The metabolic cost of sustained versus repeated isometric contractions during voluntary two-legged knee extension

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Abstract

PURPOSE: The aim of this study was to compare the metabolic energy cost of repeated and sustained voluntary isometric contractions in healthy young adults. **METHODS:** Seventeen Gonzaga University students (9 male, 8 female), aged 19-22, participated in this study. Maximal isometric knee extension contractions were performed while the rate of oxygen consumption (VO_2), heart rate (HR), rate of perceived exertion (RPE), and force were recorded. The sustained protocol consisted of 6x6 second isometric contractions with 14 seconds of rest, and the repeated protocol consisted of 12x3 second contractions with 7 seconds of rest. Each protocol was repeated twice with 5 minutes of recovery in between, and the order was randomly assigned. VO_2 was integrated to give the oxygen cost of the exercise, and force was converted to torque and integrated to give the angular impulse produced by the knee extensors. The two trials were averaged and paired t-tests were used to compare VO_2 (L/min), oxygen cost (L), HR, RPE and angular impulse between contraction protocols. **RESULTS:** During contraction bouts, no difference in oxygen cost was detected between the repeated (0.365 ± 0.203 L) and sustained (0.361 ± 0.179 L) protocols. However, in recovery, repeated contractions (0.275 ± 0.178 L) required 46.6% more oxygen than sustained contractions (0.188 ± 0.216 L) (p=0.005). In total, repeated contractions (0.640 ± 0.343 L) required 17.3% more oxygen than sustained contractions (0.548 ± 0.352 L) (p=0.008). There were no differences in HR (repeated: 96.9 ± 13.6 bpm, sustained: 99.2 ± 14.6 bpm) or RPE (repeated: 12.1 ± 2.4, sustained: 12.5 ± 2.4) between conditions. Additionally, there were no differences in angular impulse between the repeated (4372.1 ± 2363.4 J*s) and sustained (4450.6 ± 2417.5 J*s) protocols. **CONCLUSIONS:** Repeated isometric contractions require greater oxygen consumption compared to sustained contractions when the time in contraction is held constant, and this difference is observed during the recovery period. From this data, we conclude that repeated bouts of isometric contractions are more metabolically costly than sustained contractions despite the same force being applied, and these energy requirements are met by anaerobic metabolic pathways during contraction and replenished by oxidative metabolism during recovery.

Introduction

- Although in many types of muscle contractile activity the metabolic energy cost is linearly correlated with the force produced by the muscle (2, 5), isometric tetanus appears to display different kinetics.
- Prior research has suggested that the metabolic energy required to initiate isometric tetanus is greater than the cost of its maintenance, as there is a decrease in actin-myosin ATPase rate (3, 4, 6) and rate of phosphocreatine (PCr) depletion (1) following the initiation of contraction.
- It follows, then, that shorter repeated isometric contractions would be more metabolically costly than longer contractions when total time in contraction is held constant.
- In this study, we aimed to build off of the previous knowledge of the metabolic properties of isometric exercise to compare the metabolic cost of repeated and sustained voluntary isometric contractions in healthy young adults.
- We hypothesized that voluntary repeated isometric force generation would be more metabolically costly than voluntary sustained isometric exercise in the quadriceps femoris muscle group, as measured by whole-body VO_2.

Methods

Human Subjects. A total of 17 physically active subjects (9 male, 8 female) with an average age of 20.9 ± 0.9 years were recruited for this study.

Study Design. Each subject performed two separate protocols consisting of two-legged maximal knee extensions on a modified knee extensor machine (Figure 1). The repeated isometric contraction protocol consisted of 3x12 second contractions, each separated by 7 seconds of rest. The sustained protocol consisted of 6x6 second contractions, each separated by 17 seconds of rest. The order of each protocol was randomly assigned and performed twice with 5 minutes of recovery in between (Figure 2). Oxygen consumption (VO_2), heart rate (HR), force production, and rate of perceived exertion (RPE) were recorded throughout each protocol. The total time in contraction was held constant between protocols.

Data Analysis. Oxygen cost (L) and angular impulse (J*s) were calculated, and paired t-tests were used to compare VO_2 (L/min), oxygen cost, HR, RPE and angular impulse between contraction protocols.

Figure 1. ***Modified knee extensor machine.*** The position was fixed by a cable with an in-line force transducer, which allowed for measurement of force developed during the isometric contractions. Knee angle = 138-140°.

