selection since familiarization may be confounded by multiple-speed. In this study 60°/s was selected to measure the strength-speed component, where low speed is suitable for sedentary population, thus, findings are limited to this selection and may require more or less sets for familiarization for other speed selection. Finally, the resting time between sets could also influence the changes observed in addition to the proposed cross-limb transfer (i.e. 18 min from the start to the subsequent set following contralateral contractions). Another point to note is the limb that was initially used to analyze familiarization, whether the order may have contributed to our results. However, an independent t-test between the first two contractions (R1 vs L1; L1 vs R2) showed no significant difference (between dominant and non-dominant), hence, the order effect is considered unlikely. If this was to occur, the limb that assesses cross-limb transfer (L1 or R1) should require more sessions to
familiarize as compared to the opposing limb (R2 or L2). However, to the advantage of this study, the reduced number of sets that are found may have been contributed by cross-limb transfer. Future studies should investigate cross limb transfer using typical, between subject designs as suggested by Carroll et al. (2006) or through continuous contractions on a single limb before switching to the contralateral limb.

This study adds information on the contribution of a maximum isokinetic contraction to the increase in force generating capacity of subsequent trials. Another important observation is the contralateral contribution from the dominant to non-dominant limb. This information could be useful to better design a familiarization protocol and strength testing. While for researchers, the findings of this study have important implications on studies related to cross-limb transfer and limb dominance, whereby the positive effect of cross transfer that happens during familiarization is usually not considered.

5. Conclusions

In summary, this study indicates that the number of sets required for familiarization of isokinetic knee extension and flexion at 60°/s were 3 and 2 (15 and 10 contractions), respectively in sedentary male population. The presence of cross-limb transfer during familiarization was observed from dominant to non-dominant limb which confirms the role of the central nervous system during familiarization. Practically, an optimal number of sets required for familiarization will allow for an efficient (accurate and reliable) strength assessment when using an isokinetic machine for sedentary and athletes alike, as excessive contractions could cause fatigue. In addition, it is recommended that familiarization should start with the dominant limb for bilateral strength assessments.

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