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Original Article

DETERMINAÇÃO DE ASSIMETRIAS CINÉTICAS EM JOGADORES DE FUTEBOL REALIZANDO SALTO VERTICAL: PROPOSTA DE UM NOVO PROCEDIMENTO PARA DETERMINAR IMPULSO USANDO PLATAFORMA DE FORÇA

DETERMINATION OF KINETIC ASYMMETRIES IN SOCCER PLAYERS PERFORMING VERTICAL JUMP: PROPOSAL OF A NOVEL PROCEDURE TO DETERMINE IMPULSE FROM FORCE PLATE DATA

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RESUMO
O primeiro objetivo do estudo foi comparar a assimetria do pico de força (F_{pico}) de membros inferiores em dois procedimentos de análise, simultâneo e sequencial, no salto com contramovimento (SCM) de futebolistas. Foram realizadas três séries de seis SCM em duas plataformas de força. Para o procedimento sequencial, os 18 SCM foram divididos em dois blocos de nove tentativas. A média dos três melhores SCM do primeiro bloco foi utilizada para determinar o valor do F_{pico} de um MI e a média dos três melhores saltos do segundo bloco para determinar o valor do F_{pico} para o outro MI, e depois essa ordem foi invertida. Já no procedimento simultâneo, a média dos valores de F_{pico} de ambos os MI foi calculada para todos os 18 SCM. O teste t não apresentou diferenças significativas entre os procedimentos na assimetria do F_{pico} e houve uma correlação positiva significativa entre eles (r = .74). Já o segundo objetivo foi verificar a confiabilidade de um novo procedimento de determinação de impulsos gerados em cada MI no SCM. As medidas dos impulsos parciais e da assimetria do impulso mensuradas nesse novo procedimento apresentram excelente confiabilidade (CCI = .765-.963). Pode-se concluir que como não houve diferença significativa entre os valores de assimetria de F_{pico} nos procedimentos utilizados, e o procedimento simultâneo também permite a análise da assimetria do impulso, esse procedimento teria aplicações interessantes nas avaliações de campo.
Palavras-chave: Assimetria. Força. Impulso.

ABSTRACT
The first purpose of this study was to compare the lower limb peak force (F_{peak}) asymmetry in two different procedures, simultaneous and sequential, measured in countermovement jump (CMJ) of soccer players. Three series of six CMJ were performed on two force platforms. For the sequential procedure, the 18 CMJ were divided into two blocks of nine attempts. The average of the best three CMJ of the first block was used to determine the F_{peak} of a lower limb and the average of three best CMJ of the second block was used to determinate the F_{peak} of the other lower limb, and then the order was inverted. In the simultaneous procedure, the mean of F_{peak} values of both lower limbs was calculated for all CMJ. The t test did not present significant differences between the procedures in F_{peak} asymmetry and there was a significant positive correlation between them (r = .74). The second purpose was to verify the reliability of a new impulse determination procedure for both lower limbs in the CMJ. The partial impulse and impulse asymmetry measurements obtained in this new procedure presented excellent reliability (CCI = .765-.963). It can be concluded that since there was no significant differences between the F_{peak} asymmetries values between the two procedures, and the simultaneous procedures also allows the analysis of impulse asymmetry, this procedure would have interesting applications in practical evaluations.
Keywords: Asymmetry. Strength. Impulse.

Introduction

Countermovement jumps (CMJ) are frequently used to assess strength and power of the lower extremities that often depends on specificity of sport to functionally and empirically assess their values[1-3]. In the literature, two-legged CMJ performed on a single or two force platforms have been used to identify strength asymmetries measured by different variables[1,3-5]. The assessment of these asymmetries is essential to reduce injury risk[2,6,7], to control the rehabilitation process after knee injury[8,9], and to determine effects of training methods[10].

