

Low-load high-velocity resistance exercises improve strength and functional capacity in diabetic patients

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Abstract

This study investigated the effects of low-load high-velocity resistance exercises on neuromuscular and functional outcomes in patients with Type 2 diabetes (T2D) during the early-phase of resistance training. Thirty participants with T2D performed 18 training sessions (6 weeks – 3x week) in one of two groups: low-load high-velocity exercises (LLHV, n=15, 62.1±10.5 years) or recreational activities (RA, n=15 56.7 ± 19.4 years). LLHV performed resistance exercises with 3x 8reps as fast as possible with 50-60% 1RM. RA performed light activities. Strength, power, and functional tests were assessed. There was significant increasing in the knee extension peak-torque at 60°/s (7.6%) and 180°/s (12.2%), rate of force development in the LLHV group (P<0.05), whereas there were no changes in the RA group. Significant increases in functional test were observed in the LLHV group (P<0.01) with no changes in the RA group. In conclusion, the LLHV induced marked improvements in neuromuscular parameters, as well as in the functional capacity of participants with T2D.

Key Words: Type 2 diabetes; power output; rate of force development; rate of velocity development; strength training.

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Diabetes mellitus is a chronic degenerative endocrine disease that affects millions of people. There are many complications associated with diabetes, such as cardiovascular diseases, peripheral neuropathy, retinopathy, chronic renal failure and impaired mental health.¹⁻³ Diabetes is also associated with reduced muscle strength, poor muscle quality, and accelerated loss of muscle mass.⁴⁻⁷ Indeed, diabetes mellitus and insulin resistance increase the likelihood of accelerating the aging process and development of frailty syndrome.^{4, 7-10} This process may contribute to increase the risk of falls, institutionalization and disability.¹¹

Recently, it has been reported there is a greater decline in muscle strength in elderly patients with Type 2 diabetes when compared with normoglycemic controls.^{6,12} In addition, Leenders et al.⁵ reported that aging patients with Type 2 diabetes presented a greater decline in functional capacity along with the lower-body muscle mass and strength when compared with normoglycemic participants. Thus, besides the metabolic control, effective strategies are needed to prevent the exacerbated loss of strength and functional capacity in aging diabetic patients. Moreover, functional

capacity preservation should be especially addressed in aging diabetic patients, because unlike other chronic conditions, diabetes care is dependent on the patients' ability to perform self-care tasks.¹¹ Exercise programs including resistance training are one of the cornerstones of diabetes management, together with pharmacological and dietary interventions.¹³ It has been widely shown that resistance training programs, especially those with low-load high-velocity muscle actions during the concentric phase, are effective interventions to improve muscle strength, power output, rate of force development and functional capacity in elderly participants.¹⁴⁻¹⁹ In the study Bottaro et al.²⁰ reported greater increases in functional performance were observed after resistance training performed with explosive muscle actions. In fact, studies have shown that muscle power seems to be a more important predictor of functional performance in elderly adults than muscle strength alone.^{21,22} Despite the effectiveness of low-load high-velocity resistance training on strength performance and functional capacity in the elderly, its effects upon patients with type 2 diabetes remains to be elucidated. Furthermore, although the positive effects of resistance exercises on glycemic control and others

disorders associated with diabetes have been often investigated,^{23,24} the effects of resistance training on neuromuscular parameters, such as power output and rate of force development (RFD) and rate of velocity development (RVD) are poorly investigated in participants with diabetic's patients. Therefore, the aim of this study was investigate the effects of low-load high-velocity resistance exercises on neuromuscular and functional outcomes in patients with Type 2 diabetes during the early-phase of resistance training. Our hypothesis was that significant strength and functional capacity gains would be observed in the diabetic patients, even after short period of training (i.e., 6 weeks of training).

Material and Methods

This study was approved by the University Institutional Review Board (035/11).

