EFFECTS OF DIFFERENT REST INTERVALS ON MUSCLE PERFORMANCE IN CHILDREN

José Carlos de Britto Vidal Filho[1], Carlos Ernesto Santos Ferreira[2], Marcelo Pereira Magalhães de Sales[3], Jeeser Alves de Almeida[3] and Martim Bottaro[3]

[1]Professor at the Department of Physical Education of the Catholic University of Brasília, DF, Brazil.
[2]Professor at the Department of Physical Education of the Catholic University of Brasília, DF, Brazil.
[3]Graduate Program in Physical Education of the Catholic University of Brasília, DF, Brazil.

ABSTRACT
The purpose of this study was to compare the effect of two different rest intervals between sets of isokinetic knee extension exercise on peak torque (PT), and Total Work (TW) in children. A total of 18 boys (11.1 ± 0.52 years old, 32.9 ± 3.32 kg and 142.6 ± 4.78 cm, Tanner stage 1 and 2) performed 3 sets of 10 unilateral isokinetic knee extension repetitions at 60°/s and 180°/s. The rest intervals between sets were 1 and 2 minutes. There was no significant decline in PT and TW when 1 and 2 min rest intervals were used at 60°/s and 180°/s. The present study indicated that children need only 1min to recover muscle performance, indicating high resistance to muscle fatigue during high-intensity resistance exercise at different movement speeds.
Key-words: Resistance exercise. Children. Muscle fatigue. Rest interval. Isokinetic exercise.

INTRODUCTION

Prescription of strength training to youth has become universally accepted by qualified professional organizations. Initially, the American College of Sports Medicine (1993) and the National Strength and Conditioning Association (NSCA) (1996) have declared that, when dully supervised, weight training (WT) for children and adolescents is efficient and safe. More recently, Malina (2006) revised 22 experimental protocols with WT and concluded that these programs, with an adequate technical supervision, are safe and do not have negative impacts on the growth and maturation of pre-adolescents. WT for children has been often used by Physical Education professionals, because it can bring benefits to motor development (BEHRINGER et al., 2011), improvement in body composition of overweight or obese children (McGUIGAN et al., 2009), as well as positive results regarding self-perception on body image (LUBANS, AGUIAR and CALLISTER, 2010).

Moreover, Faigenbaum et al. (2009) have recently published an official statement by the NSCA - considered an important authority in WT - about the benefits from this practice for youth, also affirming that this type of training can increase muscle strength, decrease cardiovascular risks, increase the development of motor skills, reduce risks for injuries in young athletes, promote improvements in psychosocial well-being and development of habits and practice of physical exercise during childhood and adolescence.

Several studies conducted with different populations have been conducted aiming to comprehend and explain the effects of WT on muscle performance (BOTTARO; RUSSO; OLIVEIRA, 2005; CHENG; RICE, 2005; HILL-HAAS et al., 2007; ROBINSON et Al., 1995; WILLARDSON; BURKET, 2005). These studies reported that adaptations derived from this kind of training depend on variables such as frequency, load, number of sets and repetitions, type of contraction and interval between sections and sets; however, inadequate control and great variety of manipulation of these variables in studies about WT have contributed to a great variation and inconsistency in the results presented. In this context, chronic and acute alterations of WT in different training programs and populations, especially in children, still need to be better clarified.

On the other hand, the rest interval (RI) between sets of exercises, regarded as an important variable of WT, is often neglected in investigations, being little studied in children. The length of the recovery period significantly changes acute, metabolic, hormonal and cardiovascular responses of weight training, as well as the performance of subsequent sets (KRAEMER et al., 1993a; KRAEMER et al., 1993b; KRAEMER et al., 1997; BOTTARO et al., 2009; ERNESTO et al., 2009).

Regarding isokinetic muscle contractions, available data demonstrate that rest intervals influence on strength production during subsequent tests. Pincivero et al. (1999) suggest a RI of approximately 160 seconds between sets, so that strength can be recovered in young individuals. With similar results, Bottaro et al. (2010) reported that one minute is enough for young adults. In turn, Parcell et al. (2002) reported that a time of 60 seconds between sets is enough for the recovery of the peak torque in young adults assessed through isokinetic dynamometers.

The behavior of energetic systems in different age groups seems to be directly related to the RI. The speed of anaerobic glycolysis in children is limited by the activity of some enzymes, like pyruvate dehydrogenase complex (PDC) and phosphofructokinase (PFK). The latter presents a lower activity in muscle cells of boys aged 11-13 years old (ERIKSSON; GOLLNICK; SALTIN, 1973) and 16-17 years old (ERIKSSON; GOLLNICK; SALTIN, 1974), when compared with young adults (KUNO et al., 1991). These findings suggest a lower speed of anaerobic glycolysis in children. Thereby, the ideal time of RI between sets of resistance exercises in children may not be the same for adults and seniors. Thus, the purpose of this study was to verify the effects of different recovery intervals between sets of isokinetic resistance exercises on muscle fatigue responses in children.