Newton et al.[5] identified strength asymmetry, measured by the peak force (F_{peak}), between the lower extremities (right vs. left and dominant vs. non dominant) via CMJ where the ground reaction force (GRF) was measured simultaneously for both legs using two force platforms. Impellizzeri et al.[4] proposed a new vertical jump force test for the assessment of strength asymmetry, also measured by the F_{peak}, using only a single force platform with sequential determination of GRF for each leg and calculated test-retest reliability for different repetitions of the test. The highest intraclass correlation coefficient (ICC) of .91 was attained when five repetitions were conducted. While this result indicated good reliability, the authors did not consider possible differences between the procedure of assessment, namely, the simultaneous and sequential determination of the GRF. Therefore, one of the purposes of the present study was to compare the measures obtained for F_{peak} and F_{peak} asymmetry between the simultaneous procedure and the sequential procedure. The hypothesis for this purpose was that no significant differences will exist between sequential procedure (via the data from one force platform) and simultaneous procedure (via the data from two force platform) concerning F_{peak} and F_{peak} asymmetry.

Despite the possibility of determining the lower limb impulse via force platforms, the only variables examined in the above cited studies were vertical F_{peak}[4,5] and average force during concentric phase[5]. However, since propulsion forces and change in velocity of the human body are mechanically determined by the impulse (impulse-momentum relation) and jumping height is also determined by impulse, this variable seems to be as important as the F_{peak} for functional assessment of lower extremity strength asymmetries. A possible reason for not reporting impulse in previous analyses of strength asymmetries may be a challenge in the determination of right and left lower limbs impulses separately (partial impulses) if weight distribution between lower limbs is uneven and/or the lack of methodological information in literature on how to assess strength asymmetries in impulse production.

Although the determination of impulse of a single legged CMJ can be performed as described by Linthorne[11], integrating the force-time curve, the determination of the partial impulses created by each lower limb during a two-legged CMJ is not as simple. Seeing that individuals do not typically support exactly 50% of their body weight (BW) on each lower limb and seldom perform the movement symmetrically. This may also result in different durations of impulse phase for the right and left lower limb, generated by differences between both lower limbs concerning the start of the impulse phase and take off.

Benjanuvatra et al.[2] compared strength asymmetry of single and two-legged CMJ and also measured the partial impulses of both lower limbs for the CMJ under the condition of even body weight distribution between lower limbs. To generate a baseline for the numerical integration of the force-time characteristics constituting 50% of the BW, Benjanuvatra et al.[2] adjusted “vertical GRF of each limb to 50% of body weight because the left and right limbs are coordinated cooperatively to accelerate the center of mass upward”. The authors concluded that similarly overloading both lower limbs, this distribution would then be maintained throughout the execution of the movement. As a result, the authors present the normalized impulses of left and right lower limb (impulse divided by body mass) assuming that both limbs have the same impulse duration. However, these authors disregarded possible asymmetries in the duration of the movement and that the force production throughout the CMJ may not be symmetrical, thus, equalizing the weight distribution at the beginning of the movement, could alter issues related to movement’s pattern and the natural force production pattern of each volunteer.

The method described by Benjanuvatra et al.[2] may be convenient, if body weight distribution at the beginning of the impulse phase is adjusted to 50% of the BW supported by each lower limb and if symmetric duration of impulse phase is assumed. Further considerations may however be necessary to determine partial impulses of both lower limbs for asymmetric body weight distribution and impulse phase duration. Therefore, it could be questioned if the starting condition for CMJ (distribution of BW) should be habitual or adjusted to 50% of BW by feedback from the test instructor. Thus, the second aim of this study was to introduce a new procedure to determine the partial impulses created by each lower limb during a CMJ on two force platforms, with simultaneous measures, that permits the assessment of the habitual movement pattern without interference of the test instructor to adjust weight distribution to 50% of body weight and to determine its reliability. With the hypotheses that the new procedure to determine partial impulses in a simultaneous analysis (via the data from two force platforms) will lead to significantly reliable results of partial impulses and impulse asymmetries.

Methods

Participants

The participants in this study were 31 male elite young soccer players (age = 19.1 ± .7 years, height: 176.8 ± 5.8 cm, body mass: 73.3 ± 11.2 kg). They trained four times a week and all had at least five years of competition experience. Via self-report and an administered health questionnaire, athletes had no adverse medical history, no injuries of the lower extremities or hip joints for the past six months. The research project was approved by the Ethics Committee according to the Brazilian legislation (CAAE – 01513712.8.0000.5149), and all subjects provided written informed consent.

