Rev Bras Cineantropom Hum

original article

DOI: http://dx.doi.org/10.5007/1980-0037.2018v20n3p332

Effect of downhill walking training on neuromuscular variables

Efeito do treinamento de caminhada no declive em variáveis neuromusculares

Thiago Pires de Oliveira[1,2,3]
Leonardo Coelho Rabello de Lima[1,4,5]
Felipe Bruno Dias de Oliveira[1,6]
Benedito Sérgio Denadai[1]
Camila Coelho Greco[1]

Abstract – Walking involves small adjustments to maintain body balance. However, the demand for these adjustments may be different during downhill walking. The aim of this study was to analyze the effect of periodized downhill walking training on neuromuscular responses of knee flexors (KF). Seventeen active males (Age = 22.9 ± 3.9 years) were randomly assigned into two groups: control, level walking (CG, N = 8) and downhill walking (DWG, N = 9). Individuals performed the following procedures, in different days: 1) Maximal voluntary contractions to determine peak torque (PT) and rate of torque development (RTD) at different time intervals from the onset of muscle contraction. The test was performed before (Pre) and after (Post) a 4-week downhill walking training period. PT and peak RTD did not change after the training period ($p > 0.05$). However, there was significant increase in RTD at 150 ms and 200 ms after the onset of muscle contraction ($p < 0.05$). Additionally, the electromyographic activity (root mean square) of the biceps femoris and semitendineous muscles presented an increase after the training period ($p < 0.05$). Thus, downhill walking training can promote improvement RTD and muscle activity in the late phase of muscle contraction, which can have important implications during downhill walking, in which a rapid action of KF can help body balance against the disturbance generated by the slope.

Key words: Walking; Electromyography; Muscle strength.

Resumo – *O ato de caminhar envolve pequenos ajustes para manutenção do equilíbrio corporal. No entanto, a demanda por estes ajustes pode ser diferente na caminhada no declive. O objetivo deste estudo foi analisar o efeito do treinamento periodizado de caminhada em declive na resposta neuromuscular dos músculos flexores do joelho (KF). Dezessete indivíduos ativos do gênero masculino (Idade = 22,9 ± 3,9 anos) foram divididos randomicamente em dois grupos: controle, com caminhada no plano (CG, n = 8), e caminhada em declive (DWG, n = 9). Os indivíduos realizaram os seguintes procedimentos, em diferentes dias: 1) Contrações voluntárias máximas para determinar o pico de torque (PT) e a taxa de desenvolvimento de torque (RTD) em diferentes intervalos de tempo após o início da contração. Os testes foram realizados antes (Pré) e após (Pós) um período de quatro semanas de treinamento de caminhada em declive. O PT e a RTD pico não apresentaram mudança após o período de treinamento ($p > 0,05$). No entanto, houve aumento significante na RTD nos momentos 150 e 200 ms para o grupo DWG ($p < 0,05$). Além disso, a atividade eletromiográfica (root mean square) do músculo bíceps femoral e do semitendinoso apresentou aumento após o período de treinamento ($p < 0,05$). Portanto, o treinamento de caminhada em declive pode promover aumento na RTD em sua fase tardia e na ativação muscular, o que pode ter implicações em condições de caminhada no declive, que podem auxiliar a estabilizar o corpo contra a perturbação gerada pelo declive.*

Palavras-chave: *Caminhada; Força muscular; Eletromiografia.*

1 “Júlio de Mesquita Filho” State University. Institute of Biosciences. Laboratory of Human Performance. Rio Claro, SP. Brazil

2 Anhanguera University Center. Leme, SP. Brazil.

3 Claretiano College. Rio Claro, SP. Brazil.

4 Salesiano University Center of São Paulo. School of Physical Education. Campinas, SP. Brazil.

5 “Hermínio Ometto” University Center. School of Biological Sciences and Health. Araras, SP. Brazil.

6 “Albert Einstein” Israeli Hospital. Israeli Institute of Education and Research. São Paulo-SP. Brazil.

Received: February 10, 2018
Accepted: April 23, 2018

INTRODUCTION

Gait (ambulation or walking) implies a constant displacement of the center of mass (CM), which, although of small magnitude, tends to provide a constant loss response and balance recovery. This characteristic occurs even on a flat surface, which tends to offer the most natural condition for the performance of these adjustments[1-2]. On the other hand, during downhill walking, there is a tendency to increase the thrust ratio suffered due to the action of the force of gravity, thus producing accelerations that can generate disturbances in the posture and compromise the gait control[3-4]. Such interferences may cause responses in specific areas responsible for gait stability and postural control on any surface, especially in the vestibular, visual and somatosensory systems, and also generate adjustments in muscle control[5-6].

