

Research article

## The influence of velocity overshoot movement artifact on isokinetic knee extension tests

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### Abstract

Exercise on an isokinetic device involves three distinct movement phases: acceleration, constant velocity, and deceleration. Inherent in these phases are unique occurrences that may confound test data and, thereby, test interpretation. Standard methods of data reduction like windowing and other techniques consist of removing the acceleration and deceleration phases in order to assure analysis under constant velocity conditions. However, none of these techniques adequately quantify the velocity overshoot (VO) movement artifact which is a result of the devices resistance imposed to the limb. This study tested the influence of VO on isokinetic data interpretation. A computational algorithm was developed to accurately identify each movement phase and to delineate the VO segment. Therefore, the VO was then treated as a fourth and independent phase. A total of sixteen healthy men ( $26.8 \pm 4.7$  yrs,  $1.76 \pm 0.05$  m, and  $79.2 \pm 9.4$  kg) performed two sets of ten maximal concentric extension repetitions of their dominant knee (at  $60^\circ \cdot s^{-1}$  and  $180^\circ \cdot s^{-1}$ ), on separate days and in a counterbalanced order, on a Biodex System 3 Pro dynamometer. All the phases of the isokinetic exercise were measured in terms of their biomechanical descriptors and according to the developed algorithm, the windowing method, and a data reduction technique that eliminates the first and last  $10^\circ$  of the total range of motion. Results showed significant differences ( $p < 0.05$ ) between the constant velocity phases found by each method: the largest segment was obtained with the windowing method; the second one, with the algorithm; and the smallest, with data reduction technique. The point of peak torque was not affected by none of the techniques, but significant differences ( $p < 0.05$ ) were found between the data including and not including the VO phase, concerning total work, time interval, and average length of load range: VO represents more than 10% of the amount calculated in constant velocity phase. As a consequence, the correct removal of VO was suggested as a required procedure to adequately interpret isokinetic tests. Therefore, the use of the proposed algorithm is advisable in order to perform analysis according to the isokinetic definition.

**Key words:** biomechanics, dynamometry, constant velocity, phases of movement.

### Introduction

Muscular strength is a valuable attribute to perform many sports and simple day-to-day activities. Thus, the assessment of muscular strength is essential for understanding the performance capacity of an individual (Bottaro et al., 2005). Commercially available isokinetic machines have

created lots of clinical application for injury rehabilitation, measurements of muscular torque, work, power, or endurance. However, many internal and external factors in the isokinetic testing procedures can have an undesirable effect on the test results.

The isokinetic dynamometer is a device that controls the velocity of an exercising limb by means of a preset speed-governing mechanism (Brown, 2000). As more force is exerted against the lever arm of the dynamometer, the energy of the moving limb is absorbed by the apparatus and returned as additional resistance to the limb movement (Brown et al., 1995a; 1995b). Movement, therefore, occurs at a constant predetermined speed in the range of motion referred to as load range (LR) (Brown, 2000) where the dynamometer imposes an external load to the limb movement. However, an exercising limb must free accelerate (Sapega et al., 1982) to the preset speed and decelerate at the end of the exercising range. These phases are performed without the benefit of externally imposed resistance and, consequently, should not be considered during test interpretation (Brown, 2000). But the absence of dynamometer resistance in acceleration (ACC) and deceleration (DEC) phases is not the only reason for isokinetic data misinterpretation: velocity overshoot (VO) and impact artifact are also reported causes (Brown, 2000). The VO is a movement artifact that occurs when the limb accelerates past the desired speed and the dynamometer tries to slow the limb. This generates two effects: (a) a torque spike (or torque overshoot) as a consequence of the braking mechanism of the dynamometer (Wilk et al., 1992; Brown, 2000), and (b) a short period of time where the angular velocity oscillates until its stabilization at the preset speed (Sapega et al., 1982; Chen et al., 1994). The impact artifact has an effect similar to VO and it is observed during deceleration when the dynamometer begins to slow the lever arm in preparation for stopping at the turnaround point. This causes a torque spike at the end of the repetition due to the lever arm impacting the mechanical end stop (Brown, 2000). Both VO and impact artifact produce undesirable behavior and are usually removed with ACC and DEC phases prior to isokinetic test interpretation. Wilk et al. (1992) related the use of an "isokinetic window" which consists of removing all data that has not been obtained at the preset isokinetic speed or 95 percent of that speed. This technique has been shown to increase the reliability of testing via the control of aberrant torque production (Wilk et al., 1992). They