Procedures

Data collection was conducted during preseason training, when the players practiced four times a week with one additional preparation game. The test procedure took place during the same day for all individuals. After a 10 min warm-up, consisting of jogging with self-paced moderate velocity and three submaximal CMJs, the subjects performed three sets of six CMJ with a rest interval of 5 min between the sets and 60 s between the repetitions of each set. All jumps were performed on two side-by-side mounted force platforms (AMTI OR5-6, Watertown, MA, USA) and vertical GRF were recorded separately for each leg at a frequency of 1 KHz and low-pass filtered at 50 Hz in fourth-order, using a zero-lag Butterworth filter in data acquisition and analysis software DASYLab 10.0. (Norton, MA, USA).

To determine individual F_{peak} strength asymmetries as proposed by Impellizzeri et al.[4], the sequential procedure of F_{peak} for each lower limb was administered two ways. First, it consisted of the F_{peak} of the first nine jumps (six jumps of the first set and first three jumps of the second set) for one leg. Next, the following nine jumps (second three jumps of the second set and six jumps of the third set) for the contralateral leg were analyzed. According to Impellizzeri et al.[4] the mean of the three highest values of the peak GRF for each leg was calculated and used for the determination of F_{peak} asymmetry. This procedure allows two possibilities for the calculation of F_{peak} (according to Impellizzeri et al.[4] mean of the three highest values). The first possibility is the calculation of mean of the three highest values of the first nine jumps for the first leg and mean of the last nine jumps for the contralateral leg and the second possibility is the inverse procedure (calculation of mean of the three highest values of the last nine jumps for the first leg and mean of the first nine jumps for the contralateral leg) (Figure 1).

The result of individual F_{peak} asymmetry determined by the simultaneous procedure was the mean of the difference between right and left side of all 18 simultaneous measurements (Figure 1).

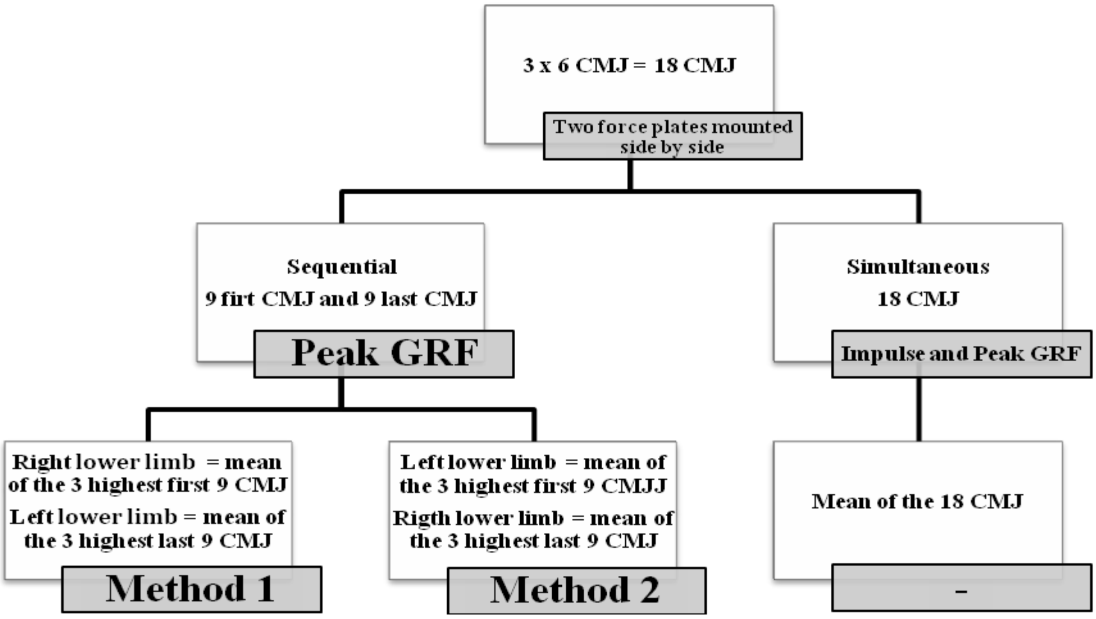

Figure 1. Experimental design scheme.
Source: The authors

To prevent any influence of upper limb movements on the vertical impulse, each athlete's hands were held at their hips, and they were asked to jump as high as possible. The individuals were instructed to remain stationary with both feet in parallel position. They initiated the jump after a verbal command of "go" that was given when the body weight line measured by both force platforms reached a plateau. No special advice concerning weight and force distribution was provided to assure the individual and habitual execution of CMJ and to avoid any influence of the test administrator.