For a better understanding of gait, many authors have analyzed the behavior of certain muscle groups; however, the action of knee flexor muscles (KF) seems to be still poorly understood in the downhill walking condition (DW), and there are some contradictions in literature with respect to the action of these muscles in DW. In a study by Franz and Kram[4], the authors found that the action of the biceps femoralis muscle (BF) during downhill walking was similar to walking on a flat surface. On the other hand, Hunter et al.[7] found greater action of BF during almost all the balance phase during DW. In fact, under conditions where instability is imposed during gait on a flat surface, both the hamstring muscles and the muscles that form the sural triceps tend to respond very rapidly (60-80 ms after the onset of contraction) and such a response, found in the study by Hunter et al.[7] was suggested as a form of rapid action of muscles (particularly BF) in order to stabilize the body in the downhill walking condition. Thus, a variable that could greatly aid the understanding of neuromuscular responses in this condition is the rate of torque development (RTD), which represents the ability to generate muscle strength rapidly at initial moments of muscle contraction[8]. Reduction in the ability to produce rapid force, expressed through the impairment of RTD, particularly of the plantar flexor and hip extensor muscles, has been related to greater risk of falls[9-10], especially in older adults, possibly due to the importance of this variable in the postural readjustment.

A significant part of studies on downhill walking have analyzed acute responses to exercise. Thus, the analysis of neuromuscular responses after DW training sessions could be interesting and provide important implications for training prescription in the context of physical fitness, health promotion and quality of life. Therefore, the aim of this study was to analyze the effect of periodized downhill walking training on the neuromuscular response of KF muscles in active individuals. The hypothesis of this study was that DW training would cause an increase in the RTD of KF, particularly in function of the importance of these muscles in this condition, without alteration of this variable after walking training on a flat surface.

METHODOLOGICAL PROCEDURES

Participants

Participants were 17 physically active male volunteers (Age = 22.9 ± 3.9 years; Body mass = 77.9 ± 14.6 kg and Height = 1.74 ± 0.08 m). No volunteer was engaged in any type of aerobic or resistance training for a minimum of six months and had no medical history of muscle or joint problems. All volunteers were verbally informed and in written of their rights, potential risks and benefits and signed the free and informed consent form. During the study period, there was no withdrawal by volunteers or absences on the days of experiment. This project was approved by the Research Ethics Committee of the Institute of Biosciences, UNESP, Rio Claro Campus (CEP-IB-UNESP) Protocol number: 4371.

Adaptation to experiment and test protocol

Before starting the experimental period, all subjects performed two sessions of familiarization with the isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, Shirley, NY, USA) on different days in order to reduce the learning effects regarding the maximum voluntary contraction tests of the study (CVM).

Experimental design

All tests were performed under controlled temperature (21 °C) and at the same time of day to avoid possible external interferences in results and volunteers were randomly divided into two groups: control, n = 8 (CG) and DW training, n = 9 (DWG). The experiment was developed over six weeks, with the first week being used to apply pre-tests (force and EMG variables). From the second to the fifth week, the training protocol was applied, containing a total of 28 sessions, seven sessions / week, held from Monday to Friday with two extra sessions on Tuesday and Thursday to complete the seven weekly sessions. The last week was destined to the accomplishment of post-tests (force and EMG variables).

Training

The initial walking speed for the DWG group was 5 km / h with 16% slope. For the CG group, the initial velocity was 4.5 km / h with 0% slope. For both groups, each training session lasted 20 minutes and the initial velocity increased by 0.5 km/h at the beginning of each week. In order to modify the training intensities, the velocity in downhill walking was 0.5 km / h higher than in the control condition, since in downhill walking, the energy cost is lower in relation to the flat surface[11].

Rate of Torque Development (RTD)

Two isometric CVM were performed for KF muscles, with 5 s of duration and 3 minutes of recovery between them. Volunteers were instructed in a standardized way to carry out “the effort as fast and strong as possible”.

