Title

Factors influencing bilateral deficit and inter-limb asymmetry of maximal and explosive strength: motor task, outcome measure and muscle group

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Key words

Maximal voluntary strength; rate of torque development; knee; dynamometry; athletes.

Abbreviations

MVC	Maximal voluntary contraction
RTD	Rate of torque development

Abstract

Purpose The purpose of the present study was to investigate the influence of strength outcome (maximal voluntary contraction (MVC) torque vs. rate of torque development (RTD)), motor task (unilateral vs. bilateral) and muscle group (knee extensors vs. flexors) on the magnitude of bilateral deficits and inter-limb asymmetries in a large heterogeneous group of athletes.

Methods 259 professional/semi-professional athletes from different sports (86 women aged 21 ± 6 years and 173 men aged 20 ± 5 years) performed unilateral and bilateral "fast and hard" isometric maximal voluntary contractions of the knee extensors and flexors on a double-sensor dynamometer. Inter-limb asymmetries and bilateral deficits were compared across strength outcomes (MVC torque and multiple RTD measures), motor tasks and muscle groups.

Results Most RTD outcomes showed greater bilateral deficits than MVC torque for knee extensors, but not for knee flexors. Most RTD outcomes, not MVC torque, showed higher bilateral deficits for knee extensors compared to knee flexors. For both muscle groups, all RTD measures resulted in higher inter-limb asymmetries than MVC torque, and most RTD measures resulted in greater inter-limb asymmetries during unilateral compared to bilateral motor tasks.

Conclusions The results of the present study highlight the importance of outcome measure, motor task and muscle group when assessing bilateral deficits and inter-limb asymmetries of maximal and explosive strength. Compared to MVC torque and bilateral tasks, RTD measures and unilateral tasks could be considered more sensitive for the assessment of bilateral deficits and inter-limb asymmetries in healthy professional/semi-professional athletes.

Introduction

The assessment of thigh muscle strength with objective and valid procedures is extremely valuable to practitioners, researchers and clinicians working in different areas. This is usually conducted under static open-kinetic chain conditions by means of an adjustable chair equipped with a force/torque sensor (Edwards et al. 1977; Jaric 2002; Sarabon et al. 2013). Typically, subjects are asked to maximally contract their knee extensor/flexor muscles unilaterally, either by building up force progressively or rapidly, while the force/torque-time curves are recorded for subsequent analysis. The most commonly evaluated variables are the maximal voluntary contraction (MVC) torque, and the rate of torque development (RTD), calculated as the Δtorque/Δtime ratio at different time intervals or as the maximal slope of the torque-time curve. Of note is that RTD has received increasing interest in recent years as an indicator of explosive strength, mainly because it is believed to be more functionally relevant than pure maximal strength (Maffiuletti et al. 2016).

Unilateral deficits in muscle strength are often evaluated in clinical and sport settings, either as between-subject (patients vs. controls) or within-subject comparisons (inter-limb asymmetries). A growing body of literature shows a high prevalence of inter-limb strength asymmetries across a range of strength-related variables in many athletic populations (Bishop et al. 2018b). Recent systematic reviews have suggested that different inter-limb asymmetries measured across a range of tasks may be associated with detrimental effects on sport performance; however, the findings are not entirely consistent (Bishop et al. 2018b; Maloney 2019). For strength-related variables, the 10% threshold is commonly used to represent clinically-meaningful asymmetries (Bell et al. 2014; Hoffmann et al. 2007). However, asymmetries as low as 5% have also been linked with poorer performance (Bishop et al. 2019b). Thus, given the conflicting evidence to date regarding the extent and consequences of asymmetries for sport-related performance, a more mechanistic approach seems warranted to explore some of the factors potentially under-pinning these controversial results.