The determination of impulse by the time characteristics of the GRF of the two legs described by Linthorne[11] is shown in equation [1] and Figure 2.

Equation 1.

$$I = \int_{t0}^{tf} F \; dt - BW\,(tf - t0) \qquad [1]$$

In which, BW = Body weight; F = Ground reaction force of both legs; t0 = Begin of impulse phase; tf = End of impulse phase.

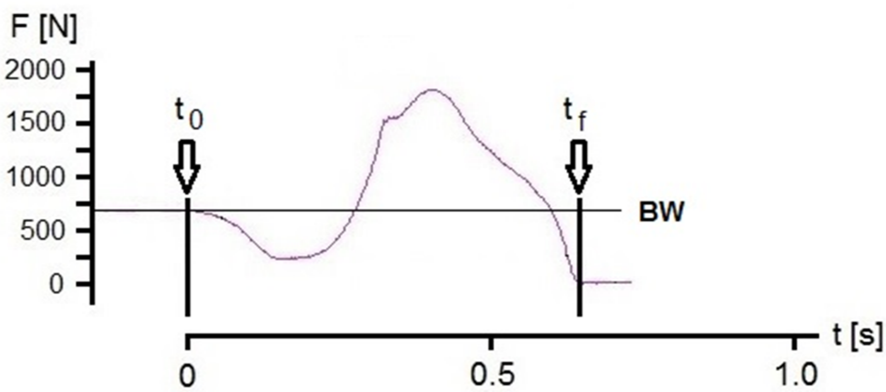

Figure 2. Force-time characteristics of two-legged CMJ. BW = body weight, t_0 = begin of impulse phase, t_f = end of impulse phase
Source: The authors

Since the sum of the impulses of the right and left lower limbs results in the impulse calculated as described previously (equation 1), the reference line for integration of the force-time characteristics of each lower limb must be half of the body weight independent of the weight distribution between lower limbs and the integration interval must be between t0 to tf even if the impulse period of each lower limb is different. Any other reference line for integration (e.g. level of body weight supported by one of the lower limbs) or integration interval (impulse phase limits of each lower limb) would result in a wrong determination of partial impulses which could easily be proofed by adding the partial impulses that must result in the impulse determined by equation 1 according to Linthorne[11]. This procedure assures the determination of partial impulses of both lower limbs in relation to 50% of the entire impulse created by each lower limb which means absolute symmetry of impulse production.

Figure 3 shows an example of asymmetries that may occur in the beginning and at the end of an impulse phase for each leg with initial unequal weight distribution where the partial impulses need to be calculated according to the equations [2] and [3] for the right (I_r) and left lower limb (I_l), respectively. This necessitates that the moments of start and end of the CMJ must be identified first, followed by integration of the force-time characteristics over this time interval with 50% of BW as the reference value.