The contraction of highest isometric peak torque (IPT) was considered for analyses. All force tests were performed on the isokinetic dynamometer synchronized to a biological signal acquisition module (EMG System®, Brazil), with frequency of 1000 Hz. Torque data were filtered (Butterworth, 4th order, cutoff frequency 10 Hz) and analyzed in MatLab 6.5 software. IPT was considered the highest torque value produced. RTD was determined through the inclination of the torque-time curve at 30, 50, 100, 150 and 200 ms after the onset of contraction[12-13].

Acquisition of the electromyographic signal (EMG)

Force tests were synchronized with the electromyographic signal collection by a four-channel biological signal acquisition module. Electrodes were placed in the semitendinosus (ST) and biceps femoris (BF) muscles. Ag/AgCl, disposable, passive and bipolar contact surface electrodes were placed according to SENIAM[14], and the reference electrode was placed in the ulna styloid process. Electrodes were connected to a 100-times gain preamp, and collections started with EMG activity values below 5 μV. The gain promoted in the electromyograph was 20 times, which totaled a gain of 2000 times. A high pass filter (2nd order Butterworth, 20 Hz cutoff frequency) and a low pass filter (4th order Butterworth, 500 Hz cutoff frequency) were used. Analogical signals were transformed into digital by an A/D plate with input range from -5 to +5 V and were analyzed by a specific software with sampling frequency calibrated at 1000 Hz. Data were analyzed in MatLab 6.5 software. RMS (root mean square) was determined by the average RMS over a period of one second (0.5 s before 0.5 s after IPT) for IPT. For peak RTD and RTD at different time intervals after onset of contraction, the mean RMS was used in the period from the onset of contraction until peak RTD or 30 ms, 50 ms, 100 ms, 150 ms and 200 ms after the onset of contraction, for the RTD at different time intervals. RMS was normalized by the maximum RMS value (% RMS max) in the period of time used for IPT analysis.

Statistical analysis

Data are expressed as mean ± SD. Data normality was verified through the Shapiro-Wilk test. For the variables that present normal distribution, the analysis of the training effect was performed by two-way ANOVA (group x time) supplemented by the LSD test. Variables that did not present normal distribution were compared by the Friedman test (repeated measures) or Kruska-Wallis test (non-repeated measurements). In all tests, significance level was $p < 0.05$.

RESULTS

Anthropometric variables (age, body mass, height and body mass index) did not show significant difference after training in any of the groups ($p > 0.05$).

The IPT and peak RTD values of KF muscles did not show significant differences between pre and post training moments ($p > 0.05$) (Table 1).

Table 1. Mean values ± SD of isometric peak torque (IPT), rate of peak torque development (peak RTD) of control (CG) training groups (DWG), before (Pre) and after (Post) the training period

	CG (n = 8)		DWG (n = 9)	
	Pre	Post	Pre	Post
IPT (N×m)	112.0 ± 29.8	114.2 ± 29,2	114.5 ± 34.4	115.7 ± 31.9
peakRTD (N×m.s^{-1})	632.6 ± 227.1	589.9 ± 213.9	514.1 ± 151.9	579.5 ± 127.9

However, when RTD data were analyzed at the different time intervals after the onset of contraction, a statistical difference was observed at Post moment in relation to Pre moment at times 150 ms and 200 ms after onset of contraction ($p < 0.05$) (Figure 1).

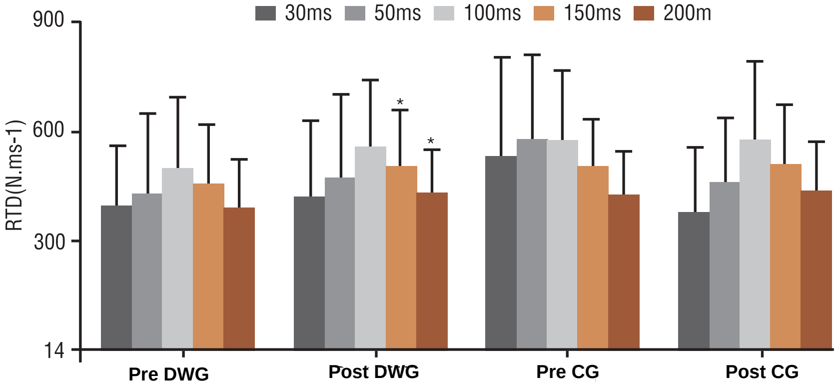

Figure 1. Mean values ± SD of the rate of torque development at times (RTD) for control (CG, n = 8) and training groups (DWG, n = 9), before (Pre) and after training. * $p < 0.05$ compared to Pre.

