The Impact of Force Versus Cadence on VO_2 During a Step Incremental Test

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The most accurate method for assessing aerobic fitness for athletes and non-athletes is through the measurement of maximal oxygen uptake (VO_{2MAX}). VO_{2MAX} is defined as the maximum rate of oxygen uptake a person can experience while exercising, which measures how efficiently the respiratory, circulatory and muscular systems can work together (Hawkins et al., 2007). The step incremental test (SIT) is a commonly used protocol to assess VO_{2MAX} where intensity increases in discrete steps until the participant can no longer continue. In this protocol, the force or cadence can be manipulated, which may result in a different VO_{2MAX} at a given power output. Therefore, the purpose of this study is to explore the impact of force and cadence while undergoing the step incremental test.

Previous research has shown that the impact of force or cadence on VO_{2MAX} is a result of multiple different factors such as age or training status. Some studies suggest that individuals will experience a greater level of VO_2 when performing exercises with higher force production than cadence (Millet et al., 2002). On the contrary, other studies suggested that high cadence, low force exercise would result in a greater VO_2 (Neptune et al., 1997). These conflicting results may be due to differences in study designs and protocols, the participant population, and the method used to assess VO_2.

Considering existing research, it can be seen that there is a disagreement among researchers on the ideal force to cadence ratio used for VO_{2MAX} testing. Investigating how force and cadence can be manipulated has practical implications that can be used by coaches and athletes. Identifying the optimal combination of these factors can allow coaches to produce training programs that enhance performance and the endurance capacity of athletes; this would act as a guideline for athletes to improve their overall VO_{2MAX} in the most efficient way possible.

The research question this study will investigate is: “What is the effect of force versus cadence on VO_2 during a step incremental test?” It is predicted that if a high force and steady cadence variation of the SIT is performed, then the VO_2 would be greater. This is because at higher forces, there is an increase of muscle fiber recruitment and activation which leads to a greater energy demand, and thus, greater oxygen uptake (Millet et al., 2002).

Methods

Participant(s)

The participant used in the data collection was a 23-year-old male, weighing 75 kilograms at a height of 172 centimeters. The participant performed an initial RAMP test to determine his maximum power output (PO_{MAX}). Using this, his 30%, 40%, and 50% PO_{MAX} was calculated for the three steps in the protocol (see *Appendix B*).

Materials

An ergometer (Ergoline GmbH; https://www.ergoline.com) was used to control the power output and read the participant’s cadence.Devices for measuring vitals include the Polar heart rate monitor (Polar Global; https://www.polar.com/en) and the Parvo-Medics TrueOne 2400 metabolic cart (Parvo-Medics; www.parvo.com). Perceived fatigue was quantified using a modified RPE scale (Borg, 1970).

Protocol Procedure

Two trials were completed in order to test the difference in VO_2 when manipulating cadence versus load. Heart rate, RPE, and VO_2 was measured in the last 30-seconds of each stage.

In the cadence–manipulation trial (protocol A), the participant was asked to cycle on the Ergoline for 4-minutes at 30-(60W), 40-(80W), and 50-percent (100W) of PO_{MAX} at 85-, 115-, and 145-rpm. This allowed the load on the ergometer to stay constant for each step (~0.7kg).

In the load-manipulation trial (protocol B), the participant cycled for 4-minutes at 30-(60W), 40-(80W), and 50-percent (100W) of PO_{MAX} at a constant 60-rpm. The load at each stage was calculated to be 1.02-, 1.36-, and 1.70kg, respectively. See *Appendix B* for calculations.

Results

Protocol A resulted in a steeper slope between absolute oxygen-uptake and power-output than protocol B when the final three 30-seconds of each stage in the SIT were plotted (see *Figure 1*). The absolute VO_2 was higher at each power output in protocol A than in protocol B.

The participant was unable to maintain the cadence required in the 100W-stage in protocol A for the full 4-minutes; he stopped after 30-seconds..