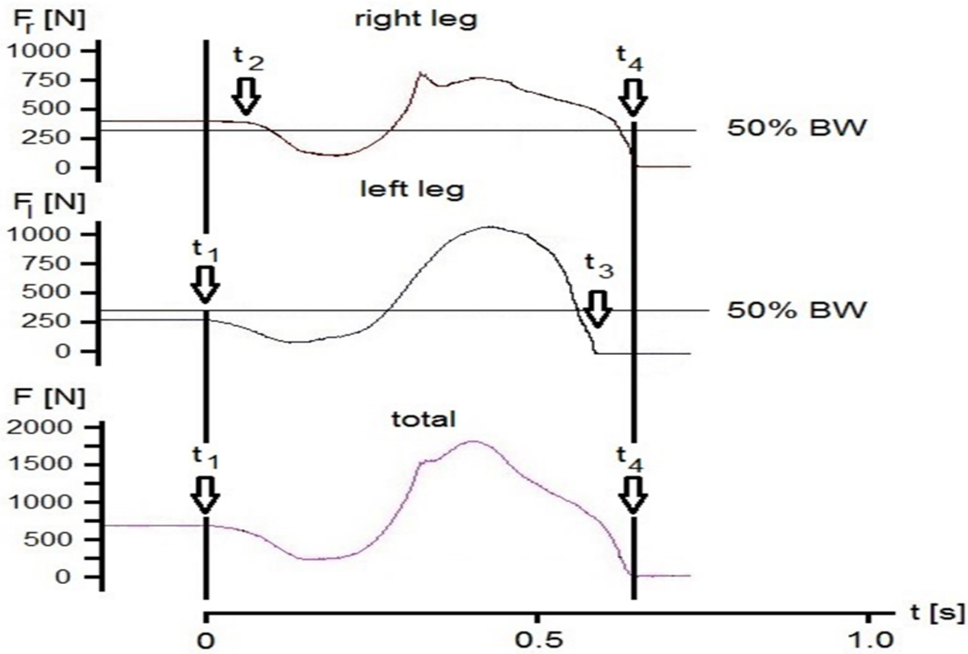

Figure 3. Bilateral differences of GRF in relation to initial weight distribution and duration of impulse. F_r = ground reaction force of the right lower limb, F_l = ground reaction force of the left lower limb, F = ground reaction force of both lower limbs, BW = body weight, t_1 = start of the impulse phase of the left lower limb, t_2 = start of the impulse phase of the right lower limb, t_3 = end of the impulse phase of the left lower limb, t_4 = end of the impulse phase of the right lower limb
Source: The authors

$$I_r = \int_{t1}^{t4} F_r \, dt - 0.5\, BW\, (t4 - t1) \quad [2]$$

$$I_l = \int_{t1}^{t4} F_l \, dt - 0.5\, BW\, (t4 - t1) \quad [3]$$

In which, F_r = Ground reaction force of the right leg; F_l = Ground reaction force of the left leg BW = Body weight; t_1 = Start of the impulse phase of the left leg; t_2 = Start of the impulse phase of the right leg; t_3 = End of the impulse phase of the left leg; t_4 = End of the impulse phase of the right leg.

The application of this procedure allows for separate determination of impulse production of the right and left lower limb even without equal weight distribution at the beginning of the jump and with different duration of impulse production. Under these conditions, impulses can only be determined by the use of two force platforms.

Statistical analysis

The strength asymmetries were quantified by the Lateral Symmetry Index (LSI), according to Clark[6]:

$$\boldsymbol{LSI}(\%) = \left(\frac{(\boldsymbol{Value\ of\ the\ right\ limb - Value\ of\ the\ left\ limb})}{\boldsymbol{greatest\ value\ for\ both\ limbs}}\right)\boldsymbol{x\ 100} \quad [4]$$

A positive LSI indicates higher values of the dynamic variables of the right lower limb, and a negative LSI indicates higher values of the left lower limb. Descriptive statistics depict mean $\pm$ standard deviation of jump height, defined as maximal elevation of the center of gravity, and normalized impulses for right and left lower limbs (impulse divided by body mass).

Therefore, the data set of 18 jumps (three sets of six jumps) was divided into two parts of nine jumps each. Subsequently, the F_{peak} of the right and left lower limb was calculated and mean of the three highest values of each part was determined. This procedure resulted in two measurements for the right and left lower limbs. Measurement 1: One F_{peak} of the right lower limb calculated as the mean of the three highest F_{peak} of the nine jumps of the first part and one F_{peak} of the left lower limb calculated as the mean of the three highest F_{peak} from the nine jumps of the second part. Measurement 2: The mean of one F_{peak} of the left lower limb of the three highest F_{peak} from the nine jumps of the first part and one F_{peak} of the right lower limb of the calculated mean of the three highest F_{peak} from the nine jumps of the second part.

Firstly, a descriptive analysis was performed as mean ± standard deviation (mean (SD)) of F_{peak} and F_{peak} asymmetry, in the sequential and simultaneous procedures, and partial impulses and impulse asymmetry in simultaneous procedure. In sequence, Shapiro Wilk test was used to test the normality of the data. All data were found to be normally distributed.

To compare sequential and simultaneous procedures, Pearson Product Moment Correlations between corresponding variables of the two procedures were calculated and finally a paired *t*-test for dependent variables was performed for F_{peak} and F_{peak} asymmetry to identify possible differences between the two procedures.