When EMG data were analyzed by means of the RMS in IPT (RMS / IPT) of ST and BF muscles for CG and DWG groups, a statistically significant difference was observed in the Post moment in relation to Pre moment for the BF muscle for DWG ($p < 0.05$) (Figure 2).

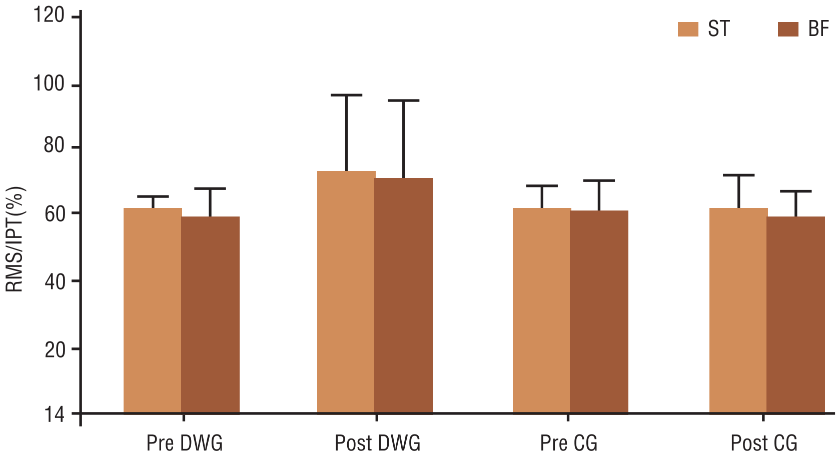

Figure 2. Mean values ± SD of root mean square normalized by peak isometric torque (RMS / IPT), of ST and BF muscles for the control (CG, n = 6) and training groups (DWG, n = 9) before (Pre) and after (Post) the training period. * $p < 0.05$ compared to Pre.

When analyzing the RMS behavior during peak RTD (%) for ST and BF muscles in relation to CG and DWG groups, a statistically significant difference was found at Post moment in relation to Pre moment for ST muscle after the training period ($p < 0.05$) (Figure 3).

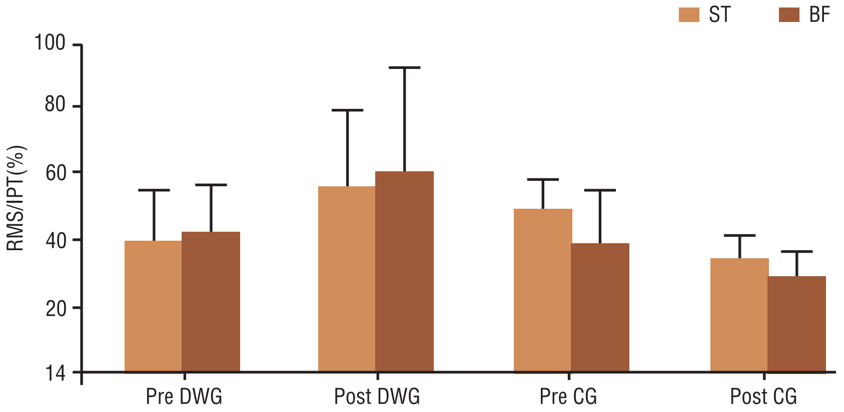

Figure 3. Mean values ± SD of root mean square normalized by the rate of peak torque development (RMS / peak RTD (%)), of ST and BF muscles for control (CG, n = 6) and training groups (DWG, n = 9), before (Pre) and after (Post) the training period. * $p <0.05$ compared to Pre.

Regarding RMS values during RTD (RTDRMSt), a significant increase was observed in the DWG group for the BF muscle at times 100, 150 and 200 ms and for ST muscle at times 50, 100, 150 and 200 ms after the training period ($p <0.05$) (Figure 4).