found significant differences between windowed and nonwindowed data during isokinetic tests. Tis and Perrin (1993) advise that using a data reduction technique that eliminates the first and last 10° of the total range of motion (ROM) may eliminate ACC and DEC areas, but this may also eliminate the peak torque range (Brown, 2000). Kurdak et al. (2005) proposed a method that calculates the first-difference of velocity and accepts fluctuations near to zero value ( $0 \pm 0.2$ ) as isokinetic. They have not found the VO artifact in their research. However, small fluctuations inside a VO segment could be mistakenly considered as isokinetic if only the first-difference is used. All the techniques are useful to diminish the movement artifacts effects. However, none of them is able to exactly quantify the contribution of the VO effect. In general, VO is considered as a segment of the ACC or LR phase. Actually, VO cannot be treated as an acceleration segment because it has an imposed external load. On the other hand, it cannot also be considered a LR segment since its velocity oscillates. By definition, isokinetic is constant velocity and represents a match between a mechanically imposed velocity and the subject's movement (Brown, 2000). Thus, a "pure isokinetic" analysis could not have VO within the range under study.

This study tested the influence of VO on isokinetic knee extension data interpretation through the analysis of biomechanical descriptors. A computational algorithm was developed to delineate the segments of each isokinetic repetition phase (IRP). The first-difference was associated with the windowing criterion and other mechanisms of signal analysis which make possible an accurate identification of IRPs. The VO segment was treated as a fourth IRP and its effects were reported independently of the three major phases (ACC, LR and DEC). This new approach was compared with the windowing method and the data reduction technique proposed by Tis and Perrin (1993), referred to here only as data reduction.

## Methods

Sixteen normal healthy adult males (age  $26.8 \pm 4.7$  years) of height  $1.76 \pm 0.05$  m and body mass  $79.2 \pm 9.4$  kg with no history of orthopedic disease participated in this study. They voluntarily read and signed a written consent form before participating in the experiment that was approved by the University Institutional Review Board.