The maximum heart rate was 183-bpm in protocol A and 155-bpm in protocol B. The maximum RPE was 14 and 16 out of 20 in protocols A and B, respectively.

Discussion

During the data collection period, some unexpected events were observed that deviated the data collection from the ideal scenario. One such limitation was that the power outputs calculated for each test were based on the participants previous RAMP incremental test (RIT). When using power output from a ramp test with a goal to exercise at a given percentage of VO_{2MAX}, the participant will experience a dissociation of VO_2. In RIT, 220 Watts correlates with 45% of VO_{2MAX}, but in constant load exercise, it was at 75% of the participants VO_{2MAX} (Keir et al., 2018). The increase of VO_2 is a result of an increased ATP turnover in fatiguing muscle fibers and recruitment of type II fibers which are less oxygen efficient compared to type I fibers

(Poole & Jones, 2012). When performing the SIT with varying cadence, the participant was unable to continue into the 3rd stage due to fatigue. This was unexpected and made it difficult to analyze the results as extraneous variables impacted the VO_2 collected during the cadence variation of the test. To reduce the effect of this limitation, exercise thresholds can be identified. With exercise thresholds, exercise domains can be predicted which provides accurate intensities to prescribe exercise that aims for a specific percentage of VO_{2MAX}.

To conduct this experiment effectively, ideally, 4 separate visits would be necessary. The first visit would be dedicated to familiarizing the participants with the protocol in order to limit any learning effect that may occur during the trials. The second visit would consist of conducting baseline tests in order to identify the exercise domains and thresholds of each participant. The next two days would be dedicated to the trials itself, where each variation of the protocol would be conducted on separate days to mitigate the effects of fatigue. The population of the participants that would be recruited would be healthy untrained individuals who are within the age range of 20 to 25 years old. This is because with trained individuals, training factors and experience can impact the results when examining force versus cadence in relation to VO_2; Athletes trained for sprinting can provide different results when compared to athletes trained for marathons (Vuorimaa et al., 1996). Hence, this training effect can be minimized when the participants are untrained. The same methodology would be implemented in the new experiment, with the only addition being using VO_2 results from baseline to determine GET (*Figure 2*). VO_2 will be measured simultaneously during exercise, similar to the pilot study. Based on the baseline results and the individual's GET, three stages of exercise intensity would be chosen for each protocol, with all stages being under GET to ensure that dissociation does not occur (Kominami et al., 2021). This would circumvent the arbitrary quality of the preliminary testing parameters, such as cadence, load, and power output.

Changes to the exercise protocol would need to be made as the exercise intensity was underestimated. In order to prescribe exercise intensity based on power output, it would be essential to determine the participants exercise domains and, more importantly, their gas exchange threshold (GET). This can be identified by performing a RIT during the second day of the study when baseline tests are conducted. The starting intensity must initiate below the GET in order to prevent dissociation of VO_2 that may appear between the RIT and SIT protocols. This would prevent the participants from unexpectedly experiencing VO_{2MAX} earlier due to the underestimation of intensity. As a result, the new exercise protocol would be highly individualized, with intensity being determined through power output and one's GET. The independent variable would remain the same as force and cadence are necessary to answer the research question. The dependent variable will also remain the same since VO_2 is the gold standard of determining one's aerobic fitness, thus, it is essential to answer the purpose of the experiment.

Finally, there are possible confounding variables that need to be controlled so that there are no external factors impacting the dependent variable (VO_2) other than the manipulation of the independent variable. First, the body weight and composition of the participants should be monitored as it can impact their VO_2. This is since individuals with more muscle mass will generally tend to have a better oxygen uptake capacity in comparison to those who have lower muscle mass (Poole & Jones, 2012). Second, the participants' hydration status should be monitored as it can possibly impact their VO_2; being overly hydrated or dehydrated could impact the oxygen carrying capacity of the blood and thus the overall VO_2 (Cheung & McLellan, 1998).

