REVIEW

Cardiac autonomic modulation adjustments in isometric exercise

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OBJECTIVE: Isometric exercise is characterized by promoting an overload on the cardiovascular system due to pulsatile contraction followed by a significant increase in muscle blood flow. The hemodynamic responses during exercise and during recovery from endurance exercise are well documented. However, there are few studies with hard data regarding the influence of isometric exercise on autonomic control, which can be obtained by analysis of heart rate variability. Thus, the object of this study was to analyze reports on cardiac autonomic regulation in isometric exercise.

METHODS: The articles used in this study were selected from Pubmed, PEDro, Medline, Lilacs and SciELO. The search was made by crossing the following keywords: isometric exercise, autonomic nervous system, cardiovascular system, and heart rate variability, which were defined based on descriptors of Health Headings (MeSH).

RESULTS: The search provided 17 articles in isometric exercise autonomic modulation characterized by decreased vagal modulation followed by increased sympathetic modulation and its reversal shortly after the end of the activity.

CONCLUSION: During isometric exercise, increased sympathetic modulation and reduced vagal modulation of the sinus node have been reported.

KEYWORDS: Autonomic Nervous System; Exercise; Cardiovascular System.

dos Santos António AM, Cardoso MA, do Amaral JAT, de Abreu LC, Valenti VE. Cardiac autonomic modulation adjustments in isometric exercise. MedicalExpress (São Paulo, online). 2015;2(1):M150102.

Received for publication on August 20 2014; **First review completed on** September 14 2014; **Accepted for publication on** October 22 2014

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INTRODUCTION

The magnitude of cardiovascular responses during physical exercise depends on the muscle mass involved, muscle tension, and duration and intensity of exercise.[1] For these quick adjustments, the cardiovascular system reacts to maintain its homeostasis. Such responses are produced by the action of the autonomic nervous system on the heart.[2] Isometric exercise is characterized by promoting a pressure overload on the cardiovascular system due to pulsatile contraction followed by a significant increase in muscle blood flow.[3–5] It is well documented that isometric exercises increase the heart rate and peripheral vascular resistance with a consequent increase in mean arterial pressure.[6] During isometric exercise, the mechanical action of muscle increases intramuscular pressure, which compresses the blood vessels, and prevents the output of metabolites produced during exercise. Their accumulation in muscle stimulates the muscle metaboreceptors, leading to increased heart rate. These cardiovascular responses are mediated by neural adjustments.[7–10] There are many studies that directly evaluate autonomic response during isometric exercise through direct recording of electrical properties of autonomic nerves, such as conduction velocity and amplitude of the peaks of neural electrical activity.[11,12]

In this context, the assessment of autonomic response can be performed indirectly through the analysis of heart rate variability (HRV), which is a simple and non-invasive method that analyzes cardiac autonomic control as well as the heart's ability to respond to pathological and physiological stimuli.[13]

Considering the importance of identifying autonomic responses induced by isometric exercise, our study describes the effects of isometric exercise on cardiac autonomic modulation.

BIBLIOGRAPHIC SEARCH

The articles used in this study were selected from Pubmed, Medline, Lilacs and SciELO database. The search was performed by crossing the following keywords: isometric exercise, static exercise, autonomic nervous system, and cardiovascular system. The terms were defined based on descriptors of Health Headings (MeSH). The studies were

DOI: 10.5935/MedicalExpress.2015.01.02

selected based on their titles. They were further analyzed and selected according to the inclusion criteria established. The title should express the focus of the study: cardiac autonomic modulation during isometric exercise and isometric training effects on autonomic control. After filtering the results to identify repetitions, all manuscripts chosen had their abstracts studied with the aim of selecting papers discussing the behavior of cardiac autonomic control during or after isometric exercise. Abstracts that approached this theme had their texts read. The selected studies had their references reviewed to identify relevant studies that were not found in the electronic search.

We included studies published between 2003 and 2014, in English and Portuguese, all of which described performed protocols of isometric exercise which analyzed the autonomic nervous system through heart rate variability and all types of study design.

To assess the methodological quality of the studies, we used the PEDro scale. The qualitative data were described and tabulated according to the authors and year of the study, population characteristics, purpose of the study, observed indices, and conclusions.