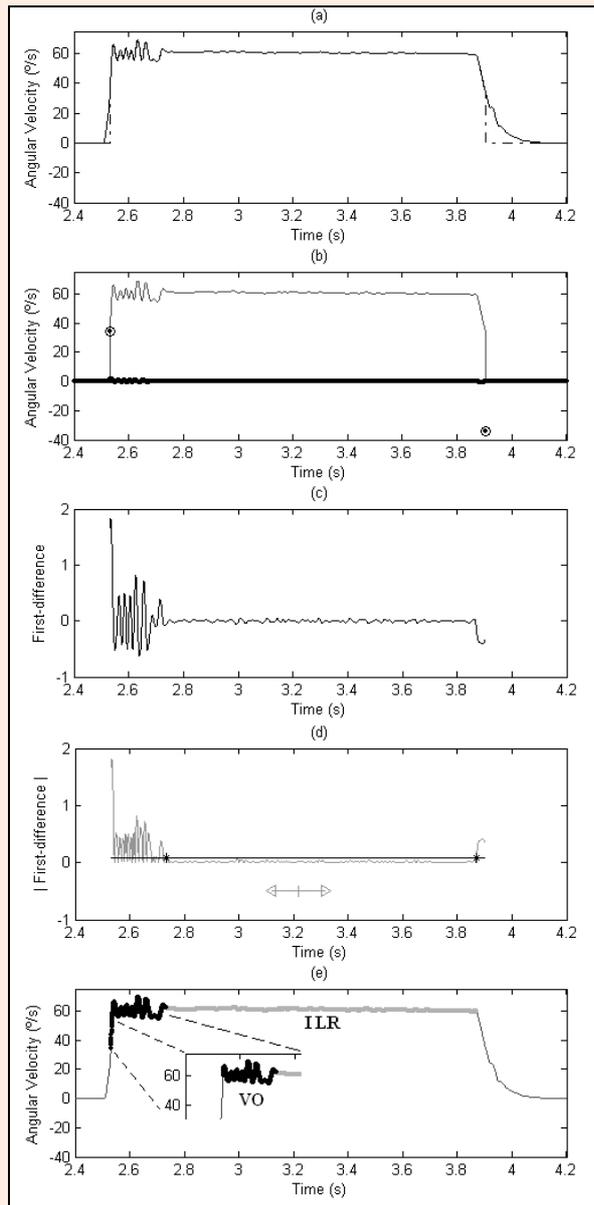
A Biodex System 3 Pro isokinetic dynamometer (Biodex Corp., Shirley, NY, USA) was calibrated and assembled with the knee attachment according to the manufacturer's specifications (Biodex, 1998). Biodex has been shown to be a reliable instrument for collecting data of human torque, joint position, and limb velocity (Brown et al., 1993; Drouin et al., 2004; Feiring et al., 1990; Gross et al., 1991; Ortqvist et al., 2007; Taylor et al., 1991). The dynamometer shaft was aligned with the assumed axis of rotation (lateral femoral condyle) of the dominant knee (right leg for all the subjects) with the subject in a seated position and the back reclined at approximately 110°. The left thigh was secured with straps as were the waist and thoracic torso (Weir et al., 1996). Arms were placed across the chest with hands grasping the straps (Stumbo et al., 2001). The lever arm pad was

positioned to place the inferior aspect immediately superior to the medial malleolus. Subjects were passively moved to 0° of extension (full extension). After, the knee was flexed about 5° to 10° to a comfortable position set as the extension mechanical stop. Then, the flexion mechanical stop was defined so as to ensure a range of motion of 85 degrees. Gravity compensation analysis was performed by the computer system software provided with the Biodex System 3 Pro.

The biomechanical signals were acquired through the dynamometer DB-15 female interface (Biodex, 1998) which provides real time analog signals of torque, angular velocity, and angular position. An adaptor was built by the authors in order to get the signals from the DB-15 interface into three separate BNC connectors to a digitizer board (BNC-2120, National Instruments, TX, USA) which sampled the biomechanical signals at 2048 samples·s<sup>-1</sup>, and converted it to digital data via a 12 bit A/D. A software tool (Schwartz et al., 2008) was used to adjust the DB-15 voltage of the recorded signals to real units (N·m, degrees·s<sup>-1</sup>, and degrees), following the manufacturer's specifications. This mechanism was used in order to get higher resolution for the digitized signals once the Biodex System 3 Pro only provides signals sampled at 100 samples·s<sup>-1</sup>. Although the rate of 100 samples·s<sup>-1</sup> is sufficient for the isokinetic exercises analysis, a better resolution was chosen for a better precision of the biomechanical descriptors calculus.

Following equipment setup, subjects were asked to perform 10 gradient sub-maximal reciprocal concentric extension (240°·s<sup>-1</sup>) and flexion (300°·s<sup>-1</sup>) repetitions for warm-up and familiarization with the equipment. For testing, subjects performed two sets of ten maximal concentric repetitions of dominant knee extension (at 60°·s<sup>-1</sup> and 180°·s<sup>-1</sup>), on separate days and in a counterbalanced order. Consistent and standard, moderate (no yelling or screaming) verbal encouragement was given. No visual feedback of the biomechanical signals was provided to subjects during the test.