In addition to the unilateral assessment of asymmetries, the inclusion of bilateral tests enables another ratio to be computed, known as the bilateral deficit. This phenomenon, which is characterized by lower force production during simultaneous maximal contraction of both limbs compared to the sum of the forces produced by each limb separately (Skarabot et al. 2016), is another important aspect to consider during strength testing. The relationship between bilateral deficit and athletic performance is however still poorly understood. Bračič et al. (2010) have linked higher bilateral deficits with poorer sprint starting performance. In contrast, Bishop et al. (Bishop et al. 2019a) showed that a larger bilateral deficit during jumping was associated with faster times during a change of direction speed task. Thus, this ratio, like asymmetry, appears to show conflicting evidence to date from the limited empirical investigations that are available. Furthermore, the bilateral deficit appears to be influenced by several factors, such as population (Howard and Enoka 1991), task (Magnus and Farthing 2008), joint angle (Kuruganti et al. 2011) and contraction velocity (Vandervoort et al. 1984). Thus, further research in this regard also seems warranted.

Given that assessment of inter-limb asymmetries and bilateral deficits has potential implications for athletic but also patient populations, it is important to understand the influence of different factors associated to the testing procedure on strength-related variables. While the differences between the effects of unilateral and bilateral resistance training approaches have already been investigated (Botton et al. 2016; Gonzalo-Skok et al. 2017; Ramirez-Campillo et al. 2018), research regarding the differences between unilateral and bilateral strength measurements is currently scarce. Similarly, it has recently been indicated that RTD measures could be more sensitive for detection of inter-limb asymmetries than MVC torque (Boccia et al. 2018), but this assumption was not tested across both unilateral and bilateral tasks. Finally, a bilateral deficit for knee extensors was reported for RTD at the 50-100 ms time interval, but not for other time intervals (Buckthorpe et al. 2013). In line with the outlined knowledge gaps, the aim of this study was to investigate the effect of strength outcome (MVC torque vs. various RTD), motor task (unilateral vs. bilateral) and muscle group (knee extensors vs. knee flexors) on the bilateral deficit and inter-limb asymmetry obtained with a double-sensor isometric dynamometer in a large heterogeneous group of professional/semi-professional athletes from different sports.

Methods

Participants

A convenience sample of 259 professional/semi-professional athletes of different age, sex and sport volunteered to participate in the study (Table 1). Invitation to the study was done through the Slovenian National Olympic Committee and the Ljubljana Ballet Ensemble and Academy. The main exclusion criteria were low back pain, general illness or injury to the lower extremities in the past 6 months as well as neurological disorders. Participants (and their parents/guardians in case they were underage of 18) were informed about testing procedures and provided written informed consent prior to participation. The study protocol and testing procedures were carried out in accordance with the Declaration of Helsinki and were approved by the Slovenian Medical Ethics Committee (approval no. 0120-99/2018/5).

Study protocol

All measurements were performed during a single testing session lasting ~40 min. Participants were asked to refrain from physical activities at least 24 hours prior to testing. After a general warm-up (10 min of low intensity running, 8 repetitions of dynamic stretching exercises for the main muscle groups, 10 repetitions of squats, push-ups and crunches), participants were positioned on an isometric chair/knee dynamometer (S2P science to practice Ltd., Ljubljana, Slovenia), with both hips at 90° and the tested knee(s) at 60° (Fig. 1). The protocol consisted of six conditions: 1) bilateral knee extension, 2) bilateral knee flexion, 3) unilateral knee extension-left, 4) unilateral knee extension-right, (5) unilateral knee flexion-left and (6) unilateral knee flexion-left, whose order was fully randomized on an individual basis. For each condition, participants completed a specific warm-up/accommodation protocol consisting of 3 submaximal trials at 50, 75 and 90% of their estimated MVC torque, followed by 3 maximal trials. They were carefully instructed to contract their knee extensor/flexor muscles "as fast and hard as possible" (Maffiuletti et al. 2016) for ~3 s and to passively rest for 30 s between each contraction. The different conditions were separated by rest periods of ~3 min. Loud verbal encouragement was consistently provided by the assessor and real-time visual feedback of the torque-time curve (sum of left and right for bilateral tasks) was also provided via the computer screen.