Lastly, the participants' nutrition can be controlled since meals and/or supplements consumed before the testing period can affect their energy levels. This can be done by standardizing pre-test meals and recording them for each participant.

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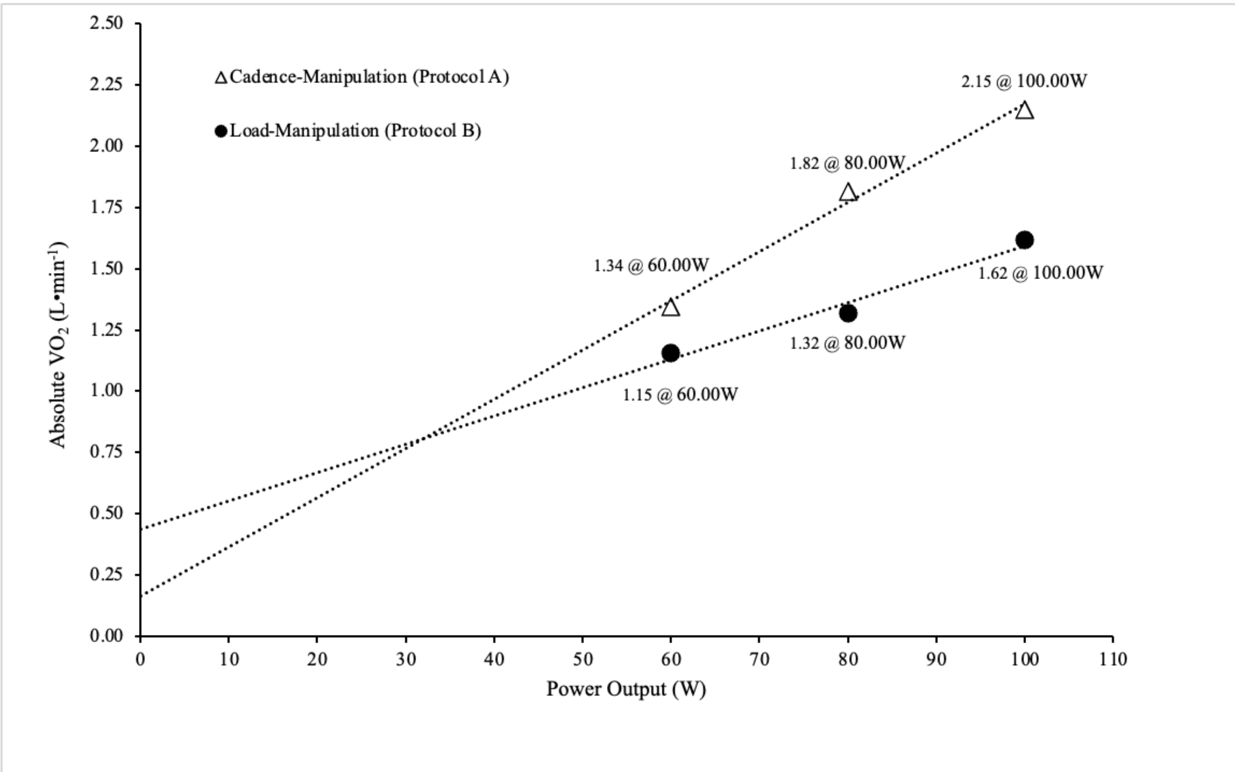
Appendix A: Tables and Figures

Figure 1

Absolute Oxygen Uptake (L/min) Measured in the Final Three 30-Second Intervals of Each Stage in the Step-Incremental Test Plotted Against Power Output.



Notes. "L" = litres; "min" = minutes; "W" = watts; "VO_2" = oxygen uptake.

The participant was only able to maintain their cadence for the first 30-seconds of the 100W stage in protocol A, so only that interval was used.