In order to calculate the biomechanical descriptors on each separate IRP a computational algorithm (Figure 1) was developed by the authors in Matlab 6.5 (MathWorks, Natick, MA, USA). The algorithm divided the LR segment into two segments: VO and an isokinetic load range (ILR) segment. First, all the values less than the mean value of the extension angular velocity are set to zero and the original signal is shifted to the dashed-dot line trajectory of Figure 1a. Second, the first-difference technique (Smith, 1998) is applied to the shifted signal. This results in the circled-dots and the bold line shown in Figure 1b. Third, the absolute values of the bold line segment between the two circle-dots are determined and their mean value calculated. Figure 1c displays a zoomed image of this bold line segment and Figure 1d shows its absolute values with a straight line representing their mean value. Fourth, the algorithm investigates the first point greater than the mean value on the left and on the right side from the center of the segment, as illustrated by the asterisks in Figure 1d. These asterisks delineate the ILR segment. Finally, VO could be considered as the region between the first circled-dot and the first asterisk. However, its



**Figure 1.** (a) extension knee movement (solid-line) and points less than the mean set to zero (dashed-dot line); (b) circled-dots and bold line found by the application of the first-difference; (c) zoomed image of the bold line segment between the circled-dots; (d) the absolute values of bold line segment, a straight line representing the mean value, and the asterisks delineating the isokinetic load range (ILR) segment; (e) the first and final approximation for velocity overshoot (VO).

**Table 1.** Percent Relation between the values of each isokinetic repetition phase and the value of total range of motion, calculated using the proposed algorithm.

PR <sub>DESCRIPTOR</sub>	60°·s <sup>-1</sup>				180°·s <sup>-1</sup>			
	ACC	VO	ILR	DEC	ACC	VO	ILR	DEC
PR <sub>TW</sub>	.52 (.11)	8.93 (1.08)	89.08 (1.26)	1.39 (.85)*	3.17 (.53)	6.70 (.57)	83.88 (1.10)	6.00 (1.05)
PR <sub>PTBW</sub>	40.9 (6.9)	68.1 (5.6)	100.0 (.0)*	41.1 (14.9)*	63.6 (13.5)	76.9 (9.4)	100.0 (.0)*	79.0 (12.1)
PR <sub>TI</sub>	2.77 (.85)	10.74 (1.06)	76.18 (3.00)	10.31 (3.06)	9.24 (1.88)	6.77 (.65)	59.42 (2.60)	24.58 (2.92)
PR <sub>AL</sub>	1.74 (.42)	11.83 (.94)	82.97 (1.16)	3.46 (.56)*	5.52 (.91)	8.70 (.78)	76.87 (.76)	8.59 (.27)

Note. Values are mean (± SD) expressed as a percentage of the respective total range of motion value; PR = Percent Relation; descriptors are total work (TW), peak torque to body weight (PTBW), time interval (TI), and average length (AL); phases are acceleration (ACC), velocity overshoot (VO), isokinetic load range (ILR), and deceleration (DEC).

\* Significantly non-normal ( $p < .05$ ) according to Shapiro-Wilk test.

starting point is adjusted to the first point with at least 95 percent of the preset speed in order to meet the criterion for windowing (Wilk et al., 1992). The result is shown in the highlighted portion of Figure 1e.

Four of the most common biomechanical descriptors were determined for each separated IRP: (1) the total work (TW) which is the total amount of work that is produced in a set (Brown, 2000; Remaud et al., 2007); (2) the peak torque to body weight (PTBW) which is the maximum torque produced in a set of repetitions, normalized to body weight (Brown, 2000); (3) the time interval (TI) in seconds of each phase of the movement; (4) the average length (AL) in degrees of each phase range.

For all subjects, the four IRPs were identified in each repetition of each set of the knee extension movement at 60°·s<sup>-1</sup> and 180°·s<sup>-1</sup>. The biomechanical descriptors were calculated from the total ROM and for each IRP. Then, the percent relation (PR) between the values of each IRP and the value of total ROM were established according to the following equation:

$$PR_{DESCRIPTOR} = \frac{DescriptorValue_{IRP}}{DescriptorValue_{totalROM}} \times 100 (\%) \quad (1)$$

Percent relation is a measure of how much each IRP contributes with the whole value of the descriptor inside a repetition.

The same procedure was repeated for the windowing (Wilk et al., 1992) and data reduction techniques (Tis and Perrin, 1993) considering only the three major isokinetic phases, since these techniques do not manage the VO artifact.