Measurement procedures

Participants were held into the testing position by a tight belt across the pelvis, and additional belts just above the knee(s). They were asked to hold the hand grips along the seat, whose position was individually adjusted. The distal shin pad of the dynamometer lever arm was attached with a strap 3-5 cm proximal to the medial malleolus, based on individual lower leg length. The mechanical axis of the dynamometer was aligned with the participant's knee axis of rotation utilizing the medial femoral epicondyle as a reference. The dynamometer is both solid and rigid, thus ensuring minimal deformability during high-force isometric contractions and accurate and reliable assessment of MVC torque and RTD (Maffiuletti et al. 2016; Sarabon et al. 2013). Knee joint torque was measured using two embedded strain gauge-based force sensors (model Z6FC3-200 kg, Hottinger-Baldwin Messtechnik GmbH, Darmstadt, Germany), one per side. Installation of the force sensors into the frame of the dynamometer was done in a way that they operated as torque sensors on a fixed force-sensor lever arm. Signals were amplified and analog-to-digitally converted (INSAmp, Isotel, Logatec, Slovenia) before being acquired at 1 kHz with a custom-built software (ARS dynamometry, S2P science to practice Ltd., Ljubljana, Slovenia). The signals were off-line filtered with a 2nd order low-pass (20 Hz) Butterworth filter. For each repetition, a 1-s time interval around the maximal torque signal (while relatively constant) was automatically chosen by the software and the average torque during this interval was recorded as the MVC torque. RTD was calculated for the 0-50, 0-100 and 0-200 ms time windows as the Δtorque/Δtime value for respective intervals. The onset of the torque rise was automatically identified as the instant at which the baseline signal exceeded 3% of MVC torque. We also quantified peak RTD as the highest positive value from the first derivative of the torque signal (i.e., the greatest slope of the torque-time curve). Signals and automatic markers positioning were manually inspected for potential software errors/inaccuracies and corrected when needed (~2.5% of cases). Trials were disregarded if baseline torque changed by more than 2.5 Nm in the 200 ms prior to torque onset and if the maximal torque plateau was not sustained for at least 1.5 s.

For all the outcomes (MVC torque, RTD 0-50, RTD 0-100, RTD 0-200 and peak RTD), only the highest value among the three repetitions of each task and side was considered for calculating bilateral deficit (Howard and Enoka 1991) and inter-limb asymmetry (Bishop et al. 2018a), according to these equations:

$$\textit{Bilateral deficit (\%)} = (100 \times \frac{left\ bilateral + right\ bilateral}{left\ unilateral + right\ unilateral}) - 100$$

$$\textit{Inter-limb asymmetry (\%)} = (\frac{max(left\ or\ right) - min(left\ or\ right)}{max(left\ or\ right)}) \times 100$$

Statistical analyses

Within-session reliability of absolute strength variables was evaluated with coefficients of variation and intraclass correlation coefficients (2,k) using the three repetitions per task and side (Atkinson and Nevill 1998). Differences in absolute strength data between motor tasks (unilateral vs bilateral) were evaluated using paired *t* tests and respective effect sizes (Cohen's *d*) were calculated. Bilateral deficits and inter-limb asymmetries were evaluated respectively with a two-way [muscle group (knee extensors, knee flexors) × strength outcome (MVC torque, RTD 0-50, RTD 0-100, RTD 0-200, peak RTD)] and a three-way ANOVA [muscle group (knee extensors, knee flexors) × motor task (unilateral, bilateral) × strength outcome (MVC torque, RTD 0-50, RTD 0-100, RTD 0-200, peak RTD)] with repeated measures. Because inter-limb asymmetries were not normally distributed (as verified with a Shapiro-Wilk test), the ANOVA was conducted on log-transformed data (Box-Cox method), while the results are still presented in non-transformed units for better clarity. When a significant interaction was observed, Tukey HSD post hoc tests were used. Effects sizes were reported as partial eta squared (η^2) and Cohen's *d* for the ANOVAs and post-hoc tests, respectively. The level of significance was set at $p < 0.05$.

Results

Absolute strength outcomes by side, motor task and sex are presented in Table 2 (knee extensors) and Table 3 (knee flexors). For the different variables, within-session coefficients of variation were comprised between 2.0 and 4.7% and intraclass correlation coefficients between 0.81 and 0.99. Effect sizes ranging between 0.02 and 0.52 were observed for the differences between motor tasks (unilateral greater than bilateral), these effects being generally larger for knee extensors compared to knee flexors, and for MVC torque and RTD 0-200 compared to the other variables.