Figure 2

Modified Procedures for Baseline Testing

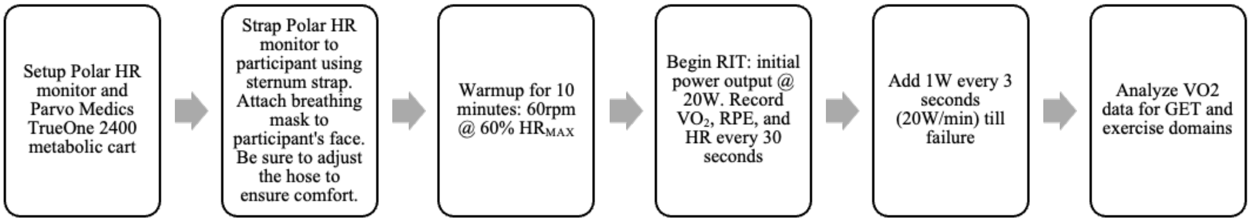


Figure 3

Modified Procedures for Protocol A

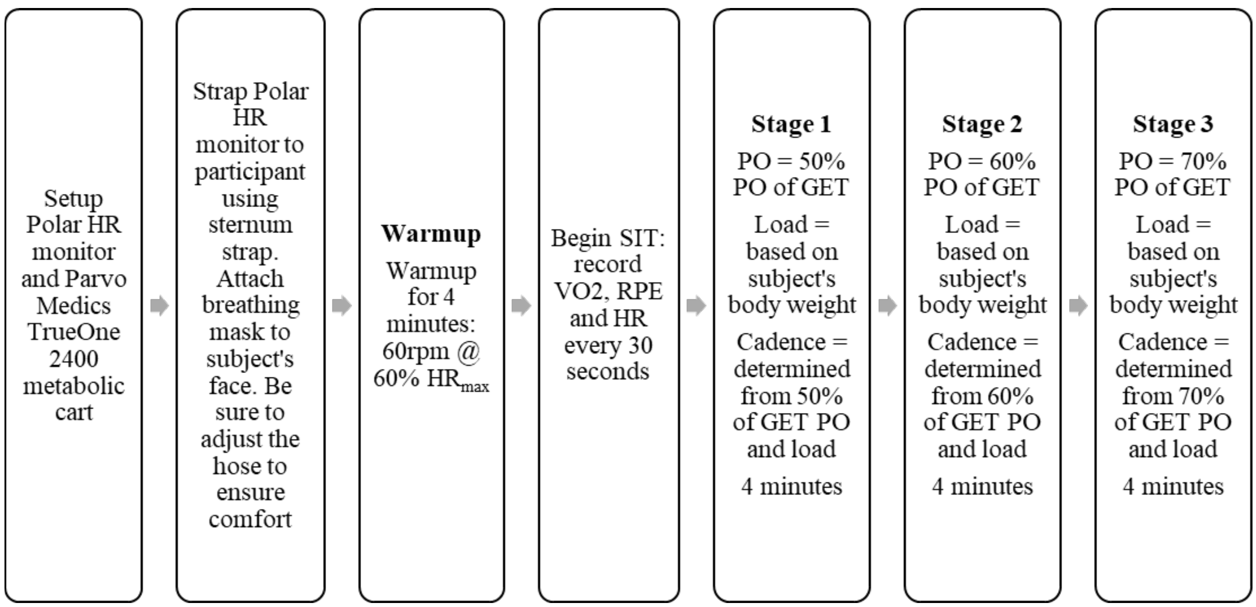
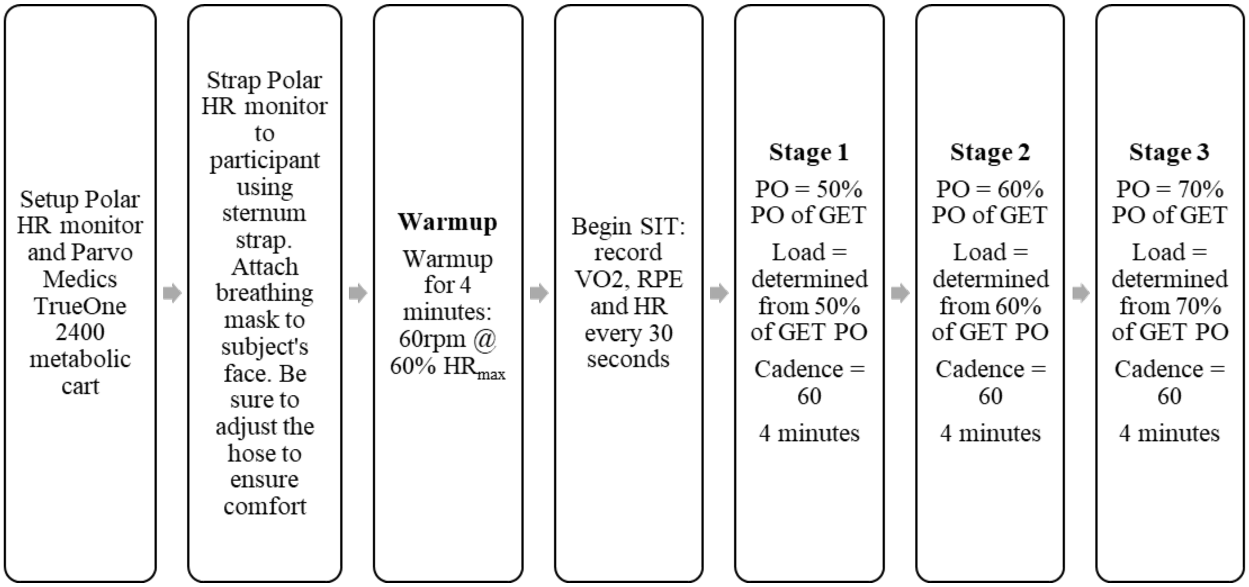