The behavior of isokinetic movement phases was focused on the PR ratio of each descriptor. Student's *t*-test for dependent samples was applied to compare normally distributed data with a level of significance of 0.05 (two-tailed) and 95% of confidence interval. Wilcoxon Signed-Rank non-parametric test (De Sá, 2007) was applied to compare non-normal data.

## Results

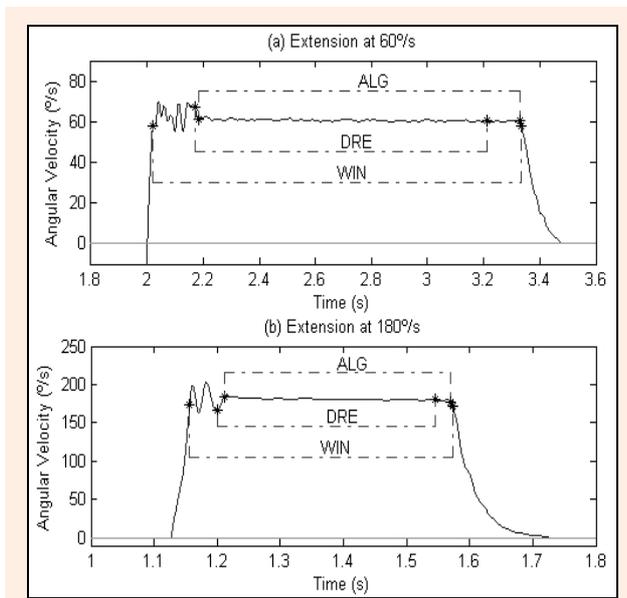
The first set of descriptor values was calculated for the four IRPs identified by the proposed algorithm (see Table 1). A comparison between the two angular velocities (60°·s<sup>-1</sup> and 180°·s<sup>-1</sup>), for each IRP, and for all of the studied descriptors revealed significant differences ( $p < 0.05$ ), except for PR<sub>PTBW</sub> (percent relation of peak torque to body weight) in ILR phase where the means are visibly equal.

**Table 2.** Angular Velocity and Coefficient of Variance for velocity overshoot and isokinetic load range phases.

Descriptor	Lower peak torque		Higher peak torque	
	VO	ILR	VO	ILR
Ang. Vel. <sub>60</sub> (°·s <sup>-1</sup> )	62.47 (4.51)	60.64 (.62)	63.06 (4.04)	60.61 (.42)
COV <sub>60</sub> (%)	7.22	1.02	6.41	.70
Ang. Vel. <sub>180</sub> (°·s <sup>-1</sup> )	179.69 (15.58)	179.10 (2.42)	184.83 (12.63)	180.79 (.93)
COV <sub>180</sub> (%)	8.67	1.35	6.83	.52

Note. Values for angular velocity are mean ( $\pm$  SD). COV = Coefficient of Variance, VO = Velocity Overshoot, and ILR = Isokinetic Load Range.

The distinct behaviors of VO and ILR are shown in Table 2 by the coefficient of variance calculated for both phases from the peak torque repetition produced by the subjects with the least and the greatest peak torque. For the least peak torque, the coefficient of variance found at 60°·s<sup>-1</sup> (180°·s<sup>-1</sup>) was 7.22% (8.67%) for VO and 1.02% (1.35%) for ILR. For the greatest peak torque, the values are 6.41% (6.83%) for VO and 0.70% (0.52%) for ILR. The higher fluctuations in VO reinforce its non-isokinetic nature. The two extreme cases of peak torque production were chosen in order to detect the smallest and the largest possible velocity variations in VO.



**Figure 2.** (a) extension knee repetition at 60°/s, the isokinetic load range (ILR) phase delineated by the proposed algorithm (ALG), and load range (LR) phases found by windowing (WIN) and data reduction (DRE) techniques; (b) extension knee repetition at 180°/s, the ILR phase delineated by ALG, and LR phases found by WIN and DRE.

Total ROM was determined at 60°·s<sup>-1</sup> (82.79  $\pm$  2.32 degrees) and 180°·s<sup>-1</sup> (83.25  $\pm$  0.80 degrees) and it was consistent with the dynamometer settings.