METHODS

Eighteen children participated in the study (11.1 ± 0.52 years old; 32.9 ± 3.32 kg; 142.6 ± 4.78 cm), classified into Tanner stages 1 and 2. All parents or legal guardians received an informed consent form, which was properly signed, in accordance with Resolution No 196/96 of the Ethics and Research Committee of the Ministry of Health. The institutional Ethics and Research Committee approved this research, under No 121/05.

Maturational stage

The classification proposed by Tanner (1962) was used, which describes five stages of genital and pubic hair development for boys. These secondary sexual characteristics are classified by comparing them with a photographic standard according to the scale proposed by Tanner (1962). Such assessment can be done through visual inspection by an expert, or self-assessment (AZEVEDO et al., 2009). In the present study, maturational development was self-assessed.

Isokinetic assessment

Peak torque (PT) and total work (TW) were measured through a Biodex System III isokinetic dynamometer (Biodex Medical, Inc., Shirley, NY). The angular speed was adjusted to 60°/s and 180°/s. Before the test, every subject performed a warm-up on a cycle ergometer, for 5 minutes. The subjects were instructed to select a resistance (25 – 50 W) that was comfortable to them and did not lead them to fatigue at a cadence of 60 rpm (BOTTARO et Al., 2005; PINCIVERO et al., 2000). The subjects sat on the seat of the cycle ergometer in a comfortable position and were tied by a belt passing through their trunk, pelvis and thighs, in order to minimize extra body movements that assisted in a production of higher peak torque

(WEIR et al., 1994). The lateral epicondyle of the femur was used as biological marker to align the axis of rotation of the knees and of the device.

With the subject positioned on the seat, allowing a free and comfortable movement of knee flexion and extension, from a position at 90° of flexion to the terminal position, the height of the seat, the regulation of the seat back, the position of the seat and of the dynamometer, and the regulation of the resistance arm were all checked. These measures were recorded toward standardizing the test position of each of the subjects, individually.

Gravity correction was obtained by measuring the torque exercised by the resistance arm and the leg (relaxed) of the subject assessed, in the terminal extension position. The values of the isokinetic variables were automatically adjusted to gravity in the software Biodex Advantage. The Biodex dynamometer was calibrated in accordance with specifications contained in the manufacturer's manual.

During the performance of the test, the volunteers were asked to keep their arms crossed at the height of their thorax (STUMBO et al., 2001). Besides, they were verbally encouraged and received visual feedback through the computer screen to reach the maximum level of exertion (HALD; SANDER, 1987).

Exercise protocol

Toward familiarization with the exercise, the volunteers performed a peak torque assessment (PT), adopting the following procedure: warm-up with 10 repetitions at a speed of 120°/s, followed by two sets of four repetitions at a speed of 60°/s, with 1min rest interval between sets.

In the experimental protocol, the volunteers performed three sets of ten repetitions, at the speeds of 60°/s and 180°/s, with RIs of one and two minutes. The use of RIs (i.e., 1 and 2 min RI) was randomly determined and they were applied in different days, separated by, at least, 72 hours, and, at most, seven days. The protocols were carried out in ascending order in relation to the angular speed, and 10 minutes of interval separated the tests at the different speeds (BOTTATO et al., 2005; PARCELL et al., 2002).

The right limb was used to standardize the test, since previous studies have not found differences in isokinetic variables between dominant and non-dominant lower limbs, in non-trained individuals (DAVIES et al., 2003).

Statistical analysis

Descriptive statistics appears as mean and standard deviation. Data normality was assessed through the Kolmogorov-Smirnov test. To assess the influence of time of recovery on dependent variables throughout the three sets, a 2 x 3 factorial analysis of variance (ANOVA) for repeated measures was performed [rest interval (one and two min) X sets (1ª, 2ª and 3ª)] for each speed considered (60°/s and 180°/s). As post hoc process, multiple comparison was used, with correction of the confidence interval through the Bonferroni method. The level of significance was set a $P < 0.05$ for all assessments.

RESULTS

Figure 1 displays PT values at the speed of 60°/s during the three sets with one and two minutes of RI. With one minute of RI the children presented a reduction of 2.03% from the 1ª to the 2ª set ($P=0.920$), of 4.49% from the 1ª to the 3ª set ($P=0.368$), and of 2.51% from the 2ª to the 3ª set ($P=0.424$); but when comparing these results, no statistically significant differences have been found in PT values.