Because bilateral deficits and inter-limb asymmetries were comparable between women and men, sex was not included as an independent variable in the ANOVAs. For bilateral deficits, a significant main effect of muscle group ($p < 0.001$; $\eta^2 = 0.052$) and strength outcome was observed ($p < 0.001$; $\eta^2 = 0.095$). The interaction between muscle group and strength outcome was also statistically significant ($p < 0.001$; $\eta^2 = 0.03$) (Fig. 2). For both muscle groups, bilateral deficits of RTD 0-50 were significantly lower compared to the other outcomes (actually, knee flexors showed a mean bilateral facilitation of RTD 0-50). In addition, knee extensors bilateral deficits were significantly higher for all RTD variables compared to MVC torque ($p < 0.01$; $d = 0.27\text{-}0.59$), except for RTD 0-50 ($p = 0.568$; $d = 0.04$). For RTD 0-50, RTD 0-100 and peak RTD, bilateral deficits were significantly higher for knee extensors compared to knee flexors ($p < 0.01$; $d = 0.16\text{-}0.37$).

For inter-limb asymmetries, a significant main effect of motor task ($p < 0.001$; $\eta^2 = 0.172$) and strength outcome was observed ($p < 0.001$; $\eta^2 = 0.555$). The motor task by strength outcome interaction was also significant ($p < 0.001$; $\eta^2 = 0.042$; Fig. 3). For both muscle groups, inter-limb asymmetries of all RTD variables were significantly higher compared to MVC torque ($p < 0.001$; $d = 0.54\text{-}2.17$), the largest asymmetry being observed for RTD 0-50. In the same way, inter-limb asymmetries of all RTD outcomes were significantly higher for unilateral compared to bilateral motor tasks ($p < 0.001$; $d = 0.12\text{-}0.44$).

Discussion

The main findings of this study regarding bilateral deficit were that (1) all RTD outcomes (except RTD 0-50) resulted in greater bilateral deficits than MVC torque for knee extensors, but not for knee flexors, and (2) all RTD outcomes (except RTD 0-200), but not MVC torque, resulted in greater bilateral deficits for knee extensors than for knee flexors. The main findings of this study regarding inter-limb asymmetry were that for both muscle groups (3) all RTD outcomes resulted in greater inter-limb asymmetries than MVC torque, with the largest asymmetry observed for RTD 0-50, and (4) all RTD outcomes resulted in greater inter-limb asymmetries during unilateral compared to bilateral motor tasks, contrary to MVC torque. Thus, bilateral deficits and inter-limb asymmetries of maximal and explosive strength were substantially affected by factors such as muscle group, outcome measure and motor task in professional/semi-professional male and female athletes of different age (including adolescents) and from different sports.

Bilateral deficits for most of the RTD outcomes (excepted RTD 0-200) were larger for knee extensors than flexors, contrary to MVC torque for which bilateral deficits were almost the same for the two muscle groups (approximately -4%). Although the seated single-joint task used here is not necessarily the best way to compare knee extensors to knee flexors, mainly due to muscle-specific differences in optimal knee angle (Lord et al. 1992), bilateral deficits of isokinetic peak torque at different angular velocities have also been found to be similar for knee extension and flexion (Brown et al. 1994; Gavilao et al. 2018). Rather, we believe that the inter-muscle differences in RTD outcomes observed in this study are possibly due to muscle-specific postural strategies in the early phase of explosive contractions (i.e., when most of the movement between the limb/body and the dynamometer occurs), and more specifically due to the fact that knee extension is produced against gravity (thus resulting in upward body motion), contrary to knee flexion. Therefore, our results confirm that bilateral deficit in explosive force production is highly influenced by postural stabilization requirements (Magnus and Farthing 2008; Skarabot et al. 2016), and is highly task- and muscle group-specific, which is in line with recent suggestions on the topic (Bishop et al. 2019a).