RESULTS

Search and selection strategy

With the use of above mentioned descriptors in the database searches, 258 manuscripts were found. The first selection resulted in the elimination of 223 manuscripts. We analyzed the content of the remaining 35 studies that passed the next stage of selection. Eighteen studies did not comply with our established criteria and were excluded. The remaining 17 texts were read and analyzed.

Characteristics of the selected studies

Table 1 presents the studies according to authors and year of publication. It shows the characteristics of the population, objectives, indices evaluated, and the score according to the PEDro scale.

DISCUSSION

HRV is a reliable technique widely used in the clinical setting for information concerning the integrity of the cardiac autonomic modulation, and it has been investigated in both healthy subjects and in patients with pathological conditions.[13,14] The objective of this review was to present studies that used isometric exercise protocols and analyzed the cardiac autonomic response through HRV. Heart rate response during isometric exercise has been studied to understand cardiac autonomic control, since there is interaction between the cardiovascular, autonomic and muscular systems while performing exercise. The cardiovascular system is influenced by the autonomic nervous system through central and peripheral commands. The central mechanism is activated by afferent signals coming from the motor cortex. It is responsible for the activation and recruitment of motor units, and activation of cardiovascular control in the medulla oblongata.[15,16] Because peripheral neural receptors are triggered by mechanical activation, nerve endings in contracting muscle send information to the cardiovascular center in the medulla oblongata where activated efferent sympathetic and parasympathetic fibers respond with actions on the heart and blood vessels.[17,18]

In this sense, the ergoreflex is a mechanism that adjusts hemodynamic responses during exercise to ensure an adequate supply of oxygen and the removal of metabolites produced in muscle. The activation of this reflex occurs in the specific skeletal muscle involved in the exercise. It is mediated by group III afferents that are activated by mechanical stimuli of pressure and stretch, and by the group IV afferent fibers that are activated by metabolic products of muscular contraction and project into the brainstem, increasing sympathetic and decreasing vagal activity.[19–21] The contribution of each type of fiber to the ergoreflex is still controversial. However, studies have suggested that muscle metaboreceptors are responsible for the reflex increase in sympathetic modulation during static exercise,[22] while muscle mechanoreceptors are responsible for increased sympathetic modulation during rhythmic exercises.[23]

Depending on the intensity of exercise, the mechanical action of the muscles during isometric exercise causes an increase in intramuscular pressure and compresses the blood vessels within the muscles. This prevents muscle blood flow with partial or complete vascular occlusion, preventing the removal of metabolites that accumulate in muscle. This in turn stimulates muscle chemoreceptors and results in increased sympathetic nerve activity.[4] During the operation of this mechanism, it is possible to evaluate the rate of the low frequency band of HRV, which represents the joint action of the sympathetic and vagal modulation, with sympathetic predominance.[13] Agiovlasitis et al.[24] found increased low frequency activity during isometric exercise compared with the resting condition in paraplegic patients. Hallman et al.[25] investigated the response of cardiac autonomic modulation in isometric contraction in patients with muscle pain, and found a reduction in the overall modulation of HR analyzed through the SDNN index as the intensity of pain increased. Shiro et al.[26] found no significant changes in the LF/HF ratio in patients with pain in the trapezius muscle, concluding that the decrease in muscle blood flow and oxygen in the trapezius muscles can derive from the sympathetic response during isometric exercise.

The intensity of the contraction also plays a key role in the hemodynamic response to isometric exercise. Fisher et al.[27] compared, in healthy young men, the hemodynamic response to handgrip exercise performed during one minute at 15, 30, 45 and 60% maximal voluntary contraction (MVC): in the last 10 seconds of each intensity, significant differences in HR were observed between rest and the two most intense bands (45 and 60% MVC). Leite et al.[28] analyzed HRV in different percentages of submaximal and maximal voluntary isometric contraction in 29 patients with coronary artery disease and found that the RMSSD index decreased during submaximal voluntary contraction from 30% to 60%, which returned to basal levels when the contraction was stopped. They also found that low intensity isometric contraction maintained for extended periods of time had the same effects on heart rate responses as observed in response to maximal high intensity isometric contraction of short duration. Nevertheless, when the contraction was interrupted these values returned to baseline. Millar et al.[29] investigated the acute effects of different isometric exercise protocols at 30% MVC on blood pressure and cardiac autonomic modulation in 18 healthy elderly subjects, and found that HRV was reduced in some but not all protocols. They concluded that