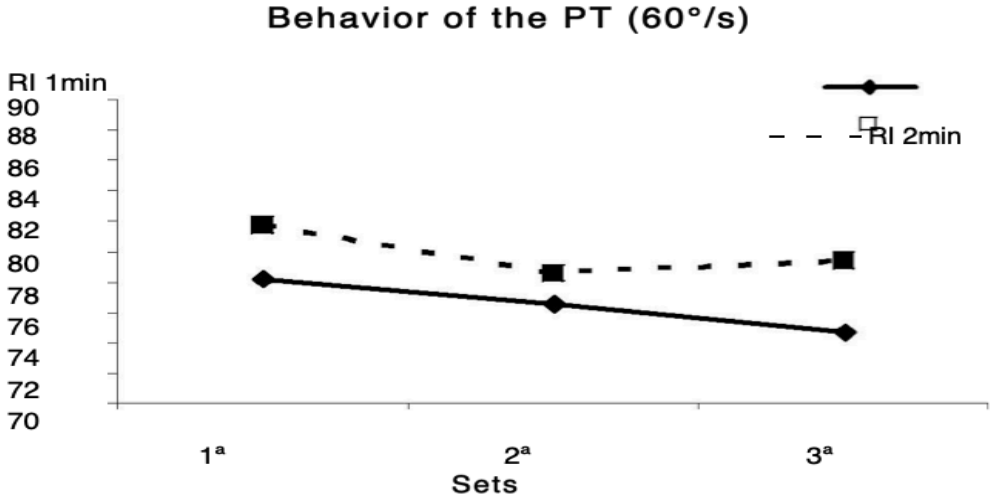

Figure 1 - Peak torque (PT) in different rest intervals (1min RI and 2min RI) at an angular speed of 60°/s.

Regarding the 2min RI, the children presented a reduction of 3.76% from the 1st to the 2nd set (P=0.355), and of 2.82% from the 1st set to the 3rd set (P=0.341), and an increase of 0.98% from the 2nd to the 3rd set (P=1.0). In the three sets, no significant differences have been found in PT values either. In the comparison between one minute and two minutes, no statistically significant differences have been observed in the children (P=0.565).

Figure 2 presents PT values at a speed of 180°/s throughout the three sets. When applying 1 min RI, the children presented a reduction of 2.33% from the 1st to the 2nd set (P=0.351), of 2.94% from the 1st to the 3rd set (P=0.61), and of 0.62% from the 2nd to the 3rd set (P==1.0).

As for the 2 min RI, the children presented a reduction of 0.66% from the 1st to the 2nd set (P=1.0), of 2.25% from the 1st to the 3rd set (P=0.439). Besides, in all three sets, no statistically significant differences have been found in PT values, at a speed of 180°/s. In relation to the RIs of one and two minutes, no statistically significant differences have been found either within the group of children (P=0.32).

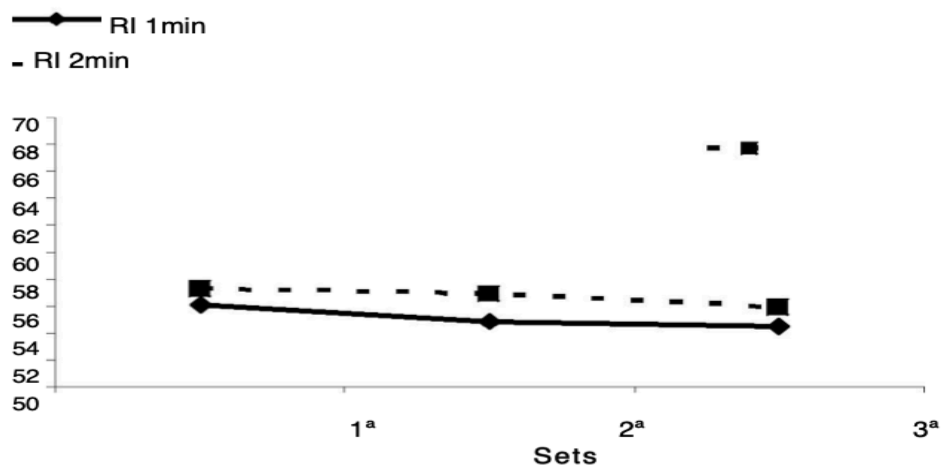

Figure 2 – Peak Torque (PT) in different rest intervals (1min RI and 2min RI) at an angular speed of 180°/s.

Figure 3 presents TW values at a speed of 60°/s along the three sets. With one minute of RI there were reductions of 0.30% from the 1st to the 2nd set (P=1.0), of 4.06% from the 1st to the 3rd set (P=1.0), and of 3.77% from the 2nd to the 3rd set (P=1.0). In all series, no statistically significant differences have been found in TW values.