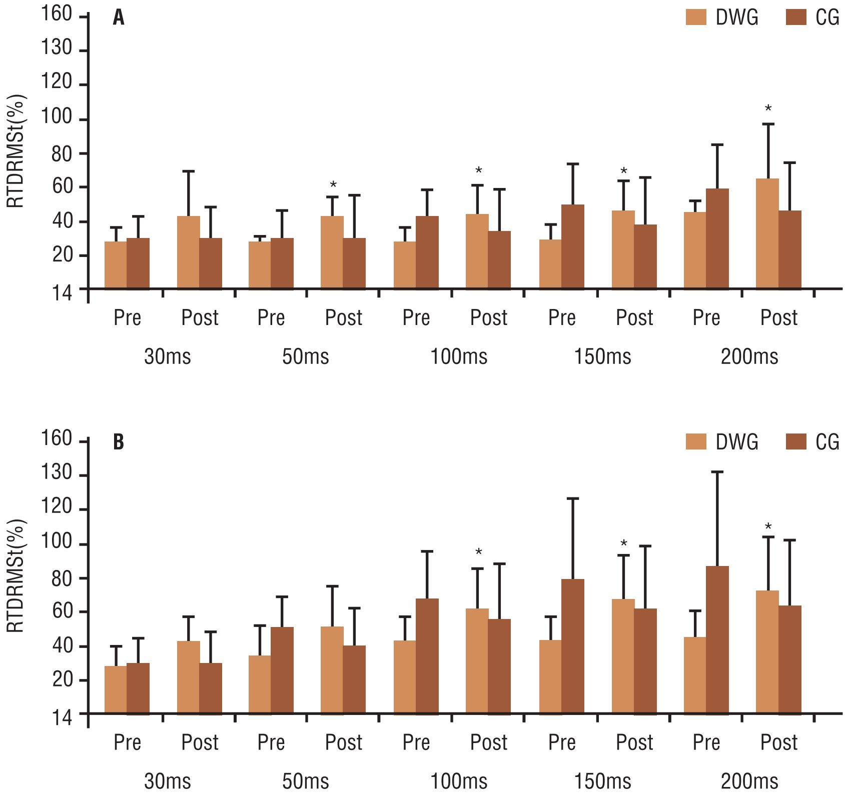

Figure 4. Mean values ± SD of root mean square during RTD (RTDRMSt) at times 30, 50, 150 and 200 ms for the semitendinosus (A) and biceps femoris (B) muscles of control (CG, n = 6) and training groups (DWG, n = 9), before (Pre) and after (Post) the training period * $p <0.05$ in relation to Pre.

DISCUSSION

The main aim of this study was to analyze the effect of periodized downhill walking training on neuromuscular responses of knee flexors (KF). An increase in rapid force production capacity was observed, evidenced by a significant change in the late phase of RTD after the onset of contraction, and higher EMG activity in the RTDRMSt of BF and ST muscles, particularly in the late phase of contraction. Therefore, as a rapid muscular action may be important to stabilize the body against the disturbance caused by the slope, DW training may be interesting to improve specific aspects regarding the reestablishment of balance in this condition.

When a detailed analysis of the action of KF muscles during the gait cycles in the flat surface, important aspects regarding the dynamic stability of the knee are observed, mainly with respect to the translational, lateral and anterior forces exerted by the tibia, the deceleration of the leg before contact of the heel with the ground and also its synergistic action to the extensor muscles of the knee in order to stabilize this joint during the gait phases[15-16]. On the other hand, downhill walking tends to provide less stability and greater balance readjustments are required compared to walking on a flat surface and other surfaces[17-18]. RTD is considered an important variable because it represents the ability to exert rapid force and, to some extent, such characteristic could be of vital importance for the maintenance of balance under different conditions[8-9-10]. In our study, a significant improvement of RTD was observed in times 150 and 200 ms. Most studies only observed the acute response to DW. Hunter et al.[7] verified that there is a significant increase in BF activity in the DW balance phase, which may help to explain the improvement in the RTD obtained in our study. According to Hunter et al.[7], there is greater stride instability at this stage, which can be corrected by the action of BF, which would facilitate a rapid adjustment of the posture required for this condition. According to observations from studies where instability is induced in the flat surface, one can perceive the importance of the balance phase in both its initial and late aspect, associated with a rapid action of muscles, which can be around 60-80 ms for hamstring muscles or occur around 200 ms for other muscles also involved in gait dynamics[19-20-21].