Table 1 - Description of studies according to the authors, year of publication, population characteristics, goals, indices evaluated, PEDro scale and conclusions

Authors and year of publication	Characteristics of the population	Objectives	Indices evaluated	Scale PEDro	Conclusion
Agiovlasitis et al., 2010	Adults with paraplegia (n = 20), mean age 22.2 ± 3.1 years, and adults without paraplegia (n = 20), mean age 25.8 ± 4.0 years.	To examine the cardiac autonomic modulation at rest and during isometric exercise in individuals with and without paraplegia.	LF HF LF/HF SampEn	5	Individuals with paraplegia showed lower heart rate complexity at rest and during static exercise.
Taylor et al., 2003	Seventeen hypertensive men and women, isometric training group (n = 9), mean age 69.3 ± 6.0 years, and the control group (n = 8) mean age 64.2 ± 5.5 years.	To evaluate the effects of isometric handgrip training on resting arterial blood pressure, heart rate variability, and blood pressure variability in older adults with hypertension.	LF HF LF/HF	7	Isometric training at a moderate intensity elicits a hypotensive response and a simultaneous increase in vagal modulation in older adults with hypertension
Millar et al., 2009	Healthy older subjects (n = 18), mean age 70 ± 5 years.	To investigate the acute changes of cardiac autonomic modulation after bilateral isometric handgrip.	SampEn	6	The results suggested improvements in acute cardiac autonomic modulation after a single bout of IHG. This may be linked to the increase of parasympathetic modulation and reduction of systolic blood pressure.
Leite et al., 2010	Men with coronary artery disease (n = 12), mean age 63 ± 11.6 years.	To evaluate the heart rate responses to different percentages of isometric contractions in patients with coronary artery disease and/or risk factors for coronary artery disease.	RMSSD	5	The RMSSD index decreased during isometric contraction with SMVC-60% except for the SMVC-30%. In the recovery period RMSSD values were similar for both intensities tested.
Shiro et al., 2012	30 female participants were divided into group with pain (n = 14), mean age 28.7 ± 4.6 years, and a control group (n = 12), mean age 29.5 ± 4.1 years.	To analysis how heart rate variability responds to the maximal isometric contraction in subjects with chronic neck pain and shoulder.	LF HF LF/HF	5	There were no significant changes in LF/HF ratio of HRV responding to isometric exercise, which would imply a reduction in sympathetic nervous system activity.
Goulopoulou et al., 2010	Healthy children (n = 23) mean age 8.3 ± 0.2 years, and healthy young adults (n = 23) mean age 22.0 ± 0.3 years.	To evaluate differences in pressor response and cardiovagal modulation during isometric handgrip exercise between children and adults.	RMSSD HF	5	That baseline cardiovagal modulation contributes to the magnitude of the pressor reflex response and determines the extent of cardiovagal autonomic adjustments during forearm isometric contraction.
Watanabe et al., 2010	Healthy volunteers (n = 51) with a mean age of 21.6 ± 0.2 years.	To evaluate the individual differences in the HR response are associated with cardiac autonomic tone and/or the function of the arterial baroreflex in the control of HR during postexercise muscle ischemia	LF HF	5	The changes in cardiac parasympathetic tone and spontaneous arterial baroreflex during postexercise muscle ischemia are associated with the large individual differences in the HR response to postexercise muscle ischemia
Hallman et al., 2011	Subjects with chronic pain (n = 23 pain, with a mean age of 40.5 ± 7.1, n = 22 control, with a mean age of 40.8 ± 7)	To investigate systemic arterial pressure and heart rate variability as well as the activity of the trapezius muscle at rest and in response to continuing to sustained hand grip with chronic pain in the neck-shoulder region.	SDNN NN50 LF HF	7	Decreased blood flow in the trapezius muscle, increase blood pressure and heart rate variability in the group with pain compared to the control group in response to handgrip was observed.
Zhang et al., 2012	Were men, mean age 23.2 ± 2.9 years (n = 17)	To evaluate the influences of isometric muscle contraction in cerebral and systemic circulation, and HRV during handgrip exercise compared with clamping jaw.	LF HF LF/HF	5	The tightening of the jaw promotes bilateral activation of the flow velocity of cerebral arteries with less effect on cardiac output and sympathetic nervous system activity in relation to handgrip exercise
Mukherjee et al., 2009	61 participants with partial epileptic seizures, were divided into groups with controlled epilepsy report (n = 30), the mean age was 19:13 ± 8.72 years and an intractable group (n = 31), mean age 22.11 ± 10.18 years old.	To compare the autonomic and psychological function in patients with partial epilepsy using sustained handgrip test.	LF HF LF/HF RMSSD SDNN NN50 pNN50	6	There was lower HRV with lower parasympathetic activity in patients with intractable epilepsy for individuals controlled epilepsy.