Participants

Thirty inactive Type 2 diabetic participants (diagnosed disease for at least ten years) volunteered to participate in the study. The diabetics were selected at random from responders to advertisements placed in health clinics, hospital, public officers, and by word-of-mouth. The volunteers were randomly assigned to either a low-load high-velocity resistance exercises (LLHV) or recreational activities (RA) group. Due to ethical reasons, the Institutional Review Board suggested that all participants should have some type of exercise intervention. Instead a non-exercise control group, to avoid any major treats of internal validity, we chose to have a recreational physical activities group. The recreational activity was performed with low intensity to avoid any kind of overload that could induce any supercompensation in strength or power.

Volunteers were excluded if they were enrolled in another exercise program and those who had less than 85% attendance in the present study. Therefore, 15 participants in the LLHV and 15 in the RA group successfully concluded the study. All participants were required to, with the exception of their T2D, be apparently healthy, have their T2D under control, and to have been given medical clearance to undertake physical activity and exercise. Additionally, participants were all sedentary and did not perform any kind of physical activity more than once a week for the past six months. A clinical examination was conducted by a physician in all participants to check if they were able to participate in the study. Before signing an informed consent, details about the study were explained to the participants, which included a description of the associated risks and benefits of participation. The study was conducted according to Declaration of Helsinki and was approved by an Institutional Review Board.

Procedures

Lower-body strength assessment

The right knee extension peak torque (PT) was measured on the Biodex system 3 Isokinetic Dynamometer (Biodex Medical, Inc., Shirley, NY). The calibration of the dynamometer was performed according to the manufacturer's specifications before every testing session. Participants sat upright with the axis of rotation of the dynamometer oriented with the lateral femoral condyle of the right knee. Belts were used to secure the thigh, pelvis, and trunk to the dynamometer chair to prevent additional body movement. The chair and dynamometer settings were recorded to ensure the same positioning for all tests. The flexor torque produced by the relaxed segment was used for gravity correction. Three sets of four knee extension isokinetic concentric contraction at 60°/s and 180°/s. Knee extension range of motion was performed between 10° and 90°, with full extension acting as the reference point. Participants were instructed to fully extend and flex the knee as strong and fast as possible during each set of exercises. In order to assess the rate of force development, three 4-s isometric contractions at 60° of knee extension were performed (0° is the full extension). The participants were instructed to fully extend the knee as strong and fast as possible during each set of exercises and the rest intervals among each isometric and dynamic contractions were 60 s, based on the recommendations of Bottaro et al.²⁵ Verbal encouragement was given throughout the testing session. The knee strap was released during each rest period to ensure unrestricted blood flow to the quadriceps. The procedures were administered to all participants by the same investigator.

Rate of force development (RFD) and rate of velocity development (RVD)

A software tool on MatLab software 6.5 was developed to estimate RFD and RVD from the file generated by the Biodex software where the signals (angular position, velocity, and torque) were sampled.²⁶ Once the original sample rate of the digitized biomechanical signals was 100 samples/s, cubic spline data interpolation was implemented as a tool feature and it was used in order to improve the accuracy.²⁷ Thus, the interpolation frequency used was 20,000 samples/s. RFD is usually obtained from the slope of the force-time curve ($\Delta\text{force}/\Delta\text{time}$), whereas, for intact joint actions as isometric contraction, RFD is calculated as the slope of the joint moment-time curve ($\Delta\text{Torque}/\Delta\text{time}$).²⁸ Possible estimates of RFD include time intervals of 0–100, 0–200, and 0–300 ms as well as the interval needed to achieve peak torque. All of the considered intervals are relative to the onset of contraction. Onset of muscle contraction is defined as the time point at which the moment curve exceeded baseline moment by 7 Nm.²⁸ Estimates of RVD were obtained from the slope of the velocity-time curve ($\Delta\text{Velocity}/\Delta\text{time}$). According to Brown and Whitehurst,²⁹ RVD is movement before matching the predetermined velocity (60°/s and 180°/s