Regarding the 2 min RI, the children demonstrated a reduction of 0.30% from the 1st set to the 2nd (P=1.0), of 0.75% from the 1st to the 3rd set (P=0.71), and of 0.45% from the 2nd to the 3rd set (P=1.0). In the comparison between one minute and two minutes of RI no significant differences have been observed either in the group of children (P=0.58) in the behavior of the TW during the three sets.

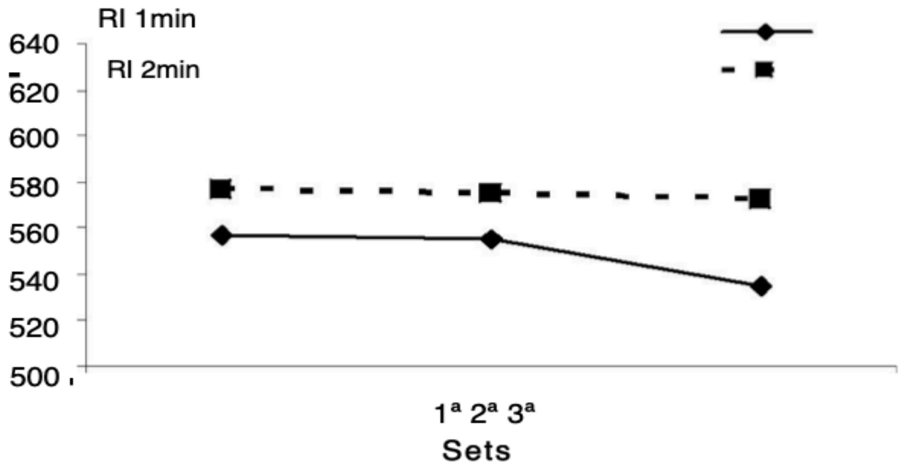

Figure 3 – Total work (TW) in different rest intervals (1min RI and 2minRI) at an angular speed of 60°/s.

Figure 4 presents TW values at a speed of 180°/s along the three sets. With one and two minutes, there were reductions of 1.77% from the 1ª to the 2ª set (P=0.90), of 4.43% from the 1ª to the 3ª set (P=1.000), and of 2.71% from the 2ª to the 3ª set (P=1.000). In all sets, no significant differences have been found in TW values.

Regarding the 2min RI, the children presented an increase of 0.21% from the 1st to the 2nd set (P=1.0), and of 0.09% from the 1st to the 3rd set (P=1.0), and reduction of 0.12% from the 2nd to the 3rd set (P=1.0). However, in all three sets no statistically significant differences have been found in TW values. In the comparison between one and two minutes no significantly differences have been found in the group of children (P=0.580).

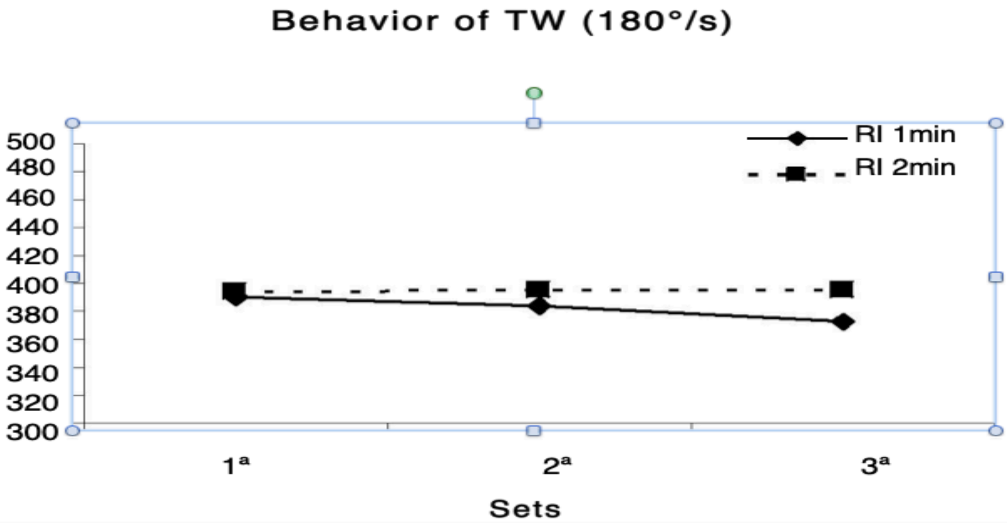

Figure 4 - Total work (TW) in different rest intervals (1minRI and 2minRI) at the angular speed of 180°/s.