Figure 4

Modified Procedures for Protocol B



Appendix B: Calculations

Step-incremental cycling test load calculation for protocol in protocol A:

$0.0093 \cdot 75kg = 0.7kg$ (10x lighter than a typical Wingate protocol in order to exaggerate cadence manipulation)

Step-incremental test power output stage calculations:

RIT PO_{MAX}=200W; therefore, $PO_{30\%MAX}$=60W; $PO_{40\%MAX}$=80W; $PO_{50\%MAX}$=100W

Protocol A cadence calculations:

Power (W) = Force (N) x Velocity (m/s)
Force = 9.81 m•s^{-2} x 0.7kg = 6.9N

$$Cadence\ (rpm)\ =\ Velocity\ (\frac{m}{s}) \times \frac{60s}{1\ min} \times \frac{1\ rev}{6m} = Velocity\ \times 10$$

Stage 1:
60W = (6.9N)(V); V = 8.7m•s^{-1}; Cadence = (8.7)(10) = 87rpm
(adjusted to 85rpm)

Stage 2:
80W = (6.9N)(V); V = 11.6m•s^{-1}; Cadence = (11.6)(10) = 116rpm
(adjusted to 115 rpm)

Stage 3:
100W = (6.9N)(V); V = 14.5m•s^{-1}; Cadence = (14.5)(10) = 145rpm

Protocol B Load Calculations:

Power (W) = Force (N) x Velocity (m/s)
Force = 9.81 m•s^{-2} x Load

$$Velocity\ (\frac{m}{s}) = \frac{60\ rev}{min} \times \frac{1\ min}{60s} \times \frac{6m}{1\ rev} = 6\frac{m}{s}$$

Stage 1:
60W = (Force)(6m•s^{-1}); Force = 10N; Load = (10N)/(9.81 m•s^{-2}) = 1.02kg

Stage 2:
80W = (Force)(6m•s^{-1}); Force = 13.3N; Load = (13.3N)/(9.81 m•s^{-2}) = 1.36kg

Stage 3:
100W = (Force)(6m•s^{-1}); Force = 16.7N; Load = (16.7N)/(9.81 m•s^{-2}) = 1.70kg