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The effect of intensity and duration of verification stages on the efficacy of VO2max testing

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The Effect of Intensity and Duration of Verification Stages on the Efficacy of VO_{2max} Testing

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Dedication

I dedicate this work to my parents and the rest of my family for supporting me every step of the way.

Acknowledgments

I would like to thank my project committee for all the time and effort spent going into this project. First, I would like to thank Dr. Christopher Womack for his help throughout the entire process. His constant support, as well as his expertise made this project possible. I would like to thank Dr. Stephanie Kurti and Dr. Nicholas Luden for being my readers for this project. Their feedback helped me grow as a student and researcher. These people played an important role in this project, and I could not have done it without them.

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Abstract

Purpose: To determine if changing the length of the recovery stage influences the effectiveness, or ability to confirm maximal oxygen consumption (VO_{2max}), of the verification phase and if the initial intensity of the stage has an impact on its effectiveness. ***Methods:*** 27 subjects (20 males and 7 females) performed four separate VO_{2max} tests separated by at least 48 hours. For each initial graded exercise test, starting speed was 3.0 mph and increased by 0.5 mph every minute until 6.0 mph was reached. After this point, elevation was increased by 3.0% every minute until volitional exhaustion. VO_2 was continuously tracked using a Parvomedics metabolic measurement system. Heart rate and RPE was gathered at the end of every minute. The highest 30s average achieved during the graded exercise test was defined as VO_{2max} for the incremental test (iVO_{2max}). Four different verification stages followed and included combinations of short (5-min) and long (15-min) rest periods, and submaximal (one stage beneath maximal workload) and supramaximal (one stage above maximal workload) intensities. ***Results:*** There were no significant difference between iVO_{2max} and verification VO_{2max} (vVO_{2max}) across all protocols. RER was lower ($P < 0.05$) during the verification stage compared to the graded exercise test for the long/submaximal and short/supramaximal protocol. HR_{max} was similar between GXT and short/submaximal verification stage, whereas the other three verification protocols elicited lower HR_{max} values. Average verification RPE was significantly higher than average GXT RPE for the long/supramaximal protocol. Though VO_{2max} was not different between GXT and verification stage, the short/submaximal protocol resulted in 81.5% of subjects with vVO_{2max} the same or higher than iVO_{2max}. ***Conclusion:*** Based on fewer tests with

vVO2max < iVO2max, it may be preferable to use shorter rest periods with submaximal initial intensity for verification stage.

Keywords: Verification stage, VO_{2max} testing, cardiorespiratory fitness.

Chapter I

Introduction

Maximal oxygen uptake (VO_{2max}) is one of the most measured variables in exercise science. VO_{2max} is typically measured through a graded exercise test (GXT) with continuous metabolic measurements using a metabolic cart. VO_{2max} has also been found to be associated with long-term health outcomes, including a reduced risk for cardiovascular disease and all-cause mortality[1]. Additionally, VO_{2max} is highly correlated with endurance performance[2].

Ensuring VO_{2max} is reached during a graded exercise test historically involves observation of a plateau at the end of the GXT. A plateau is generally defined as the period near the end of a graded exercise test where there is little to no increase in oxygen consumption (VO_2) despite increasing work rate. However, criteria used to define a plateau has varied from an increase as small as ≤54 mL/min (~ 0.8 mL/kg/min for a 70 kg individual) to ≤2.1 mL/kg/min[3]. Taylor et al. developed a VO_{2max} plateau criterion of ≤150 mL/min, which has become the most common plateau criterion[4]. Midgley et al. raised concerns about this value because it may be too specific to a particular testing protocol and subject pool[5]. Specifically, when directly applying this plateau criterion to test protocols that use small increments for the GXT, the increased VO_2 with each stage will be more likely to be lower. Furthermore, the plateau does not occur in every test subject. Some studies have reported plateau incidence as high as 100% and as low as 0%[6]. Bassett et al suggested that it occurs in about half of VO_{2max} tests[7]. Other studies have reported a plateau in about 15% of non-athletes and 50% of athletes[8]; suggesting that individuals who are more fit are more likely to achieve a plateau. Even in the absence of a plateau, it is possible that a subject achieves VO_{2max} during a graded exercise test. Because of this, secondary criteria have been proposed to verify achievement of VO_{2max}.