DISCUSSION

Isokinetic dynamometers for assessment of muscle strength in children and adolescents have been used by several researchers since the 1970s and 1980s (GILLIAM et al., 1979; OSTERING, 1986); however, studies with reference values for PT in children are scarce. Recently, Wiggin et al. (2006) assessed the PT in 3,587 children aged between six and thirteen years old. A total of 194 subjects aged, on average, 11.3 years old, were assessed, and an average PT of 80 Nm was verified, a value similar to that of the present study (79.5 Nm). Other studies have found results similar to those of this study. Holm, Steen and Olstad (2005), in a longitudinal study, monitored the variation of PT since 10 to 21 years old and found, for the age of 11.6 years old, a PT of 85 Nm. Kotzamanidou et al. (2005) reported a PT value of 80.1 Nm in children aged 10.5 years old, and Paraschos et al. (2005) presented similar data (85 Nm) in children of that same age.

In a systematic review by Benson, Torode and Singh (2008) about the effects of WT in children, the variable RI does not figure as an important factor of analysis; however, since one of the main purposes for practicing WT is the development of muscle strength and mass, knowledge on the most adequate RI for this population becomes indispensable

The first studies aiming to investigate muscle performance and recovery in children were conducted with high-intensity runs and short-length sprints on cycle ergometers. With such a purpose, Hebestreit, Mimura and Bar-Or (1993) verified that children between eight and twelve years old were able to reproduce at 100% their performance in the Wingate test, with only two minutes of rest, differently from young adults, who needed 10 minutes. The RI was significantly lower.

Similarly, Lazaar et al. (2002), with 10s runs and 30s rest intervals, found a decrease in the distance covered of 12% in children and 20% in men. The authors reported that children managed to maintain the initial power peak, while adults presented a decrease of 28.5%. Another study, by Ratel et al. (2009), observed a difference in the performance of 10s sprints on cycle ergometers, with rest interval of 15s. The children presented a decrease in power peak of 14%, and adults, 40%.

Recent researches have used isokinetic contractions with different RIs for comparison of fatigue process in different age groups. Thus, Kotzamanidou et al. (2005) verified the differences of this process between male adults and pre-adolescents through isokinetic contractions composed of 25 repetitions, at a speed of 60^{o}/s. The authors assessed the PT after RIs of one, two and three minutes. They observed that, after three minutes, those boys reached 89.1% of the initial PT, while the adults obtained only 69.4%. They concluded that data indicated a better recovery in muscle performance in all RIs in the pre-adolescents than in the adults and attributed the findings to neural factors in the process of muscle contraction.

Similarly to the study aforementioned, Zafeiridis et al. (2005) reported a faster recovery in children than in adolescents and adults, using intensity protocols of 30 seconds (four set of eighteen repetitions, with one minute of RI) and 60 seconds (two sets of thirty-four repetitions, with two minutes of RI) in isokinetic exercises of knee flexion, both for PT and TW. The authors suggested a strong relationship between energy production and anaerobic capacity, and observed that differences between the contributions of the anaerobic and aerobic pathways for energy production can explain part of the fatigue process among children and adolescents.

Paraschos et al. (2007) compared adults with pre-adolescents too, using isokinetic dynamometer, with a protocol of twenty-five repetitions at a speed of 60^{o}/s. The results demonstrate a decrease in the end of the test (after the execution of all twenty-five repetitions) of 25.7% for the pre-adolescents, and 36.1% for the adults. Regarding the fatigue process, the authors pointed that adults seem to be more sensitive than pre-adolescents due, especially, to neuromuscular factors. Therefore, all three studies aforementioned agree with the results of the present study, which demonstrated very fast recovery capacity of muscle performance in children.

About the rest interval, Dipla et al. (2009) used the 1min RI between the sets. The authors verified a significant reduction in PT and TW between the 1st and the 4th set, both in the group of adults and adolescents; however, the children managed to maintain muscle performance. In face of these results, the authors inferred that differences between intramuscular mechanisms and types of fibers contribute to explain lower fatigue in children and, then, concluded that resistance to fatigue decreases gradually from childhood until adolescence. These results agree with those of the present study, since, with the 1min RI, the children have not presented significant reduction in PT and TW during the three sets.

In another analysis, also with a purpose similar to that of the present study, that is, to verify the effects of different rest intervals in muscle performance, Faigenbaum et al. (2008) observed three rest intervals (one, two and three minutes) in three groups: 1) children (n=13, 11.3 years old), 2) adolescents (n=13, 13.6 years old) and 3) men (n=17, 21.4 years old). Isoinertial exercises were used (three sets of ten maximum repetitions). The authors found significant differences in the number of repetitions in the three RIs between the children, the adolescents and the adults. With 1min RI, the results were 27.9; 26.9 and 18.2, respectively; with 2min RI, 29.6; 27.8 and 21.4, respectively; and with 3min RI, 30.0; 28.8 and 23.9, respectively. In face of that, the authors concluded that children and adolescents have better capacity of maintaining muscle performance than adults, in moderate-intensity intermittent exercises.