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Table 1 - Pre and Post Peak torque (PT) (N.m) on different velocity

Groups		Pre	Post	F ^b	p ^b	ES
Isometric	LLHV	146.2 ± 32.8	157.1 ± 30.8	5.618	0.027	0.33
	RA	149.6 ± 53.6	158.1 ± 44.8	2.633	0.120	0.16
	F ^a	0.034	0.004			
	p ^a	0.856	0.953			
60°/s	LLHV	127.0 ± 47.0	139.9 ± 51.0	29.213	0.000	0.27
	RA	132.6 ± 37.6	137.5 ± 32.4	3.45	0.078	0.13
	F ^a	0.093	0.017			
	p ^a	0.763	0.897			
180°/s	LLHV	83.2 ± 28.4	93.3 ± 34.6	12.469	0.002	0.36
	RA	95.3 ± 28.9	97.3 ± 28.4	0.399	0.535	0.07
	F ^a	0.979	0.083			
	p ^a	0.334	0.777			

RA, recreational activities (n=15); LLHV, low-load high-velocity resistance exercises (n=15).

^aDifference between groups.

^bDifference between time.

for the present study). In other words, RVD is the slope from the point of velocity zero to the point matching the predetermined velocity.

Functional fitness test

Three components of the Rikli and Jones functional fitness test 30 were selected as a functional performance measure. This particular battery of tests was considered to be an appropriate measurement of the physiologic parameters that were associated with functional mobility in independent elderly adults and would therefore be targeted in the study's intervention. This included lower body strength and agility/dynamic balance. The following test items were conducted: 1) a 30-s chair stand test (the maximum number of times within 30 s that an individual can rise to a full stand from a seated position, without pushing with the arms) 31, 2) an 8-ft up-and-go test (standing up from a chair, walking 8 ft to and around a cone, and walking back to the original position in the shortest possible time) 32, and 3) 6 minute walk test (walk as fast as possible for 6 minutes around a 50 yard's rectangle – 20 x 5 yards 33.

Resistance training intervention

The participants began by performing six-familiarization training sessions over a 2-week period.³⁴

This familiarization period was included for two reasons: 1) initial muscle strength increases at the beginning of a training program may be associated with learning effects,³⁵ and 2) a decreased risk of injury would be more likely as most weight training injuries occur during the first 2 weeks.³⁶ When the familiarization sessions were completed, the tests of muscle strength and power were conducted, followed by the functional performance fitness tests. Participants were given a 2-day recovery period between each test. The exercise protocols were designed in accordance with published guidelines for resistance training of elderly adults.³⁷ The 6-week training regimen consisted of 18 training sessions, which were divided into three training days/week. For LLHV group the program incorporated 3 sets of 8 repetitions of the following exercises: squat on the Smith machine, lat-pull down, seated knee extension, chest press and seated knee flexion (Rightho®, Free Style e Pro, Campinas/SP, Brazil) which were interspersed by 90 s recovery intervals. The LLHV group performed all of the exercises with contractions as fast as possible in the concentric phase and 1-2 s in the eccentric phase. The rating of perceived exertion OMNI-RES scale was used to determine the training load.³⁸ On the first 9 sessions the OMNI-RES scale was set on 3 (light weight –

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Table 2 – Rate of force development (RFD) ($\text{N}\cdot\text{ms}^{-1}$) and rate of velocity development (RVD) ($^{\circ}/\text{s}^2$) (Mean \pm SD)