The results from the windowing (Table 3) and data

reduction (Table 4) techniques concerning LR phase were compared between them and with the results of ILR phase delineated by the proposed algorithm. Significant differences ( $p < 0.05$ ) showed that the largest segments for LR were found with the windowing method, followed by the ILR segments obtained with the algorithm, and finally by the segments found with data reduction technique. The average length descriptor gives a good notion of this finding. From Tables 1, 3, and 4, LR (or ILR) contributes to the following percentage of AL at 60°·s<sup>-1</sup> (180°·s<sup>-1</sup>): 95.67% (86.46%) for the windowing method, 82.97% (76.87%) for the proposed algorithm, and 75.60% (75.63%) for the data reduction technique. Table 5 summarizes these relations for TW, TI, and AL. There are no differences for the PTBW descriptor in none of the studied methods. Lastly, the LR segment found by windowing was not significantly different from the VO+ILR segment obtained with the algorithm. Figure 2 illustrates the variation of the time length segments according to the angular velocity and the identification technique used.

## Discussion

The most widely used technique for data adjustment in isokinetic exercises is the windowing technique which treats VO and LR as one isokinetic phase (Bottaro et al., 2005; Brown et al., 1995a; 1995b; Findley et al., 2006; Kurdak et al., 2005; Wilk et al., 1992; 1994). In this study, velocity overshoot was seen as a separate phase. Table 1 shows that VO has an important contribution to the descriptor values. Figure 1c illustrates how the velocity variation is accentuated in the VO phase when compared with the ILR phase. Table 2 reveals that the velocity variation in the VO is approximately 7 times larger than the variation in ILR at both velocities (60°·s<sup>-1</sup> and 180°·s<sup>-1</sup>) when the least peak torque case is observed. For the greater peak torque case, the relation increases to approximately 9 times (60°·s<sup>-1</sup>) and 13 times (180°·s<sup>-1</sup>) respectively. It means that even for individuals with low peak torque production, the VO phase has a large fluctuation when compared with ILR. Therefore, it is reasonable to consider that the ILR phase is the only part where velocity could be constant.

**Table 3.** Percent Relation between the values of the three major isokinetic repetition phases and the value of total range of motion, using the windowing technique.

PR <sub>DESCRIPTOR</sub>	60°·s <sup>-1</sup>			180°·s <sup>-1</sup>		
	ACC	LR	DEC	ACC	LR	DEC
PR <sub>TW</sub>	.38 (.11)	98.46 (.72)	1.10 (.71)*	3.47 (.81)	91.26 (1.19)	5.10 (.82)
PR <sub>PTBW</sub>	37.3 (7.7)	100.0 (.0)*	40.3 (16.4)*	63.9 (13.2)	100.0 (.0)*	79.0 (10.1)
PR <sub>TI</sub>	2.51 (.83)	87.75 (3.34)	9.74 (2.91)	9.64 (2.19)	66.82 (3.17)	23.55 (2.86)
PR <sub>AL</sub>	1.43 (.43)*	95.67 (.65)	2.93 (.38)*	6.02 (1.30)	86.46 (1.38)	7.33 (.36)

Note. Values are mean ( $\pm$  SD) expressed as a percentage of the respective total range of motion value; PR = Percent Relation; descriptors are total work (TW), peak torque to body weight (PTBW), time interval (TI), and average length (AL); phases are acceleration (ACC), load range (LR), and deceleration (DEC). \* Significantly non-normal ( $p < .05$ ) according to Shapiro-Wilk test.

**Table 4.** Percent Relation between the values of the three major isokinetic repetition phases and the value of total range of motion, using the data reduction technique.