Figure 2. ***Outline of contraction protocols.***

Results

Table 1. ***Rate of oxygen consumption (mean ± SD) during baseline, contraction, and recovery for both sustained and repeated isometric contractions.*** * indicates repeated > sustained contractions ($p < 0.05$)

	Baseline VO_2 (L/min)	Contraction VO_2 (L/min)	Recovery VO_2 (L/min)
Repeated	0.292 ± 0.079	0.459 ± 0.135	*0.344 ± 0.079
Sustained	0.292 ± 0.079	0.454 ± 0.141	0.329 ± 0.079

Table 2. ***Heart rate (mean ± SD) during baseline, contraction, and recovery for both sustained and repeated isometric contractions.*** * indicates repeated > sustained contractions ($p < 0.05$).

	Baseline HR (bpm)	Contraction HR (bpm)	Recovery HR (bpm)
Repeated	85.3 ± 14.6	95.9 ± 12.0	*85.3 ± 10.7
Sustained	85.3 ± 14.6	97.3 ± 13.6	83.6 ± 11.5

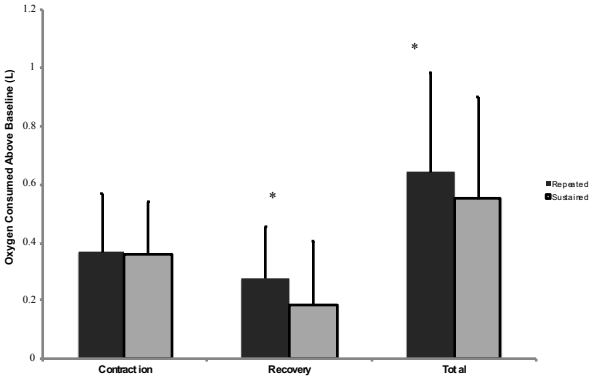

Figure 3. ***Average oxygen consumed above baseline.*** Repeated contraction bouts required 46.6% more oxygen during recovery and 17.3% in total compared to sustained contractions.* indicates repeated > sustained contractions ($p < 0.05$).

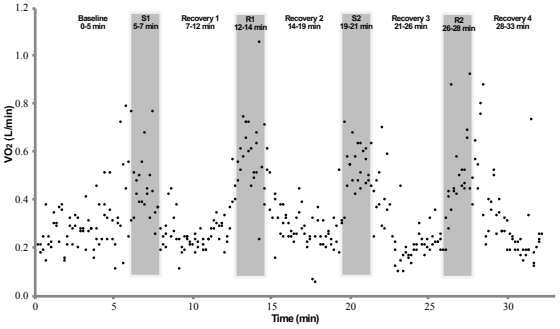

Figure 4. ***Representative VO_2 vs. time graph of a single subject.*** This subject was randomly chosen to perform the sustained protocol (S1) followed by the repeated protocol (R1). Five minutes of recovery were given in between and then the sequence was repeated (S2, R2).

- There were no differences in angular impulse between the repeated (4372.1 ± 2363.4 J*s) and sustained (4450.6 ± 2417.5 J*s) protocols.

Discussion

- The aim of this study was to evaluate the energy cost of repeated compared to sustained isometric quadriceps contractions by measuring changes in oxygen consumption.
- During the two-minute exercise bouts, there was no difference detected in the oxygen cost of contraction between the sustained and repeated contractions.
- However, during the five-minute recovery period that followed each exercise, subjects displayed greater recovery oxygen consumption following the repeated contractions compared to following the sustained contractions.
- The differences in oxygen consumption during the recovery period indicate that repeated contractions initiate more aerobic energy demand during the period following the exercise bouts rather than during the exercise itself, and in total are more energetically costly, despite time in contraction and force production being equal.
- Therefore, it is likely that the increased ATP cost of the repeated exercises is met by anaerobic metabolic pathways during contraction, such as phosphocreatine (PCr) utilization or glycolysis, and restored by aerobic metabolism during recovery.
- These results align with previous research that have displayed an increase in PCr usage and glycolysis during the initiation of contraction (1, 5), suggesting that initiating an isometric muscle contraction is more metabolically costly than its maintenance.

Conclusion

Our data indicate that repeated isometric contractions are more energetically costly than sustained contractions despite the same force being applied, and these energy requirements are most likely met by anaerobic energy production during contraction and replenished by oxidative metabolism during recovery. This further supports the notion that the metabolic requirement of initiating isometric tetanus is greater than the cost of sustaining the contraction.

Acknowledgements

We would like to thank Steve Conant, MS, C.S.C.S., for helping to build the modified knee extension machine that was essential in the success of this project.

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