(*Continued*)

Table 1 - *continued*

Authors and year of publication	Characteristics of the population	Objectives	Indices evaluated	Scale PEDro	Conclusion
La Fountaine et al., 2009.	Three players (19 ± 2 years of age), and three control subjects (19 ± 2 years).	To compare HRV in athletes who have had concussion at rest and during handgrip test.	LF HF LF/HF	5	There were no significant differences in HRV both at rest and during the handgrip test.
Lira et al., 2012.	Obese children with a mean age of 10 ± 0.4 years (n = 11) and placebo group with a mean age of 10 ± 0.7 years (n = 10).	Analyzing the effect of supplementation of vitamin C on cardiac autonomic modulation in obese children, at rest and during isometric exercise.	LF HF LF/HF	8	Vitamin C attenuated the response of cardiac autonomic modulation in obese children provided rest and during isometric exercise compared with the control group.
Silva et al., 2003	2 male volunteers, sedentary patients (26 years old), and an active (22 years old).	Investigate HRV at rest and the magnitude of the HR response to isometric exercise considering the level of physical fitness tests.	RMSM RMSSD	6	The active volunteer had higher HR variation indicates that the dynamics of vagal withdrawal was even greater than that of sedentary, indicating good adaptation to physical training.
Zhang et al., 2003.	Two women with uncontrolled hypertension (50 and 55 years of age).	To investigate whether isometric exercise reduces HRV and blood pressure.	LF HF	5	The handgrip exercise is moderately effective in reducing blood pressure, although the effect is more noticeable in the absence of hypertensive medication.
Fisher et al., 2010.	Healthy men with an average age of 23 ± 5 years (n = 9).	To verify the cardiac autonomic control during handgrip using beta adrenergic blockers.	RMSSD	5	The value of RMSSD index indicating parasympathetic modulation was greater with the adrenergic beta-blocker compared with control.
Gladwell et al., 2005.	5 healthy subjects.	To compare the cardiac autonomic response handgrip and passive stretching.	RMSSD pNN50	5	Vagal modulation decreased significantly during handgrip, whereas passive stretching was not significantly reduced.
Hartwich et al., 2013.	23 healthy young women (20 ± 0.6 years)	To evaluate the influence of muscle metaboreflex in heart rate regulation during handgrip.	RMSSD	5	Muscle metaboreflex increases heart rate due to increase in muscle sympathetic nerve modulation during handgrip.

HRV = heart rate variability; RMSSD = square root of the mean square of differences between adjacent normal RR intervals, SDNN = standard deviation of all normal RR intervals; pNN50 = percentage of adjacent RR intervals differing by duration longer than 50 ms; NN50, number of pairs of adjacent NN intervals differing by more than 50 ms; LF = low frequency component, HF = high frequency component, LF/HF = ratio of components of low and high frequency; un = normalized unit; ^{2} = ms square milliseconds, SampEn = Sample Entropy, RMSM = corresponds to the square root of the sum of the squared differences of the individual values of RR intervals for the mean value divided by the number of RR intervals.

the active recovery after isometric exercise depends on the duration and frequency of contraction.

Pivatelli et al.[30] found decreased levels of HRV in patients with coronary artery disease in the rest condition. Patients with reduced HRV, as assessed by linear methods in the preoperative period of surgical myocardial revascularization, tend to have higher morbidity and mortality. Laird et al.[31] reported increased heart rate and systolic and diastolic blood pressure in 32 healthy subjects during submaximal isometric exercise that returned to baseline after the exercise protocol end.