PR <sub>DESCRIPTOR</sub>	60°·s <sup>-1</sup>			180°·s <sup>-1</sup>		
	ACC	LR	DEC	ACC	LR	DEC
PR <sub>TW</sub>	8.23 (.87)	85.16 (1.21)	6.55 (1.62)	7.88 (.63)	83.42 (1.27)	8.53 (1.32)
PR <sub>PTBW</sub>	66.6 (6.2)	100.0 (.0)*	57.3 (6.3)	72.3 (8.2)	100.0 (.0)*	79.0 (10.1)
PR <sub>TI</sub>	12.09 (.59)	69.66 (1.85)	18.25 (2.11)	14.32 (1.33)	58.37 (2.32)	27.31 (2.69)
PR <sub>AL</sub>	12.17 (.34)*	75.60 (.69)*	12.19 (.36)*	12.04 (.12)	75.63 (.23)	12.10 (.12)

Note. Values are mean ( $\pm$  SD) expressed as a percentage of the respective total range of motion value; PR = Percent Relation; descriptors are total work (TW), peak torque to body weight (PTBW), time interval (TI), and average length (AL); phases are acceleration (ACC), load range (LR), and deceleration (DEC).

\* Significantly non-normal ( $p < .05$ ) according to Shapiro-Wilk test.

Previous studies have focused on the importance of removing the ACC and DEC phases from the results analysis (Maly et al., 2006; Messier et al., 2005; Wilk et al., 1992; 1994). It is well understood that they are not isokinetic phases. However, keeping them in the analysis of certain descriptors causes less impact than keeping the VO phase. Looking at the behavior of total work at 60°·s<sup>-1</sup> (Table 1), we can see that VO contributes about 8.93% of the work realized in total ROM, whereas ACC and DEC summed are about 1.91%. For the angular velocity of 180°·s<sup>-1</sup>, ACC and DEC phases summed contribute about 9.17% of the work in total ROM against 6.7% of VO, what is still a high value. This increase of ACC+DEC can be observed in PR<sub>TI</sub> descriptor (3.3 times higher for ACC and 2.8 times higher for DEC) and it is related to the time necessary to reach a higher angular velocity and to stop the movement at the end of the repetition. Consequently, there was a reduction of the VO+ILR segment at 180°·s<sup>-1</sup> (see PR<sub>AL</sub> descriptor in Table 1), which has been repeatedly reported for increased dynamometer speed (Brown et al., 1995a; 1995b; 1998; Lander et al., 1985; Osternig, 1975; 1986).

Comparing VO with ILR, the work produced in VO is approximately 10% (at 60°·s<sup>-1</sup>) and 8% (at 180°·s<sup>-1</sup>) of the work produced in ILR. Thus, an analysis of total work considering VO+ILR as an isokinetic segment could suggest that a subject produced 10% (8%) more work than he really did under isokinetic conditions at 60°·s<sup>-1</sup> (at 180°·s<sup>-1</sup>).

Since the windowing technique does not distinguish VO from ILR phase, the entire load range is used for analysis (Table 3). Consequently, treating VO as an isokinetic segment significantly modifies results interpretation since velocity is not constant in the VO segment (see comparisons in Table 5). Therefore, the windowing technique does not provide appropriate conditions for a “pure isokinetic” analysis. There is not a scientific definition for what the expression “pure isokinetic” means. For the data of this work, and based on Table 2 results, it is reasonable to consider all the segments with coefficient of

variance less than or equal to 1.35 (for angular velocity) as a pure isokinetic segment. However, this is not a generalization because it depends on angular velocity, peak torque produced and the dynamometer used, which deserves specific investigations.

Looking at the LR results for the data reduction technique in Table 4, they seem similar to the ILR results of Table 1, especially at 180°·s<sup>-1</sup>. However the differences are reported in Table 5 and illustrated in Figure 2. It is easy to observe in Figure 2 that a part of the isokinetic segment is eliminated when the last 10° are subtracted from the total ROM at both angular velocities. This evidence justifies the possible loss of peak torque range related by Brown (2000). However, no loss of peak torque was observed in the present study. The PR<sub>PTBW</sub> descriptor indicates that peak torque occurred in the load range for all three techniques and for both angular velocities. Figure 2 also reveals that the first 10° segment would not be large enough to completely remove the VO phase in both velocities. Therefore, a portion of the analysis segment would not be isokinetic, compromising results interpretation.