In spite of the methodological difference concerning the type of exercise used in the study by Faigenbaum et al. (2008), the results found are similar to those of the present study, both in high-intensity intermittent exercises (three sets of ten repetitions at 60^o/s) as in moderate-intensity exercises (three sets of ten repetitions at 180^o/s); that is, children have a good capacity of recovering muscle performance, regardless of the type of exercise performed.

The fact that children have a faster recovery than adults do after performing an intense physical exercise seems to be well accepted by professionals who work with physical activities, but Falk and Dotan (2006) state that data demonstrating this difference are surprisingly scarce.

Some mechanisms that can explain the advantage of this faster recovery in children in comparison with adults after a high-intensity intermittent exercise would be a higher percentage of type I muscle fibers, lower activity of the glycolytic metabolism, lower neuromuscular activation, lower capacity of activation of type II fibers, better regulation of the acid-base mechanism and, finally, a higher rate of re-synthesis of CP. (RATEL et al, 2006; FALK; DOTAN 2006). Other factor that may explain that relates to the low capacity of strength production in children when compared with other populations (FAINGENBAUM et al., 2008). Pincivero et al. (2000) demonstrated that a greater strength production relates to a greater fatigue. A possible explanation for this relation is that stronger individuals present, during the exercise, greater intramuscular pressure (SADAMOTO; BONDE-PETERSEN; SUZUKI, 1983), greater vascular occlusion, greater accumulation of metabolites, decrease in oxygen supply in the muscle and early fatigue during muscle contraction (KENT-BRAUN et al., 2002; PARKER et Al., 2007).

Besides these factors, recent study by Ratel et al. (2009) comparing muscle oxidative capacity between children and adults through ^{31}P-Mrs, proved that the results found reflected a greater mitochondrial oxidative capacity in children. Thus, they concluded that a high capacity of ATP regeneration, through the aerobic system in children, could be an important factor for the better resistance to fatigue among this population, in high-intensity intermittent exercises.

Finally, in these important review studies on fatigue in children, the authors state that the various factors that explain this capacity of resistance influence, mainly, the range of muscle power production, affecting, thus, fatigue extension and, consequently, its recovery.

In conclusion, the findings of this study indicate that both the 1min RI as the 2min RI do not impair muscle development in children, who need only one minute of RI to maintain the same level of PT and TW at different angular speeds (60°/s and 180°/s) in subsequent sets. In face of that, these results should be taken into consideration, because they can assist Physical Education professionals in the preparation of WT programs for children, since the RI is of fundamental importance for an adequate training prescription and optimizes the results from the practice of resistance training within this population. Further studies should be conducted aiming to elucidate the main variables related to resistance training (e.g. volume and frequency of training, RI, etc.) during childhood.

REFERENCES

AMERICAN ACADEMY OF PEDIATRICS. Strength training by children and adolescents. **Pediatrics**, Evanston, v. 121, p. 835-840, 2008.

AMERICAN COLLEGE OF SPORTS MEDICINE. The prevention of sports injuries of children and adolescents. **Medicine and Science in Sports and Exercise**, Madison, v. 25, no. 8, p. 1-7, 1993. Supplement 1.

AZEVEDO, J. C. V. et al. Comparação entre avaliação objetiva e auto-avaliação da maturação sexual em crianças e adolescentes. **Jornal de Pediatria**, Rio de Janeiro, v. 85, p. 135-142, 2009.

BEHRINGER, M. et al. Effects of strength training on motor performance skills in children and adolescents: a meta-analysis. **Pediatric Exercise Science**, Champaign, v. 23, no.2, p. 186-206, 2011.

BENSON, A. C.; TORODE, M. E.; SINGH, M. A. F. Effects of resistance training on metabolic fitness in children and adolescents: a systematic review. **Obesity Reviews**, Oxford, v. 9, p. 43-66, 2008.

BOTTARO, M.; RUSSO, A.; OLIVEIRA, R. J. The effects of rest interval on quadriceps torque during an isokinetic testing protocol in elderly. **Journal of Sports Science & Medicine**, Bursa, v. 4, p. 285-290, 2005.

BOTTARO, M. et al. Effects of age and rest interval on strength recovery. **International Journal of Sports Medicine**, Stuttgart, v. 31, p. 22-25, 2010.

BOTTARO, M. et al, D. Effects of rest duration between sets of resistance training on acute hormonal responses in trained women. **Journal of Science and Medicine in Sports**, [S.l.], v. 12, p. 73-78, 2009.