Compared to MVC torque, RTD outcomes disclosed larger bilateral deficits for knee extensors (except for RTD 0-50) and also larger inter-limb asymmetries for both muscle groups (particularly for RTD 0-50). Thus, RTD seems to be more sensitive to discriminate differences between conditions, as already demonstrated for acute and chronic comparisons associated for example to fatigability (Morel et al. 2015), muscle damage (Penailillo et al. 2015), pathology (Maffiuletti et al. 2010), ageing (Bemben et al. 1991) but also rehabilitation (Angelozzi et al. 2012) and strength training (Tillin and Folland 2014). As far as the bilateral deficit is concerned, our RTD results corroborate the findings of Buckthorpe et al. (Buckthorpe et al. 2013). These authors observed no bilateral deficit for MVC torque of the knee extensors, but a significant bilateral deficit for RTD that was specific to the 50-100 ms time interval. Interestingly, they also observed a bilateral deficit for electrically-evoked force, but no difference for agonist and antagonist EMG activity, so it was conjectured that stabilizer muscles were insufficiently activated during bilateral explosive contractions. The somewhat inconsistent results obtained for the 0-50 ms time interval, both here and in this previous study, are probably due to the larger dispersion and lower reliability of RTD 0-50 data compared to longer intervals.

On the other hand, early-phase RTD has recently been demonstrated to be strongly associated with initial motor unit discharge rate and recruitment speed (Del Vecchio et al. 2019), thereby confirming that the effective neural drive to the muscle is a major determinant of explosive strength. Therefore, we interpret the differences in inter-limb asymmetries between MVC torque and RTD outcomes observed in our study as being explained, at least partly, by the relative contribution of different neuromuscular mechanisms. According to this hypothesis, the contribution of neural factors would decrease with increasing the time interval from 0-50 to

0-200 ms, and vice versa for muscular factors such as muscle size that is a major determinant of MVC torque (Maden-Wilkinson et al. 2019). Interestingly, the correlation coefficients between MVC torque and RTD have been found to progressively increase as the time from contraction onset increased, being moderate (r=0.5) at 50 ms and excellent (r=0.9) at 200 ms (Andersen and Aagaard 2006). Taken together, these results lead us to believe that RTD 0-200 should not be considered anymore as an indicator of explosive strength.

Compared to bilateral tasks, unilateral tasks disclosed larger inter-limb asymmetries for all RTD outcomes, the effect being larger for shorter time intervals, while no inter-task difference was observed for MVC torque asymmetries. Thus, unilateral tasks seem to be more sensitive than bilateral tasks to detect inter-limb asymmetries in explosive strength, at least in healthy athletes. It is important to note that the difference between unilateral and bilateral asymmetries reported here is even dampened by the formula we used (where the denominator is the maximum, either left or right), as in fact the “bilateral” formula (where the denominator is sum of left and right) would have resulted in lower inter-limb asymmetries for the bilateral task (Bishop et al. 2018a). It seems likely that the unilateral task represents a better measure of “true” explosive force generating capacity, because the load does not need to be shared (or compensated) across limbs, such as during bilateral tasks. Whether the decline in unilateral-bilateral differences in RTD asymmetries with increasing time interval also reflects a reduction in the relative contribution of neural factors (as discussed above) is quite likely, but not verifiable with our data. A possible interpretation is that bilateral knee extensions/flexions, as compared to the same unilateral tasks, would result in a lower neural drive to the muscle. Surprisingly, inter-limb asymmetries in MVC torque were not influenced by the motor task in our study, being on average close to 9% for both unilateral and bilateral actions. Simon and Ferris (Simon and Ferris 2008) observed a very large inter-limb asymmetry for maximal strength (>20%) in healthy subjects, but only for a bilateral task. However, their study was conducted on a leg press machine, which involves contractions of several muscles across multiple joints, and is therefore quite different from our exercise model. Of note, unilateral inter-limb asymmetries in MVC torque were basically tripled when considering RTD 0-50 in our study (reaching almost 28%), which raises questions about the functional consequences of such large asymmetries in healthy professional/semi-professional athletes as well as on the magnitude of explosive strength asymmetries in athletes/patients with a unilateral problem.