The occurrence of torque spikes subsequent to ACC or at the end of the repetition was not observed. The main reason is that the dynamometer used has an impact-free acceleration and deceleration mechanism which eliminates joint trauma, allowing patients to exercise and be tested at more functional speeds (Biodex, 1998). On average, the closest value of the peak torque occurred in the DEC phase at 180°·s<sup>-1</sup> as shown by PR<sub>PTBW</sub> in Table 1. This is consistent with previous reports that impact artifact and lever arm oscillation (Brown, 2000) usually occur at speeds greater than 180°·s<sup>-1</sup> (Gransberg and Knutsen, 1983; Handel et al., 1996).

## Conclusion

Based on the arguments presented, we concluded that VO artifact has significant influence on isokinetic knee extension data tests at 60°·s<sup>-1</sup> and 180°·s<sup>-1</sup>. Treating the

**Table 5.** Comparison between the Percent Relation of the load range phase determined by the proposed algorithm, windowing, and data reduction technique

PR <sub>DESCRIPTOR</sub>	60°·s <sup>-1</sup>			180°·s <sup>-1</sup>		
	LR <sub>(ALG.WIN)</sub>	LR <sub>(WIN.DRE)</sub>	LR <sub>(ALG.DRE)</sub>	LR <sub>(ALG.WIN)</sub>	LR <sub>(WIN.DRE)</sub>	LR <sub>(ALG.DRE)</sub>
PR <sub>TW</sub>	<i>t</i> (ALG < WIN)	<i>t</i> (WIN > DRE)	<i>t</i> (ALG > DRE)	<i>t</i> (ALG < WIN)	<i>t</i> (WIN > DRE)	<i>t</i> (ALG > DRE)
PR <sub>TI</sub>	<i>t</i> (ALG < WIN)	<i>t</i> (WIN > DRE)	<i>t</i> (ALG > DRE)	<i>t</i> (ALG < WIN)	<i>t</i> (WIN > DRE)	<i>t</i> (ALG > DRE)
PR <sub>AL</sub>	<i>t</i> (ALG < WIN)	<i>w</i> (WIN > DRE)	<i>w</i> (ALG > DRE)	<i>t</i> (ALG < WIN)	<i>t</i> (WIN > DRE)	<i>t</i> (ALG > DRE)

Note. PR = Percent Relation, ALG = proposed algorithm, WIN = windowing technique, and DRE = data reduction technique; LR<sub>(A,B)</sub> means a statistical comparison between the load range phase (or isokinetic load range phase for ALG) of A and B techniques with significance level of .05; *t* is the Student's *t*-test for dependent samples; *w* is the Wilcoxon Signed-Rank non-parametric test; descriptors are total work (TW), time interval (TI), and average length (AL).

VO segment as an independent phase was seen as a positive practice once its impact over biomechanical descriptors was evidenced. Therefore, the use of the proposed algorithm is advisable in order to perform analysis according to the isokinetic definition and to accurately remove the VO, ACC and DEC phases. In summary, this procedure will help the researcher to accurately assess muscle performance when using the isokinetic device. However, this study only examined angular velocities of  $60^{\circ}\cdot s^{-1}$  and  $180^{\circ}\cdot s^{-1}$ . Therefore, further studies are required at higher speeds, different joints, and different contractile modalities.

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### Key points

- Isokinetic test interpretation must be focused on the constant velocity range; traditional analysis usually removes the acceleration and deceleration phases but does not give particular attention to velocity overshoot range.
- The study of effects of velocity overshoot artifact requires a specific method for accurately delineate its interval and investigate its impact over biomechanical descriptors; this paper proposed a computational algorithm for identifying the velocity overshoot interval.
- Velocity overshoot has significant impact over biomechanical descriptors analyzed during isokinetic knee extension tests at  $60^{\circ}\cdot\text{s}^{-1}$  and  $180^{\circ}\cdot\text{s}^{-1}$ ; the algorithm proposed is an advisable method for performing isokinetic tests analysis according to the isokinetic definition.

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