The variables that are commonly monitored as secondary criteria are heart rate (HR), respiratory exchange ratio (RER), ratings of perceived exertion (RPE), and blood lactate concentration. The actual values to confirm achievement of VO_{2max} for these variables vary, with the most common criteria being HR_{max} within 10 bpm of one's age predicted maximum (220 – age), RER $\geq$ 1.10, RPE, and blood [lactate] > 8 mmol/L[9,10]. There is currently no standardization of these secondary criteria. Furthermore, secondary criteria have been criticized due to the lack of validity and sensitivity[6]. Poole et al. found that VO_{2max} determined during the GXT could be undermeasured by 27% when the RER value is 1.10 and by 16% when the RER value is 1.15[11]. Subjects also commonly achieve one or more of the secondary criteria at a submaximal intensity. Duncan et al. reported a mean maximal post-exercise blood lactate concentration of 14.3 $\pm$ 2.7 mmol/L, suggesting blood lactate concentration would commonly surpass the 8 mmol/L threshold before reaching VO_{2max}[12]. Poole et al. also showed that when using HR $\pm$ 10 bpm of age-predicted max and RER $\geq$ 1.10, criteria were met in eight healthy men at 75 – 80% of their VO_{2max}[11]. Thus, due to the lack of standardization and efficacy, use of secondary criteria is questionable for VO_{2max} testing.

Because of this, verification stages have been suggested as an effective method to make sure VO_{2max} is reached. A verification stage is conducted after the graded exercise test is complete and the subject goes through a recovery period. Weatherwax et al.

conducted a study looking at the effectiveness of a verification stage in altitude-residing runners and found that the use of a verification stage confirmed VO_{2max} in every trial[13]. Foster et al., observed that the highest VO_2 achieved in a GXT was not significantly different from the value achieved in the verification phase for both cycling and running protocols, suggesting that verification stages are at least effective in eliciting VO_{2max} during the GXT for both modes[8]. Kirkeberg et al also found that the VO_{2max} achieved during a verification phase was not significantly different from the VO_{2max} achieved during a GXT, regardless of varying durations (9 min, 11 min, 13 min) of the GXT[14]. Costa et al. conducted a meta-analysis examining 80 studies and their highest VO_2 responses during a GXT and verification phase. The results showed that the highest VO_2 achieved during the GXT and the verification phase were similar in 54 of the studies[15]. In contrast, Bhammar et al. found that a verification phase resulted in significantly higher VO_{2max} values compared to the VO_{2max} achieved during the graded exercise test[16]. Furthermore, unpublished observations for our lab show that depending on the VO_2 sampling time, a verification phase yielded a higher VO_{2max} in 31-62% of the tests, including some who had achieved secondary criteria and/or a plateau (unpublished observations). Thus, prior studies found subjects reach or exceed the VO_{2max} that was achieved during the initial test, suggesting that a verification phase will either confirm VO_{2max} was reached during the GXT or produce a higher VO_{2max}.

The duration of the recovery phase has varied throughout studies; Bhammar et al. used a recovery period of 15 minutes for a GXT lasting 8-10 min, whereas Foster et al. had recovery periods of 1 minute and 3 minutes. Kirkeberg et al. used 3 minutes as the recovery period and Midgely et al. suggested a recovery phase should be from 5-15 minutes[9]. Rest period durations of 20 minutes have previously been shown to result in similar verification stage efficacy as 60 minute rest periods, suggesting that rest period duration does not influence the efficacy of the verification stage[17]. Furthermore, a meta-analysis by Costa et al. suggested mean differences between the GXT and verification phase were not affected by potential moderators, such as verification phase intensity, verification phase duration, or type of recovery[15]. This suggests that the duration of the recovery period or the intensity of the verification phase will not influence the effectiveness of a verification stage to confirm VO_{2max}. However, mean differences may not truly reflect efficacy of a verification stage as the verification stage could still have caused an increase in VO_{2max} in several individual tests. As an example, unpublished data from our lab show that while average VO_{2max} from the verification stage and from the GXT were not significantly different, the VO_{2max} from the verification stage was >2% higher in over 40% of subjects. Furthermore, it is unknown if variations in rest stage duration under 20 minutes affects the ability of a verification stage to determine if VO_{2max} has been reached.