Regarding the EMG analysis in the DW condition, data presented in literature indicate that, even if there is a marked knee flexion in relation to the ankle in the double support phase as the slope is imposed, there are differences between the behavior of KF muscles against the slope[17]. Franz and Kram[4] found that in the slope, the stride frequency was higher and in the support phase, it was lower, especially at slope levels above 5%. The muscular activity of BF, evidenced by EMG, was similar to the response obtained on the flat surface, for both the support phase and the balance phase. Hunter et al.[7] found higher EMG activity of BF during most of the balance phase, especially when individuals were advised to pay more attention to instability caused by slope activating BF to help in stability rather than using potential gravitational energy to cause greater economy (relaxing body on the slope). The difference between results of studies regarding the EMG activity of BF can be explained, at least in part, by the difference in slope level used, since in the study conducted by Franz and Kram[4], slopes were 5.2%, 10.5% and 15.8%, but in the study by Hunter et al.[7], the slope was 26.8%, requiring a greater activation of BF muscles.

In our study, the 16% slope over the four weeks of training (28 sessions) was shown to be sufficient to cause RMS / IPT increase for the BF muscle, in addition to the improvement in RTD, where a significant increase was observed in the EMG signal observed through the RTDRMSt at times 30, 150 and 200 ms after the onset of BF muscle contraction and 100, 150 and 200 ms after the onset of ST muscle contraction. In the previously mentioned studies[4,7], the kinematics and EMG muscle activity analyses were acutely collected during DW and in all cycles of strides. In our study, all EMG analyses were collected during CVM, which makes a direct comparison with these studies difficult.

It has been suggested that the higher EMG activity after training represents higher recruitment, higher firing frequency[22] and greater synchronization of motor units[23-24]. In our study, RMS presented alteration in IPT for the BF muscle. On the other hand, Narici et al.[25] did not find increase in the muscular EMG activity of agonist muscles, although the torque peak and the cross-sectional area increased after resistance training. Garfinkel and Cafarell[26] also found no change in the EMG signal, even though they observed a significant improvement in muscle strength and in the cross-sectional area after the resistance training period. In another study, Gault et al.[27] analyzed a condition similar to the present study and found no improvement in RMS in the DW condition, even though they observed a 5% improvement in the strength of the knee extensor muscles after 12 weeks of training. On the other hand, Anderson et al.[28] observed a decrease in the RMS signal of KF, as well as in all muscles analyzed, after four weeks of periodized training aimed at improving balance. For the author, such a response evidences a better efficiency of the target musculature when required to perform greater stability.

One limitation of the present study is the fact that the measures of muscular activity response during walking both in the slope and in flat conditions have not been performed acutely, which in some ways makes it difficult to further analyze the effects of downhill walking on the response of parameters associated to the activity of the muscles studied in both conditions. Future studies with analysis of the response of neuromuscular parameters in the downhill walking condition may contribute to a greater understanding of the effects of exercise on this condition, compared to walking on a flat surface.

CONCLUSION

In general, both the natural displacement and that in the DW condition tends to increase the thrust relationship (displacement of the center of mass), producing accelerations that may disturb the posture and provide less stability compared to the flat condition[3-4-17]. However, it appears that a period of four weeks of periodized DW training promotes an adaptive response of KF, both in its ability to produce rapid force and in KF muscle activity. These responses may have important implications for an efficient resumption of balance during downhill walking.