Intervals		LLHV	RA	F ^a	p ^a
RFD 0-100 ms (Isometric)	Pre	369.3 \pm 218.5	596.0 \pm 404.9	2.803	0.11
	Post	459.2 \pm 220.0	508.6 \pm 331.9	0.175	0.681
	F ^b	2.432	1.916		
	p ^b	0.135	0.181		
	ES	0.41	-0.22		
RFD 0-200 ms (Isometric)	Pre	316.2 \pm 154.0	449.6 \pm 236.0	2.547	0.126
	Post	396.3 \pm 126.7	429.4 \pm 217.4	0.198	0.661
	F ^b	6.668	0.353		
	p ^b	0.018	0.559		
	ES	0.52	-0.09		
RFD 0-300 ms (Isometric)	Pre	271.4 \pm 107.2	364.4 \pm 164.7	2.552	0.126
	Post	328.2 \pm 79.1	350.4 \pm 134.2	0.232	0.635
	F ^b	7.143	0.367		
	p ^b	0.015	0.552		
	ES	0.53	-0.09		
RVD (180 ^o /s)	Pre	1569.6 \pm 634.9	2161.2 \pm 958.6	3.006	0.098
	Post	1695.1 \pm 535.3	1688.1 \pm 919.6	0.001	0.982
	F ^b	0.371	4.389		
	p ^b	0.549	0.049		
	ES	0.20	-0.49		

RA, recreational activities (n=15); LLHV, low-load high-velocity resistance exercises (n=15).

^aDifference between groups.

^bDifference between time.

approximately 50% of 1 RM) and on the last 9 sessions it was set on six (moderated weight - approximately 60% of 1 RM).

Recreational activities intervention

Same as LLHV group, the RA participants began by performing six-familiarization training sessions over a 2-week period. This familiarization period was included for RA performed the same number of intervention sections as LLHV group. When the familiarization sessions were completed, the tests of muscle strength

and power were conducted, followed by the functional performance fitness tests. Participants were given a 2-day recovery period between each test. The RA group performed 18 training sessions alternated one of the followed interventions: 1) 40 min of very low-intensity walk, 2) 40 min of dance class, 3) 40 min of light stretching. The activities performed by the RA group were guided by a trained instructor who was instructed to conduct activities as lightly as possible (low intensity). Participants could not greatly increase their breathing rates (i.e., they could not be panting).

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Table 3 – Functional capacity outcomes pre and post training (Mean ± SD)

Functional tasks	Groups	Pre	Post	F ^b	p ^b	ES
8-Ft up-and-go (s)	LLHV	5.5 ± 0.9	5.2 ± 0.9	2.85	0.102	-0.33
	RA	5.2 ± 0.7	5.2 ± 0.7	0.079	0.780	0.00
	F ^a	0.796	0.031			
	p ^a	0.38	0.862			
30s Chair stand (rep)	LLHV	16.3 ± 4.2	20.2 ± 5.3	15.777	0.000	0.93
	RA	15.1 ± 3.6	15.8 ± 4.3	0.548	0.465	0.19
	F ^a	0.756	6.209			
	p ^a	0.392	0.019			
6min walk (m)	LLHV	623.8 ± 72.9	675.0 ± 67.8	12.777	0.002	0.7
	RA	584.2 ± 73.5	596.9 ± 48.2	0.849	0.366	0.17
	F ^a	1.816	10.987			
	p ^a	0.191	0.003			

RA, recreational activities (n=15); LLHV, low-load high-velocity resistance exercises (n=15).

^aDifference between groups.

^bDifference between time.

Statistical analysis

Descriptive statistics were expressed as means (±SD). The normality of data was tested by Shapiro-Wilk test. The possible effects of training were tested by a 2-way mixed factor ANOVA [group (LLHV and RA) x time (pre and post-test)] for all dependent variable followed by the LSD post-hoc procedure whenever necessary. Due to the initial difference, comparison between groups was determined by the analysis of covariance (ANCOVA) in the PT, RFD and RVD variables. The Effect Size (ES) was calculated from Pre to Posttest by the formula

$$ES = \frac{\text{Posttest Mean} - \text{Pretest Mean}}{\text{Pretest SD}}$$

(SD = standart deviation).³⁹

The probability level of statistical significance was set at $\alpha < 0.05$. All calculations were performed using SPSS (version 19.0).