It is concluded that muscle group, outcome measure and motor task had a considerable effect on bilateral deficits and inter-limb asymmetries of maximal and explosive strength in a large heterogeneous group of professional/semi-professional athletes. Specifically, knee flexors showed larger bilateral deficits in explosive strength than knee flexors, MVC torque provided lower inter-limb asymmetries than most of the RTD outcomes, and unilateral tasks resulted in larger explosive strength asymmetries than bilateral tasks. These findings have important implications for the valid assessment of thigh muscle strength in sport, clinical and research settings, especially in relation to inter-limb asymmetries. In this respect, we recommend that the evaluation of pure maximal strength should whenever possible be combined to, or even replaced by, the assessment of RTD in healthy and injured athletes, and more particularly so with unilateral tasks and short time intervals.

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Fig. 1 Measurement set-up. Knee extension-flexion isometric dynamometer`s rigid metal frame (a), length adjustable seat (b), fixation belts over the pelvis and distal thigh (c), above-the ankle fixation to the action point, thinly padded and well fixated (d), embedded sensors detecting torque at the axis (e), connected through the amplifiers and A/D convertors to the computer (f).

Fig. 2 Bilateral deficit results by muscle group and strength outcome. Data are mean ± 95% confidence intervals. *: greater deficit for knee extensors than for knee flexors ($p < 0.01$); a: greater deficit than RTD 0-50 for knee flexors ($p < 0.05$); b: greater deficit than MVC torque and RTD 0-50 for knee extensors ($p < 0.05$); c: greater deficit than MVC torque, RTD 0-50 and RTD 0-100 for knee extensors ($p < 0.01$).

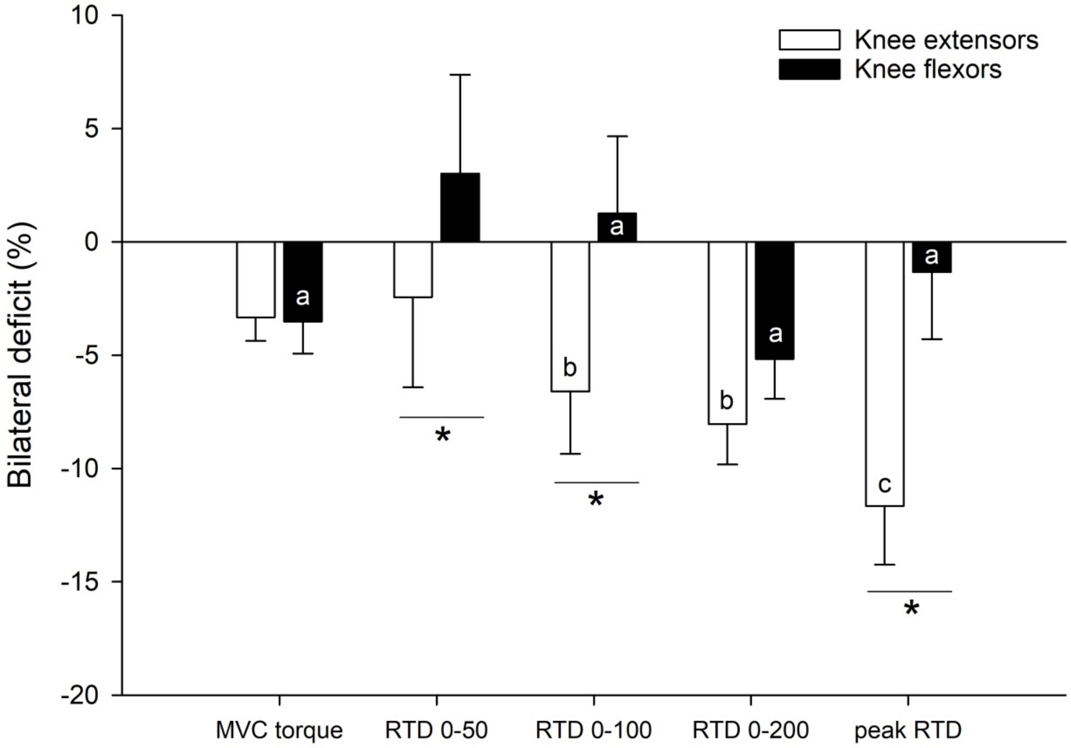

Fig. 3 Inter-limb asymmetry results by motor task and strength outcome. Data are mean ± 95% confidence intervals. *: unilateral greater than bilateral ($p < 0.001$); a: greater than all the other outcomes for the same task ($p < 0.001$); b: greater than MVC torque and RTD 0-200 for the same task ($p < 0.001$); c: greater than MVC torque for the same task ($p < 0.05$); d: greater than MVC torque, RTD 0-100 and RTD 0-200 for the same task ($p < 0.001$).