The intensity of the verification stage ranges from lower than the last stage completed during the VO_{2max} test to workloads higher than the highest achieved from the GXT[9]. Nolan et al. compared the intensity of the verification phase and found that a verification phase at 105% of the maximum intensity from the GXT confirmed the 'true' VO_{2max} in all trials compared to 62.50% of trials with a 115% GXT intensity verification phase[17]. This suggests that using an excessively high workload for the verification stage can reduce the ability to achieve VO_{2max}. However, it is not fully known whether submaximal verification stages result in a more or less efficacious verification stage. It is important to note that as of now, there is no standardization of the verification stage and it is unknown whether a duration or intensity of the verification stage influences its effectiveness.

The two purposes of this study are to determine if changing the length of the recovery stage influences the effectiveness, or ability to confirm VO_{2max}, of the verification phase and if the initial intensity of the stage has an impact on its effectiveness. We hypothesize that the intensity and duration of the recovery phase will not influence the effectiveness of the verification stage.

Chapter II

Methods

Subjects: This study will use 40 subjects (20 males and 20 females). Each subject will be between 18 and 40 years of age on the first testing day. Subjects will complete a health questionnaire to be sure they are free of any know cardiovascular, metabolic or renal disease. Subjects will also need to be free of any injury or condition that would prevent them from exerting effort sufficient to obtain a VO_{2max}.

Protocol: Each subject will complete four separate VO_{2max} tests separated by at least 48 hours. For each initial graded exercise test, starting speed will be 3.0 mph and will increase by 0.5 mph every minute until 6.0 mph is reached. After this point, elevation will increase by 3.0% every minute until volitional exhaustion. VO_2 will be continuously tracked using a Parvomedics metabolic measurement system (Parvomedics; Salt Lake City, UT). A Polar T31 heart rate monitor (Polar Electro, Inc.; Bethpage, NY) will obtain the subjects' heart rate at the end of each minute. RPE will be gathered every minute using a Borg RPE scale. The highest 30s average achieved during the graded exercise test will be defined as VO_{2max} for the incremental stage (iVO_{2max}). Maximal workload will be defined as the highest stage achieved, if the subject completed at least 30s of that stage.

After each graded exercise test, an active rest period will occur, followed by a verification stage. The length of the rest period and starting intensity of the verification stage will differ across the four tests; the rest period and verification stage will be every combination of short (5 min) and long (15 min) rest period and submaximal (one stage below the maximal workload reached) and supramaximal (one stage above maximal workload reached). The four different trials will be: 1) short duration/submaximal, 2) short duration/supramaximal, 3) long duration/submaximal, 4) long duration/supramaximal. There will be four potential orders of the trials, which will be counterbalanced. The orders will be (1-2-3-4, 2-3-4-1, 3-4-1-2, 4-1-2-3). VO_2, HR, and RPE will be gathered the same way as the graded exercise test. The highest 30s average for VO_2 will be defined as verification stage VO_{2max} (vVO_{2max}).

Statistical Analyses: Delta VO_{2max} will be defined as vVO_{2max} - iVO_{2max}. A repeated measures ANOVA will be used to compare delta VO_{2max} across trials with active rest period duration (5 min, 15 min) and verification intensity (submaximal, supramaximal) as within-subject factors. Post-hoc testing will be done using paired t-tests. For vVO_{2max} to be considered to exceed iVO_{2max}, it will have to exceed that value by more than 2%. The proportion of test where $vVO_{2max} > iVO_{2max}$ across the four verification stage protocols will be compared using Chi-squared.