REFERENCES

1. Fugimoto M, Chou LS. Sagittal plane momentum control during walking in elderly fallers. Gait Posture 2016; 45:121-6.
2. Vlutters M, van Asseldonk EH, van der Kooij H. Center of mass velocity-based predictions in balance recovery following pelvis perturbations during human walking. J Exp Biol 2016; 219 (Pt 10): 1514-23.
3. Solano PS, Vargas LF. Age- related differences when walking downhill on different sloped terrains. Gait Posture 2016; 41:153-8.
4. Franz JR, Kram R. The effects of grade and speed on leg muscle activations during walking. Gait Posture 2012; 35: 143-7.
5. Cappellini G, Ivanenko YP, Dominici N, Poppele RE, Lacquaniti F. Motor patterns during walking on a slippery walkway. J Neurophysiol 2010; 103(2):746-60.
6. Rossignol S, Dubuc R, Gossard JP. Dynamic sensorimotor interactions in locomotion. Physiol Rev 2006; 86 (1): 89-154.
7. Hunter LC, Hendrix EC, Dean JC. The cost of walking downhill: Is the preferred gait energetically optimal? J Biomech 2010; 43(10):1910-5.
8. Aagaard P, Simonsen EB, Andersen JL, Magnusson P, Dyhre-Poulsen P. Increased rate of force development and neural drive of human skeletal muscle following resistance training. J Appl Physiol 2002; 93 (4):1318-26.
9. Morcelli MH, Rossi DM, Karuka AH, Crozara LF, Hallal CZ, Marques NR, et al. Peak torque, reaction time, and rate of torque development of hip abductors and adductors of older women. Physiother Theory Pract 2016; 32(1):45-52.
10. Palmer TB, Thiele RM, Williams KB, Adams BM, Akehi K, Smith DB, et al. The identification of fall history using maximal and rapid isometric torque characteristics of the hip extensors in healthy, recreationally active elderly females: a preliminary investigation. Aging Clin Exp Res 2015; 27(4):431-8.
11. Entin PL, Gest C, Trancik S, Richard Coast J. Fuel oxidation in relation to walking speed: influence of gradient and external load. Eur J Appl Physiol 2010; 110(3):515-21.
12. Andersen LL, Aagaard P. Influence of maximal muscle strength and intrinsic muscle contractile properties on contractile rate of force development. Eur J Appl Physiol 2006; 96:46-52.
13. Andersen LL, Andersen JL, Zebis MK, Aagaard P. Early and late rate of force development: differential adaptive responses to resistance training. Scand J Med Sci Sports 2010; 20(1):162-9.
14. Hermens HJ, Freriks B, Merletti R, Hägg G, Stegeman D, Blok J, et all. editors. SENIAM 8: European recommendations for surface electromyography. Roessingh Research and Development bv; 1999.
15. Lange GW, Hintermeister RA, Schlegel T, Dillman CJ, Steadman JR. Electromyographic and Kinematic Analysis of Graded Treadmill Walking and the implications for Knee Rehabilitation. J Orthop Sports Phys Ther 1996; 23(5): 294-301.
16. Hedayatpour, N. Muscular Co-Activation of the Knee Flexor-Extensor Muscles During Multi-Directional Perturbations. World J Med Sci 2012; 7(2): 87-90.
17. Hong SW, Wang TM, Lu TW, Li JD, Leu TH, Ho WP. Redistribution of intra- and inter-limb support moments during downhill walking on different slopes. J Biomech 2014; 47(3):709-15.

18. Sheehan RC, Gottschall JS. At similar angles, slope walking has a greater fall risk than stair walking. Appl Ergon 2012; 43(3):473-8.
19. Eng JJ, Winter DA, Patla AE. Strategies for recovery from a trip in early and late swing during human walking. Exp Brain Res 1994; 102(2):339-49.
20. Schillings AM, van Wezel BM, Mulder T, Duysens J. Muscular responses and movement strategies during stumbling over obstacles. J Neurophysiol 2000; 83(4):2093-102.
21. Pijnappels M, Bobbert MF, van Dieën JH. How early reactions in the support limb contribute to balance recovery after tripping. J Biomech 2005; 38(3):627-34.
22. Suzuki H, Conwit RA, Stashuk D, Santarsiero L, Metter EJ. Relationships between surface-detected EMG signals and motor unit activation. Med Sci Sports Exerc 2002; 34(9):1509-17.
23. Seger JY, Thorstensson A. Muscle strength and myoelectric activity in prepubertal and adult males and females. Eur J Appl Physiol Occup Physiol 1994; 69(1):81-7.
24. Yao W, Fuglevand RJ, Enoka RM. Motor-unit synchronization increases EMG amplitude and decreases force steadiness of simulated contractions. J Neurophysiol 2000; 83(1):441-52.
25. Narici MV, Hoppeler H, Kayser B, Landoni L, Claassen H, Gavardi C, et al. Human quadriceps cross-sectional area, torque and neural activation during 6 months strength training. Acta Physiol Scand; 157(2):175-86.
26. Garfinkel S, Cafarelli E. Relative changes in maximal force, EMG, and muscle cross-sectional area after isometric training. Med Sci Sports Exerc; 24(11):1220-7.
27. Gault ML, Clements RE, Willems ME. Functional mobility of older adults after concentric and eccentric endurance exercises. Eur J Appl Physiol 2012; 112(11): 3699-707.
28. Anderson GS, Deluigi F, Belli G, Tentoni C, Gaetz MB. Training for improved neuro-muscular control of balance in middle aged females. J Bodyw Mov Ther 2019; 20(1):10-8.

CORRESPONDING AUTHOR
Thiago Pires de Oliveira
Rua 3, Avenida: 9 e 11, número: 646,
Bairro: Saúde.
CEP 13500 313 Rio Claro – SP,
Brasil.
Email: airthiago@yahoo.com.br