CHENG, A. J.; RICE, C. L. Fatigue and recovery of power and isometric torque following isotonic knee extensions. **Journal of Applied Physiology**, Washington, DC, v. 99, p. 1446-1452, 2005.

DAVIES, G. J.; HEIDERSCHEIT, B.; BRINKS, K. Test interpretation. In: BROWN, L. E. (ed.). **Isokinetics in human performance**. Champaign: Human Kinetics. 2003. p. 3-24.

DIPLA, K. et al. Fatigue resistance during high-intesnsity intermittent exercise fron childhood to adulthood in males and females. **European Journal of Applied Physiology**, Berlin, v. 106, p. 645-653, 2009.

ERIKSSON, B. O.; GOLLNICK, P. D.; SALTIN, B. Muscle metabolism and enzyme activities after training in boys 11 to 13 years old. **Acta Physiologica Scandinavica**, Stockholm, v. 87, p. 485-487, 1973.

ERIKSSON, B. O.; GOLLNICK, P. D.; SALTIN, B. The effects of physical training on muscle enzyme activities and fiber composition in 11 years old boys. **Acta Paediatrica Belgica**, Bruxelles, v. 28, p. 245-252, 1974. Supplement 1.

ERNESTO, C. et al. Effects of different rest interval on isokinetic muscle performance among older adults. **Revista Brasileira de Fisioterapia**, São Carlos, v. 13, p. 65-72, 2009.

FAIGENBAUM, A. D. et al. Effect of rest interval length on bench press performance in boys, teens and men. **Pediatric Exercise Science**, Champaign, v. 20, p. 457-469, 2008.

FAIGENBAUM, A. D. et al. Youth resistance training: updated position statement paper from the National Strength and Conditioning Association. **Journal of Strength Conditioning Reserch**, [S.l.], v. 23, p. S60-79, 2009. Supplement 5.

FALK, B.; DOTAN, R. Child–adult diferences in the recovery from high-intensity exercise. **Exercise and Sports Sciences Reviews**, [S.l.], v. 34, no. 3, p. 107-112, 2006.

GILLIAM, T. B. et al. Isokinetic torque in boys and girls ages 7 to 13: Effect of age, height and weight. **Research Quarterly**, Washington, DC, v. 50, p. 599-609, 1979.

HALD, N. A. S.; SANDER, E. J. Effect of visual feedback on maximal and submaximalisokinetic test measurements of normal quadriceps and hamstrings. **Journal of Orthopaedic and Sports Physical Therap**, Washington, DC, v. 9, p. 86-93, 1987.

HEBESTREIT, H.; MIMURA, K. I.; BAR-OR, O. Recovery of muscle power changes in after high-intensity short-term exercise: comparing boys. **Journal of Applied Physiology**, Washington, DC, v. 74, p. 2875-2880, 1993.

HILL-HAAS, S. et al. Effects of rest interval during high-repetition resistance training on strength, aerobic fitness, and repeated-sprint ability. **Journal of Sports Science**, London, v. 25, no. 6, p. 619-628, 2007.

HOLM, I.; STEEN, H.; OLSTAD, M. Isokinetic muscle performance in growing boys from pre-teen to maturity. An eleven year longitudinal study. **Isokinetics and Exercise Sciense**, Lansdale, v. 13, p. 153-158, 2005.

KENT-BRAUN, J. A. et al. Human skeletal muscle responses vary with age and gender during fatigue due to incremental isometric exercise. **Journal of Applied Physiology**, Washington, DC, v. 93, p. 1813-1823, 2002.

KOTZAMANIDOU, M. Et al. Differences in recovery between adult and prepubertal males after a máximal isokinetic fatigue task. **Isokinetics and Exercise Science**, Lansdale, v. 13, p. 261-266, 2005.

KRAEMER, J. B. et al. Effects of single vs. multiple exercises sets of weight training: Impact of volume, intensity and variations. **Journal of Strength and Conditioning Research**, Lincoln, v. 11, p. 139-147, 1997.

KRAEMER, W. J. et al. Effects of different heavy-resistance exercises protocols on plasma B-endorphin concentrations. **Journal of Applied Physiology**, Washington, DC, v. 74, p. 450-459, 1993.

KRAEMER, W. J. et al. Changes in hormonal concentrations following different heavy-resistance exercise protocols in women. **Journal of Applied Physiology**, Washington, DC, v. 75, p. 594-604, 1993.

KUNO, S. et al. Muscle metabolism during exercise using phosphorus 31 nuclear magnetic resonancespectroscopy in adoslescents. **European Journal of Applied Physiology**, Berlin, v. 62, p. 151-156, 1991.