Chapter III

Manuscript

Introduction

Maximal oxygen uptake (VO_{2max}) is one of the most commonly tested variables in exercise science and is associated with numerous long-term health outcomes[1]. A plateau in VO_2 at the end of the test has historically been used to ensure VO_{2max} is reached during a graded exercise test (GXT). The most common plateau criterion is an increase of $\leq$150 mL/min, but due to a variety in exercise protocols employed and variability between subjects, this criterion my not be reproducicle[2,3]. Furthermore, plateaus are not always evident, as plateau incidence rates range from 0 – 100%[4]. Due to this, secondary criteria have been used to verify VO_{2max}. The most common secondary criteria used are: HRmax within 10 bpm of age-predicted maximum, RER > 1.10, RPE at or near maximal values, and blood [lactate] > 8 mmol/L[5,6]. Each of these secondary criteria have been criticized for lack of sensitivity and validity, as well as a lack of standardization and efficacy[4].

Because of this, a verification stage has been suggested as a method to ensure achievement of VO_{2max}. A verification stage begins at a workload close to maximal workload from the GXT and is conducted after the graded exercise test is complete and the subject goes through a recovery period. Several studies have found that verification stages result in similar VO_{2max} values as achieved during the GXT[7,8,9,10]. Furthermore, Bhammar et al. reported that verification stages result in a significantly higher VO_{2max} compared to the VO_{2max} achieved during the GXT[11]. Finally, unpublished data from our laboratory suggest that verification stages yield higher VO_{2max} values in about 40% of tests, including 8 out of 12 tests in which a plateau was evident had a higher vVO_{2max}.

This suggests that a verification stage will either confirm VO_{2max} was reached during the GXT or allow for a higher VO_{2max}.

The duration of the recovery stage has varied in the literature, and researchers have suggested that recovery stage duration does not impact on verification stage efficacy. Nolan et al. compared 20 minute recovery stages to 60 minutes recovery stages, and found no difference between the two, which may suggest that rest period duration is not an important factor. However, recent recommendations are for a rest period of 5-15 minutes, but currently no studies have addressed whether the lower and higher ends of this recommended range influence verification stage efficacy.

In addition to the duration of recovery, there is also significant variability in the intensity selected for the first verification stage, ranging from lower than the last stage completed during the GXT to workloads higher than the highest achieved from the GXT. Previous studies have examined the effect of verification stage intensity, but results have varied. One study showed that workloads at 110% of VO_{2max} can reduce the ability to achieve VO_{2max}[12], while another study showed that differences between GXT VO_{2max} and verification stage VO_{2max} is not influenced by verification stage intensity[10]. It is unknown whether submaximal verification stage intensity result in a more or less efficacious verification stage.

Therefore, the two purposes of this study were to determine if the length of the recovery stage and/or the initial intensity of the verification stage had an impact on verification stage efficacy. We hypothesized that the intensity and duration of the verification stage would not influence the effectiveness of the verification stage.

Methods

Subjects:

The study included 27 subjects (20 males and 7 females). Average age was 20.9 $\pm$ 1.4 years, average height was 176.6 $\pm$ 7.4 cm, and average weight was 75.5 $\pm$ 13.5 kg. Subjects were not allowed to consume any food, drink, or caffeine 3 hours leading up to the exercise test, except water. Subjects also refrained from exercise on the day of testing. Informed consent was obtained from all subjects prior to participation and that the protocol was approved by the James Madison University Institutional Review Board.

Graded Exercise Test:

Each subject completed four separate VO_{2max} tests separated by at least 48 hours. For each initial graded exercise test, starting speed was 3.0 mph and increased by 0.5 mph every minute until 6.0 mph was reached. After this point, elevation was increased by 3.0% every minute until volitional exhaustion. VO_2 was continuously tracked using a Parvomedics metabolic measurement system (Parvomedics; Salt Lake City, UT). A Polar T31 heart rate monitor (Polar Electro, Inc.; Bethpage, NY) was used to obtain heart rate at the end of each minute. RPE was obtained every minute using a Borg RPE scale. The highest 30s average achieved during the graded exercise test was defined as VO_{2max} for the incremental test (iVO_{2max}). Maximal workload was defined as the highest stage achieved, if the subject completed at least 30s of that stage.