Results

Thirty participants were divided in two groups: LLHV (n=15, 62.1 ± 10.5 years, 161.5 ± 8.6 cm, 75.1 ± 16.7 kg – mean blood glucose 134.2 ± 28.09 mg/dl) and RA (n=15, 56.7 ± 19.4 years, 166.2 ± 7.4 cm, 77.7 ± 18.0 kg - mean blood glucose 163.3 ± 48.05 mg/dl).

Strength performance

The strength performance variables are presented in Table 1 and 2. Before the training period, there were no significant differences between groups in the isokinetic peak torques, as well as in the RFD variables. There were significant increases, but trivial in peak torque at 60°/s (7.6%, $P < 0.001$, ES=0.27) and 180°/s (12.2%, $P < 0.01$, 0.36) in the LLHV group, whereas no significant changes were observed in the RA group (3.7% and 2.1%, respectively). After the intervention period, there were no significant differences ($P > 0.005$). (Table 1). Regarding the RFD variables, there were significant increases in the LLHV group in RFD at 0-200ms (25.3%) and 0-300ms (20.9%) intervals ($P < 0.05$), whereas no changes were observed in the RA group. Regarding the RVD (at 180°/s), there was a significant reduction in the RA (-21.89%, $P < 0.05$), whereas a no significant increase (8%) in the LLHV was reported. No significant differences between groups in the RFD and RVD variables were observed after training (Table 2).

Functional capacity

The functional capacity variables are presented in the Table 3. Before the training period, there were no

significant differences between groups in the 6 min walking test, stand up from a chair ability, and time-up-and-go test. After the exercise intervention, there was significant improvement in the 6 min walking test performance in the LLHV group (8.2% $P<0.01$), whereas no significant change was observed in the RA group (2.2%). In addition, only the LLHV group increased the stand up from a chair ability (24.2%, $P<0.001$), while no change was observed in the RA group (4.8%, $P>0.05$). Moreover, no significant changes were observed in both LLHV (-4.6%, $P=0.1$) and RA (-0.6%, $P=0.78$) groups in the time-up-and-go test performance. After the interventions, the LLHV group showed significant greater performance in the 6 min walking test ($P<0.05$), and in the stand from a chair ability test ($P<0.05$) while no significant change was observed in RA group.

Discussion

The primary findings of the present study was that only 6 weeks of low-load high-velocity resistance exercises improved muscle strength, power output, and functional capacity in Type 2 diabetics participants. In addition, physical activity intervention composed by low-intensity walking, dancing classes and stretching exercises did not induce any changes in the strength, power, and functional capacity. It has been shown that patients with Type 2 diabetes have a greater decline in the muscle strength and functional capacity, as well as accelerated loss of muscle mass when compared with normoglycemic controls.^{4,7,12} Indeed, diabetes complications such as peripheral vascular diseases and peripheral neuropathy are associated with poor gait ability, impaired balance and greater risk of falls.⁴⁰⁻⁴² Thus, preservation of functional capacity should be especially addressed in aging diabetic patients, because these individuals are at greater risk of development of frailty syndrome, institutionalization and disability.^{8,10,11} Nevertheless, the effects of resistance exercise intervention upon functional outcomes in participants with Type 2 diabetes are poorly investigated. In the present study we choose to test the effectiveness of low-load high-velocity resistance exercises in patients with diabetes, because in elderly, it has been shown that this type of resistance training promotes greater functional outcomes enhancements than traditional resistance training.^{16-20,43} For example, Bottaro, Machado have shown greater improvement in the sit-to-stand ability after high-velocity resistance training compared with traditional resistance training (42.8 vs. 6.05%, respectively).²⁰ Recently, Geirsdottir et al.⁴⁴ showed that 12 weeks of traditional resistance training improved ~13% the 6 minutes walking performance in diabetic elderly Icelanders. Different from Geirsdottir et al.,⁴⁴ using high-velocity instead of traditional resistance training, the present study also reported an improvement (8%) on the 6 minutes walking performance that was achieved in only half time of the training period (i.e. 6