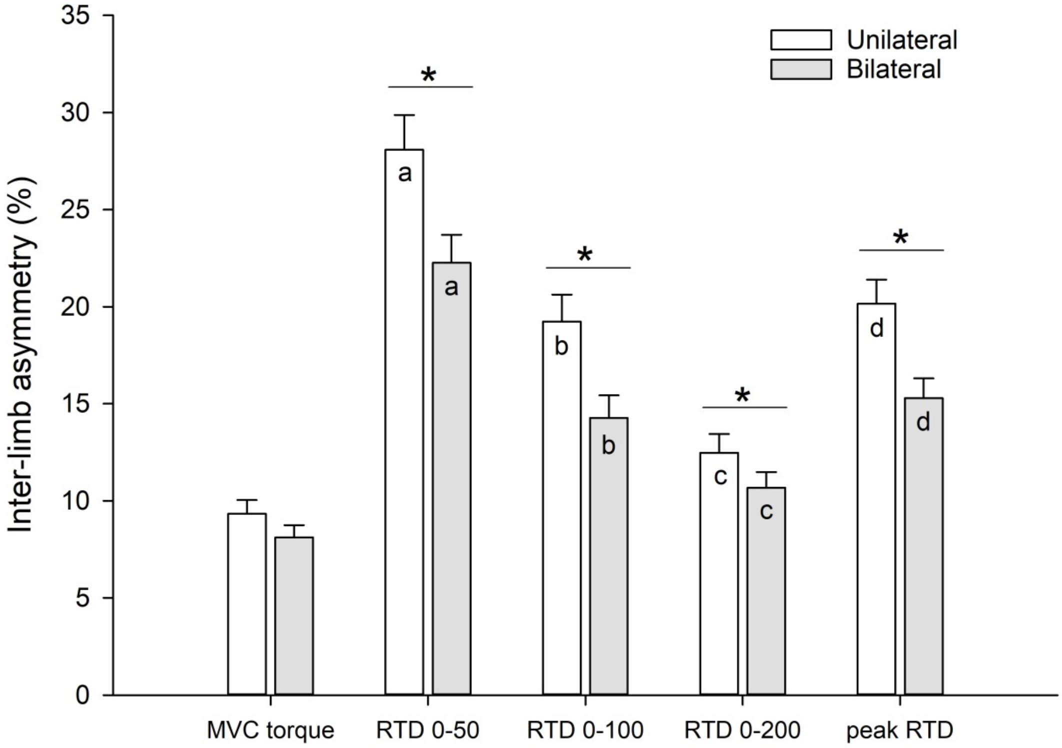

Table 1 Characteristics of the participants by sex and sport type

	Women (n = 86)		**Men (n = 173)**	
	Mean ± SD	Range	Mean ± SD	Range
Age (years)	21 ± 6	14-42	20 ± 5	13-40
Height (cm)	166 ± 5	153-180	181 ± 9	146-205
Weight (kg)	57 ± 7	38-75	73 ± 13	36-110
	n	National	n	National
Individual sports	33	64%	48	65%
Team sports	0	0%	101	0%
Dance sports	53	8%	24	0%

Individual sports include track and field (n = 31), speed skating (n = 18), karate (n = 16) and ju-jitsu (n = 16); team sports include basketball (n = 11), football (n = 49) and volleyball (n = 41); dance sports include ballet (n = 42), hip-hop (n = 21) and Latin dance (n = 14). National refers to the percentage of athletes who won a medal at the Slovenian National Championships preceding the assessments.