Verification Stage:

After each graded exercise test, an active rest period occurred, followed by a verification stage. The length of the rest period and starting intensity of the verification stage differed across the four tests; the rest period and verification stage was every combination of short (5 min) and long (15 min) rest period and submaximal (one stage below the maximal workload reached) and supramaximal (one stage above maximal workload reached) intensities. The four different trials were: 1) short duration/submaximal, 2) short duration/supramaximal, 3) long duration/submaximal, 4) long duration/supramaximal. There were four potential orders of the trials, which were counterbalanced. The orders were (1-2-3-4, 2-3-4-1, 3-4-1-2, 4-1-2-3). Seven subjects completed order 1, seven subjects completed order 2, seven subjects completed order 3, and six subjects completed order 4. VO_2, HR, and RPE were gathered the same way as the graded exercise test. The highest 30s average for VO_2 was defined as verification stage VO_{2max} (vVO_{2max}).

Statistical Analysis:

VO_{2max}, RER_{max}, HR_{max}, and RPE_{max} were compared using a repeated measures ANOVA with stage (GXT, verification stage) and protocol (short/submaximal, long/submaximal, short/supramaximal, and long/supramaximal) as within-subject factors. Post-hoc testing was performed using paired t-tests. vVO_{2max} had to exceed iVO_{2max}, it had to exceed iVO_{2max} by more than 2% to be considered higher or lower respectively. The proportion of test where vVO_{2max} exceeded, equaled, or was less than iVO_{2max} across the four verification stage protocols were compared using Chi-squared. A priori statistical significance was set at $P < 0.05$.

Results:

Table 1 shows average VO_{2max}, RER_{max}, HR_{max} and RPE_{max} for all four trials. There was no significant difference between iVO_{2max} and vVO_{2max} for all four trials. For RER_{max}, we observed a main effect for protocol and a stage x protocol interaction, where average verification RER was significantly less than less than GXT RER for the long/submaximal and short/supramaximal protocols. For HR_{max}, we observed a significant effect of stage and a stage x protocol interaction, where verification HR_{max} was significantly less than GXT HR_{max} for each protocol except short/submaximal. HR_{max} was not obtained for one subject, so the analysis was performed on the remaining 26 subjects. For RPE_{max}, we observed a significant stage x protocol interaction, in which the verification RPE_{max} was significantly higher than GXT RPE_{max} for the long/submaximal protocol

Table 2 shows the number of subjects with verification stage VO_{2max} higher, equal to, and lower than the incremental stage VO_{2max}. The short/submaximal protocol had a lower ($p < 0.05$) percentage of subjects where $iVO_{2max} > vVO_{2max}$ than either the short/supramaximal or the long/supramaximal. Furthermore, the proportion of tests where $iVO_{2max} = vVO_{2max}$ was higher ($p < 0.05$) in the short/submaximal than in the long/submaximal.

Discussion:

There was no significant difference between average iVO_{2max} and vVO_{2max} across the different protocols, regardless of rest duration and starting intensity. This is consistent with Costa et al., who reported that GXT VO_{2max} will yield similar results to verification stage VO_{2max}, regardless of potential moderators, such as verification phase intensity, verification phase duration, or type of recovery[10]. The short/submaximal protocol appears to be least likely to produce a vVO_{2max} lower than iVO_{2max}. Furthermore, our results also suggest that the long/submaximal protocol is less likely than the short/submaximal to produce a vVO_{2max} the same as iVO_{2max}. Therefore it appears that vVO_{2max} is typically the same or higher as iVO_{2max} when using the short/submaximal protocol. Overall, the short/submaximal protocol yielded vVO2max values that were the same or higher in 81.5% of tests compared to the short/supra (51.8%), long/submaximal (59.5%), and long/supramaximal (55.5%) protocols. The short/submaximal protocol was also the only protocol to yield HR_{max} and RER_{max} values similar to the incremental test, suggesting that subjects were able to avoid fatiguing before being able to reach maximal heart rate only in this protocol. When a verification stage is used, ideally vVO_{2max} should be the same or higher than iVO_{2max}. In spite of this, no other study has analyzed the proportion of tests over and under iVO_{2max} when using a verification stage. Although there was no significant difference between average vVO_{2max} and iVO_{2max} across the four protocols, supramaximal intensities appear to be more likely to produce a vVO_{2max} lower than iVO_{2max}. Previous research has suggested that excessively high workloads can reduce the ability to achieve VO_{2max}[12]. This could be possible due to subjects reaching premature fatigue due to the high intensity.