weeks). Thus, our findings suggest that the three times a week low-load high-velocity resistance training is an effective way to promote rapid functional capacity increases in subject with Type 2 diabetes individuals, who are at greater risk of functional and neuromuscular declines during the aging process. A unique finding of the present study was the increase in the capacity of rapid force development (RFD) in the diabetic patients. Along with the increase in peak torque at 60°/s, the present study demonstrates that the patients with diabetes also improved peak torque at 180°/s, as well as RFD in different time intervals (i.e., 0-200ms and 0-300ms). These findings are especially important because RFD seems to be more associated with the functional outcomes than maximal strength *per se*.⁴⁵ Functional activities in daily life, as well as the capacity to prevent falls are actions characterized by a limited time to produce force, which is considerably less time than it takes to develop the maximal force.^{28,46} Moreover, muscle power decreases more rapidly than maximal strength during the aging.⁴⁷ Furthermore, in aging patients with Type 2 diabetes, besides the exacerbated decline in muscle strength,^{5,6} it has been shown that this population has a lower capacity to improve strength than normoglycemic individuals.⁴⁸ Thus, effective strategies to promote neuromuscular gains in diabetics is needed, and the present findings showed that the low-load high-velocity resistance exercises were able to improve not only maximal strength, but also RFD in this population in just six weeks of resistance training intervention. Rate of velocity development (RVD) represents the acceleration of a limb, which refers to the ability to reach top speed quickly, and may be also advantageous to the human performance.^{29,49} In the present study, there was a significant reduction in RVD in the RA group, whereas a non-significant increase was observed in the LLHV group. It can be speculated that maintaining the ability to rapidly increase the velocity of motion (RVD) may allow the aging diabetic participants resume the stability against unbalances. However, although muscle power output and RFD are strongly associated with the functional capacity in elderly,^{21,28,46} it seems that this the first study to investigate the effects of resistance training on the RVD in patients with Type 2 diabetes. Thus, the relationship between RVD and functional capacity in aging participants need to be further investigated. In addition, future studies are granted in order to compare the effects of low-load high-velocity resistance exercises vs traditional resistance training (i.e., moderate/heavy load and slow concentric phase) in functional capacity outcomes in diabetics. In despite of this limitation, it seems that this is the first study investigating the effects of low-load high velocity resistance exercises in diabetics patients during the early-phase of the resistance training period. Another possible limitation of the present study was the absence of a control group not performing any type of physical

activity. In summary, the present study showed that a short-term high-velocity resistance exercises performed with low intensity (i.e., $\geq 60\%$ 1RM) induced improvements in muscle strength and power parameters, as well as in functional capacity of participants type 2 diabetes. Moreover, the recreational physical activity intervention composed of low-intensity walking, dancing classes and stretching exercise were not sufficient stimulus to induce the same benefits. Although the group LLHV obtained significant improvements in PT, it should be noted that the magnitude of these gains are trivial ($ES < 0.50$). Perhaps longer-lasting interventions (more than 6 weeks) can lead to greater gains. From a practical standpoint, a high-velocity resistance exercises intervention using light intensity (i.e., 50-60% of 1RM) should be include in the exercise programs in order to improve strength, power output, and functional capacity in subject with type 2 diabetes.

List of acronyms

T2D – type 2 diabetes

LLHV – low-load high-velocity resistance exercises

RA – recreational activities

RFD – rate of force development

RVD – rate of velocity development

PT – peak torque

Author's contributions

RC and MB conceived and supervised the project. RC, MB and EC helped the elaboration of the methodology and the prototype characterization. RC, JD and FL performed the experiments and optimized the methodology. RC and FS contributed to data analysis and interpreted the results. RC wrote the manuscript and MB and EC helped in revising it.

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Conflict of Interest

The authors declare no conflict of interests.

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