For the analysis of reliability of simultaneous procedure, $ICC_{3,k}$ was calculated for the right and left lower limb impulse and F_{peak} and F_{peak} and impulse asymmetries. The ICC of the variables of simultaneous measurement was calculated using the means of the three highest jumps of each set of six jumps. All statistical procedures were calculated via SPSS 18.0 (Chicago, Illinois, USA) with an alpha of p=.05 level of significance.

Results

Table 1 describes the mean and standard deviation (mean(SD)) of the variables analysed in the different measurement procedures: simultaneous (two force platforms) and sequential (one force platform) starting with the right lower limb and starting with the left lower limb. Calculation of LSI takes into consideration the direction of dominance (positive and negative values) which results in a mean close to zero. Since the direction of lateral differences result in means close to zero, Table 1 also depicts additional mean and standard deviation of the absolute LSI, which is calculated only via positive values and does not take into consideration the direction of lateral dominance.

Table 1. Descriptive analysis of the sequential and simultaneous procedures

	Variables	Mean(SD)
Sequential procedure	*Peak force (N) – left (beginning with left lower limb)*	890.30(157.78)
	Peak force (N) – right (beginning with left lower limb)	896.31(154.44)
	LSI of peak force (%) (beginning with left lower limb)	.73(9.28)
	Absolute LSI of peak force (%) (beginning with left lower limb)	7.79(4.89)
	Peak force (N) – left (beginning with right lower limb)	885.04(156.05)
	Peak force (N) – right (beginning with right lower limb)	894.09(156.34)
	LSI of peak force (%) (beginning with right lower limb)	1.04(8.72)
	Absolute LSI of peak force (%) (beginning with right lower limb)	7.17(4.89)
Simultaneous procedure	*Peak force - left (N)*	860.94(145.48)
	Peak force - right (N)	868.69(144.14)
	LSI of peak force (%)	.92(6.87)
	Absolute LSI of peak force (%)	5.36(4.30)
	Impulse – left (Ns)	78.93(19.58)
	Impulse – right (Ns)	82.14(18.03)
	LSI of impulse (%)	3.86(26.32)
	Absolute LSI of impulse (%)	23.87(12.16)

Source: The authors

These results (Table 1) indicate the mean and dispersion of impulse are greater than that of F_{peak}, which must be considered for the interpretation of relevant asymmetries. Since asymmetries of more than 15% of F_{peak} seem to indicate relevant differences according to Impellizzeri et al.[4] this should not occur in relation to the impulse production because of greater dispersion.

Differences between the two procedures were analyzed by correlation analysis and paired *t*-test. Since the determination of partial impulses without previous adjustment of weight distribution requires the use of two force platforms as described previously, the comparison of the two procedures can only be performed for the F_{peak} of the right and left lower limb and the LSI of F_{peak}, respectively.

There are statistically significant correlation between F_{peak} and LSI F_{peak} of sequential (beginning with left or right lower limb) and simultaneous procedures (Sequential procedure beginning with left lower limb: left peak force: r=.932, p=.001, effect size=.096; right peak force: r=.961, p=.001, effect size=.090; LSI peak force: r=.690, p=.001, effect size=-.011; Sequential procedure beginning with right lower limb: left peak force: r=.975, p=.001, effect size=.079; right peak force: r=.967, p=.001, effect size=.084; LSI peak force: r=.737, p=.001, effect size=-.008).

There are statistically significant differences between the F_{peak} of sequential and simultaneous procedures (Left lower limb peak force: beginning with left lower limb x simultaneous procedure: t = 29.363, p=.008, effect size=.193; beginning with right lower limb x simultaneous procedure: t = 24.1, p=.001, effect size=.159; Right lower limb peak force: beginning with left lower limb x simultaneous procedure: t = 27.622, p=.001, effect size =.184; beginning with right lower limb x simultaneous procedure: t = 25.404, p=.001, effect size=.168), but there are no statistically significant differences (p>.05) between the LSI F_{peak} of the different procedures (Sequential procedure beginning with left lower limb x simultaneous procedure: t = -.188, p=.877, effect size=-.023; Sequential procedure beginning with right lower limb x simultaneous procedure: t = .128, p=.905, effect size =.016).