A shorter rest period may be more likely to produce a higher VO_{2max} due to VO_2 still being elevated following the short rest period, whereas longer rest periods may allow VO_2 to return closer to resting values. In the present study, the vVO_{2max} was lower than the iVO_{2max} value for both long rest duration protocols over 40% of the time. This was also the case for the short/supra, but not the short/submaximal protocol, where the proportion of tests with a lower vVO_{2max} dropped to 18.5% More research needs to be done on verification stages and rest periods, but it does appear that supramaximal intensities may be more likely to yield a lower vVO_{2max}.

A recommendation could be made based on the current data to employ verification stages similar to the short/submaximal stage used in the present study. This would appear to result in a greater proportion of tests above or equal to VO_{2max} from the GXT. Furthermore, from a practical standpoint, less time would be taken up with the recovery stage and the use of a starting point below maximal workload could be beneficial for subject comfort. Some limitations to this study were that our findings were limited to treadmill exercise using our specific protocol. It is unknown if these findings can be generalized to other testing modalities or to other treadmill protocols with different workload increments for each stage. Furthermore, the subjects consisted of young, relatively fit individuals, so the relative efficacy of the verification stages that were tested may not translate to older and/or sedentary populations.

Colletively, data from the current study suggest no difference in iVO_{2max} and vVO_{2max} despite varying rest duration and initial stage intensity for the verification stage. However, practitioners may want to consider shorter duration rest periods and submaximal initial intensities due to a lower probability of a low vVO_{2max} and due to practical considerations.

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Results:

Table 1. Average VO_{2max}, RER_{max}, HR_{max}, and RPE_{max} values for all iVO_{2max} and vVO_{2max} protocols. HR_{max} was not obtained for one subject, so the analysis was performed on the remaining 26 subjects.

	Short/Submaximal		Long/Submaximal		Short/Supramaximal		Long/Supramaximal	
	Incremental	Verification	Incremental	Verification	Incremental	Verification	Incremental	Verification
VO_{2max} (mL/kg/min)	50.32 ± 9.42	50.47 ± 10.00	50.56 ± 9.20	50.06 ± 9.53	50.89 ± 8.63	49.66 ± 9.61	49.91 ± 9.80	49.52 ± 9.42
RER_{max}	1.17 ± 0.20	1.14 ± 0.76	1.14 ± 0.11	1.04 ± 0.11*	1.15 ± 0.09	0.91 ± 0.09*	1.14 ± 0.08	1.25 ± 1.00
HR_{max} (bpm)	188.2 ± 10.2	186.4 ± 9.1	188.4 ± 9.8	183.0 ± 10.1*	188.3 ± 8.3	184.2 ± 10.2*	187.5 ± 11.3	182.2 ± 11.0*
RPE_{max}	18.8 ± 1.3	18.9 ± 1.3	18.7 ± 1.7	18.7 ± 1.6	18.4 ± 1.8	18.7 ± 1.4	18.5 ± 1.8	19.0 ± 1.4*

*Verification stage significantly different from GXT ($P<0.05$).

Table 2. The number of subjects with verification stage VO_{2max} 2% over, within 2%, and 2% under the incremental stage VO_{2max}.

	Short/Submaximal	Short/Supramaximal	Long/Submaximal	Long/Supramaximal
>2%	7 (25.9%)	6 (22.2%)	11 (40.7%)	5 (18.5%)
same	15 (55.6%)[c]	8 (29.6%)	5 (18.5%)	10 (37.0%)
<2%	5 (18.5%)[b,d]	13 (48.1%)	11 (40.7%)	12 (44.4%)

a-different than short/sub, b-different than short/supra, c-different than long/sub, d-different than long/supra.

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