Table 2 Knee extensor strength results by side, motor task and sex, with the associated reliability scores and effect sizes for the difference between unilateral and bilateral tasks

	Left			Right		
	Unilateral	Bilateral	ES	Unilateral	Bilateral	ES
MVC torque (Nm)						
Women	152 ± 32	146 ± 34	0.26*	153 ± 26	145 ± 27	0.32*
Men	214 ± 59	209 ± 61		215 ± 59	209 ± 60	
CV (%)/ICC	2.01/0.99	2.21/0.99		2.26/0.98	2.19/0.98	
RTD 0-50 (Nm/ms)						
Women	648 ± 341	588 ± 270	0.05	724 ± 347	633 ± 272	0.11
Men	962 ± 491	1028 ± 637		1117 ± 610	1097 ± 659	
CV (%)/ICC	4.04/0.85	4.73/0.88		4.29/0.87	4.58/0.90	
RTD 0-100 (Nm/ms)						
Women	817 ± 283	734 ± 258	0.15*	855 ± 265	749 ± 240	0.33*
Men	1188 ± 429	1159± 504		1264 ± 450	1186 ± 483	
CV (%)/ICC	3.02/0.92	3.44/0.93		3.05/0.93	3.32/0.94	
RTD 0-200 (Nm/ms)						
Women	631 ± 167	557 ± 153	0.29*	641 ± 149	559 ± 138	0.40*
Men	881 ± 273	844 ± 299		904 ± 278	853 ± 291	
CV (%)/ICC	2.37/0.95	2.70/0.96		2.39/0.96	2.62/0.96	
Peak RTD (Nm/ms)						
Women	1454 ± 447	1261 ± 435	0.26*	1566 ± 571	1290 ± 502	0.52*
Men	2184 ± 805	2062 ± 927		2440 ± 1034	2110 ± 987	
CV (%)/ICC	2.87/0.92	3.48/0.94		3.36/0.94	3.65/0.94	

Data are mean ± SD. *: unilateral greater than bilateral ($p < 0.01$).
CV: coefficient of variation; ES: effect size; ICC: intraclass correlation coefficient.

Table 3 Knee flexor strength results by side, motor task and sex, with the associated reliability scores and effect sizes for the difference between unilateral and bilateral tasks

	Left			Right		
	Unilateral	Bilateral	ES	Unilateral	Bilateral	ES
MVC torque (Nm)						
Women	81 ± 17	78 ± 18	0.32*	83 ± 18	80 ± 18	0.34*
Men	125 ± 40	119 ± 36		129 ± 40	123 ± 36	
CV (%)/ICC	2.41/0.98	2.24/0.99		2.37/0.97	2.25/0.99	
RTD 0-50 (Nm/ms)						
Women	303 ± 169	306 ± 170	0.12	319 ± 173	315 ± 175	0.03
Men	449 ± 252	488 ± 275		502 ± 286	514 ± 269	
CV (%)/ICC	4.62/0.81	4.45/0.84		4.62/0.85	4.40/0.84	
RTD 0-100 (Nm/ms)						
Women	390 ± 136	379 ± 122	0.02	417 ± 135	388 ± 125	0.03
Men	574 ± 243	575 ± 231		607 ± 260	614 ± 222	
CV (%)/ICC	3.49/0.88	3.28/0.88		3.63/0.91	3.17/0.88	
RTD 0-200 (Nm/ms)						
Women	319 ± 75	299 ± 70	0.24*	331 ± 74	305 ± 72	0.21*
Men	465 ± 160	445 ± 146		483 ± 163	466 ± 143	
CV (%)/ICC	2.76/0.92	2.54/0.94		2.71/0.95	2.50/0.94	
Peak RTD (Nm/ms)						
Women	695 ± 226	666 ± 213	0.04	749 ± 251	693 ± 225	0.07
Men	1066 ± 411	1066 ± 422		1136 ± 483	1129 ± 432	
CV (%)/ICC	3.06/0.88	3.04/0.89		3.29/0.92	3.00/0.89	

Data are mean ± SD. *: unilateral greater than bilateral ($p < 0.01$).
CV: coefficient of variation; ES: effect size; ICC: intraclass correlation coefficient.