The reliability of the simultaneous procedure was verified by the $ICC_{3,k}$ calculation. The values ranged from .810-.882 (p<.001). According to Cichetti[12], ICC values between .75 and 1 are considered excellent. The results for all variables are presented in table 2.

Table 2. Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) for the variables of the simultaneous procedure

	ICC	Sig.	SEM
Peak force - left	.846	.001	33.957 N
Peak force - right	.848	.001	33.135 N
LSI of Peak force	.840	.001	1.667%
Impulse - left	.882	.001	3.452 Ns
Impulse - right	.810	.001	3.913 Ns
LSI of impulse	.834	.001	6.651%

Source: The authors

Discussion

The purposes of the present study were to compare two different procedures, sequential and simultaneous measurements, of F_{peak} and F_{peak} asymmetry values and to determine the reliability of a new procedure to determine partial lower limb impulse and impulse asymmetry.

The results of ICC of the two procedures, the simultaneous and the sequential measurements indicate high reliability[12] for the determination of F_{peak} and LSI that measures F_{peak} asymmetries. The high reliability partially explains a consequence of the repeated measurements and the calculation of the mean of the highest F_{peak}. The correlation of the results (F_{peak}) of the two procedures are very high; however, F_{peak} of sequential procedure are slightly higher as demonstrated by the descriptive results in Table 1 and the results of the t-test. However, the slightly higher values of F_{peak} for the right and left lower limb determined by sequential procedure did not result in significant differences for LSI between the two procedure. Therefore, if only F_{peak} asymmetry during CMJ is investigated, the procedure suggested by Impellizzeri et al.[4] for sequential determination has the advantage of only half of the equipment needed.

Asymmetry of impulse production without interference of the test administrator in relation to weight distribution can only be performed by simultaneous measurement of the GRF of the two lower limbs, which requires the use of two force platforms and the determination of partial, lateral impulses. Thus, an interference to control body weight distribution, as proposed by Benjanuvatra et al.[2] can be avoided. The determination of partial impulses of the right and left lower limbs as well as the determination of asymmetry of impulse production by simultaneous measurements using two force platforms is also characterized by good reliability with ICC of .81[12]. The above described procedure for determination of partial impulses created by each lower limb, which calculates partial impulses of both lower limbs in relation to 50% of the entire impulse, assures the precise determination of partial impulses while the subject maintains his/her habitual individual movement pattern without previous adjustment of weight distribution by coaching from the test administrator.

Since vertical jumps similar to standardized CMJ are sport specific movements and conducted with maximization of jump height, the principle aim of the jump is maximal vertical impulse. Furthermore, impulse is the mechanical variable that determines the alteration of movement velocity and propulsion, versus peak force. Therefore, the analysis of strength asymmetries during CMJ should also include the assessment of differences of impulse production between the two lower limbs. The analysis should also include the habitual condition of each individual and any orientation concerning the distribution of body weight. The application of two force platforms and simultaneous measurements appears to be an appropriate and adequate procedure for the identification of asymmetric impulse production.

The use of two synchronized force platforms, or the simultaneous procedure, has the advantage of the completion of fewer CMJ trials to evaluate the levels of strength asymmetry, which in the sport context can represent a time saving allowing the evaluation of a greater number of athletes and fewer trials can maintain a high motivation level in these evaluated athletes. In addition, the evaluation of the strength asymmetries levels in the simultaneous procedure ensure that this evaluation is being performed in the same CMJ trial, which may also better represent sports situations that athletes rarely perform CMJ with only one lower limb, as suggested by Benjanuvatra et al.[2].

One problem with the simultaneous procedure is the difficult portability of the equipment. Or if the equipment is not portable, the athletes displacement to the laboratory environment may unfeasible the evaluation of this class of individuals. And with the results in the present study, the sequential procedure of F_{peak} asymmetry is not made unfeasible.

Conclusion

The determination of peak force asymmetry may be performed by sequential measurement and the use of a single force platform. Since the jump height is determined by impulse production, the interpretation of strength asymmetries should be done by the simultaneous procedure proposed to calculate the partial impulses without the interference of the researcher feedback during the CMJ.

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