LAZAAR, N. et al. Performance during intermittent running exercise: effect of age and recovery duration [in French]. **Biométrie Humaine Kiné-Anthropométrie**, [S.l.], v. 20, p. 29-34, 2002.

LUBANS, D. R.; AGUIAR, E. J.; CALLISTER, R. The effects of free weights and elastic tubing resistance training on physical self-perception in adolescents. **Psychology Sports Exercise**, Amsterdam, v. 11, p. 497-504, 2010.

MALINA, R. M. Weight training in youth-growth, maturation, and safety: an evidence-based review. **Clinical Journal of Sport Medicine**, New York, v. 16, p. 478-487, 2006.

McGUIGAN, M. R. et al. Eight weeks of resistance training can significantly alter body composition in children who are overweight or obese. **Journal of Strength and Conditioning Research**, Lincoln, v. 23, n. 1, p. 80-85, 2009.

NATIONAL STRENGTH AND CONDITIONING ASSOCIATION. **Youth resistance training**: position statement paper and literature review. Colorado Springs: NSCA, 1996.

OSTERNIG, L. Isokinetic dynamometry: implications for muscle testing and rehabilitation. **Exercise and Sport Science Reviews**, [S.l.], v. 144, p. 45-79, 1986.

PARASCHOS, A. et al. Fatigue differences between adults and prepubertal males. **International Journal of Sports and Medicine**, Stuttgart, v. 28, p. 958-963, 2007.

PARCELL, A. C. et al. Minimum rest period for strength recovery during a common Isokinetic testing protocol. **Medicine and Science in Sports and Exercise**, Madison, v. 34, p. 1018-1022, 2002.

PARKER, B. A. et al. Sex differences in leg vasodilation during graded knee extensor exercise in young adults. **Journal of Applied Physiology**, Washington, DC, v. 103, p. 1583-1591, 2007.

PINCIVERO, D. M. et al. Gender differences in relationship between quadriceps work and fatigue during high-intensity exercise. **Journal of Strength and Conditioning Research**, Lincoln, v. 14, n. 2, p. 202-206, 2000.

Pincivero, D. M. et al. The effects of rest interval on quadriceps torque and perceived exertion in healthy males**.** **Journal of Sports Medicine and Physical Fitness**, Torino, v. 39, n. 4, p. 294-299, 1999.

RATEL, S. et al. Effects of age and recovery duration on performance during multiple treadmill sprints.
International Journal of Sports and Medicine, Stuttgart, v. 27, p. 1-8, 2006.

RATEL, S. et al. High-intensity intermittent activities at school: controversies and facts. **Journal of Sports and Medicine and Physical Fitness**, Torino, v. 44, p. 272-80, 2008.

RATEL, S. et al. Skeletal muscle oxidative capacity in children: a 31P-MRS study. **Fundamental & Clinical Pharmacology**, Paris, v. 23, p. 79-85, 2009.

ROBINSON, J. M. et al. Effects of different weight training exercise/rest interval on strength, power and high intensity exercise endurance. **Journal of Strength and Conditioning Research**, Lincoln, v. 9, no. 4, p. 216-221, 1995.

SADAMOTO, T. et al. Skeletal muscle tension, flow, pressure, and EMG during sustained isometric contractions in humans. **European Journal of Applied Physiology Occupational Physiology**, Berlin, v. 51, p. 395-408, 1983.

STUMBO, T. A. et al. The effect of hand-grip stabilization on isokinetic torque at the knee. **Journal of Strength and Conditioning Research**, Lincoln, v. 15, no. 3, p. 372-377, 2001.

TANNER, J. M. **Growth at adolescence**. Oxford: Blackwell Scientific Publications, 1962.

WEIR, J. P.; WAGNER, L. L.; HOUSH, T. J. The effect of rest interval lenght on repeated maximal bench presses. **Journal of Strength and Conditioning Research**, Lincoln, v. 8, p. 58-60, 1994.

WIGGIN, M. et al. Percentile values of isokinetics peak torque in children six through thirteen years old. **Pediatric Physical Therapy**, Baltimore, p. 3-18, 2006.

WILLARDSON, J. M.; BURKET, L. N. A comparison of three different rest intervals on the exercise volume completed during a workout. **Journal of Strength and Conditioning Research**, Lincoln, v. 19, p. 23-26, 2005.

ZAFEIRIDIS, A. et al. Recovery during high-intensity intermittent anaerobic exercise in boys, teens, and men. **Medicine and Science in Sports and Exercise**, Madison, v. 37, p. 505-512, 2005.

Auhtor address: José Carlos de Britto Vidal Filho, Condomínio do Lago Sul conj. C Casa 05, Brasília-DF, Brasil. E-mail: josec@ucb.br