With respect to the long term aftereffects, studies suggest that progressive resistance exercise results in small reductions in systolic and diastolic resting pressures.[32] Taylor et al. concluded that isometric training at moderate intensity causes a hypotensive response and a simultaneous increase in vagal modulation in elderly patients with hypertension, after submitting them to a protocol of isometric handgrip exercise for 10 weeks.[33] Raimundo et al.[34] evaluated the cardiac autonomic modulation in patients with stroke before, during, and after an acute bout of aerobic exercise. They suggest that stroke patients show a reduced HRV during and at least 30 min after exercise, due to an autonomic imbalance reflected in increased indices that represent the sympathetic nervous system. Watanabe et al.[35] evaluated 51 healthy subjects that underwent isometric exercise with 30% of maximum voluntary contraction for 1 minute. They concluded that, in humans, the response of the heart muscle metabolic reflex activation after isometric exercise varies considerably among individuals, and that these differences reflect changes in cardiac parasympathetic tone and baroreflex sensitivity.

Iellamo[36] et al. reported that levels of muscle tension caused by isometric contraction resulted in an immediate increase in heart rate in the first seconds (5 to 10 seconds), and this increase is due to reduced vagal modulation of the sinusal nodule. Somers et al.[37] investigated adjustments in cardiac autonomic modulation in a group of women who performed isometric exercise, and reported reduction of sympathetic modulation and increased vagal modulation minutes after isometric exercise. They conclude that isometric training decreases muscle chemoreflex stimulation during exercise and attenuates the response of the sympathetic nervous system, based on evaluating eight healthy individuals submitted to the protocol of isometric exercise of the upper limbs for six weeks.

A study by Negrao et al.[38] showed that during isometric exercise, obese subjects have higher muscle sympathetic nerve activity and heart rate, while metaboreflex control of muscle sympathetic nerve activity is decreased in comparison to normotensive eutrophic subjects. Lira et al.[39] noted that oral supplementation with 500 mg of vitamin C for 45 days can restore cardiac autonomic modulation in obese children during isometric exercise, suggesting oxidative stress generated changes in cardiac autonomic modulation in this population. Moreno et al.[40] found decreased parasympathetic modulation during isometric exercise in both an adult group and in a group of children; however, the children showed greater reduction in HF index in response to isometric exercise compared with the adults. They also demonstrated that a hydration protocol, despite resulting in smaller alterations in the HRV indices, was insufficient to significantly influence these indices during physical exercise. During the recovery period, it induced significant changes in cardiac autonomic modulation, promoting faster recovery of HRV indices.

Our study presents some points that are worth pointing out. As a study review, it does not add new elements in the literature. Nevertheless, it raises important hypotheses for further investigation regarding the involvement of exercise pressor responses, cardiac autonomic regulation, and exercise physiology.

CONCLUSION

During isometric exercise, cardiac autonomic modulation is characterized by decreased vagal modulation followed by increased sympathetic modulation. The same autonomic components reverse immediately after the end of the contraction.

AJUSTES DE MODULAÇÃO CARDÍACA AUTONÔMICA NO EXERCÍCIO ISOMÉTRICO

RESUMO

OBJETIVO: O exercício isométrico é caracterizado por promover uma sobrecarga no sistema cardiovascular devido à contração pulsátil seguida por aumento significativo no fluxo sanguíneo muscular. As respostas hemodinâmicas durante o exercício e durante a recuperação do exercício de resistência estão bem documentados. No entanto, existem poucos estudos com dados concretos sobre a influência do exercício isométrico no controle autônomo, a qual pode ser obtida pela análise da variabilidade da frequência cardíaca. O objetivo deste estudo foi analisar publicações sobre a regulação autonômica cardíaca durante o exercício isométrico.

MÉTODOS: Os artigos utilizados neste estudo foram selecionados do Pubmed, PEDro, Medline, Lilacs e SciELO. A pesquisa foi feita através do cruzamento das seguintes palavras-chave: exercício isométrico, sistema nervoso autônomo, sistema cardiovascular, e variabilidade da frequência cardíaca, que foram definidas com base nos descritores das rubricas de Saúde (MeSH).

RESULTADOS: A pesquisa forneceu 17 artigos sobre modulação autonômica em exercício isométrico: esta modulação caracterizou-se pela diminuição da ação vagal, seguida de aumento da modulação simpática e sua reversão logo após o cessar da contração.

CONCLUSÃO: Durante o exercício isométrico, ocorre aumento da modulação simpática e redução da modulação vagal sobre o nódulo sinusal.

UNITERMOS: sistema nervoso autônomo, exercício, sistema cardiovascular.

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