The efficacy of a discontinuous graded exercise test in measuring peak oxygen uptake in children aged 8 to 10 years

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ABSTRACT: As children's natural activity patterns are highly intermittent in nature, and characterised by rapid changes from rest to vigorous physical activity, discontinuous exercise tests may be considered ecologically valid for this population group. This study compared the peak physiological responses from a discontinuous and continuous graded exercise test (GXT_D, GXT_C, respectively) during treadmill exercise in children. Twenty-one healthy children (9.6 ± 0.6 y) completed GXT_D and GXT_C in a randomised order, separated by 72-hours. Following each GXT, and after a 15-minute recovery, participants completed a verification test at 105% of the velocity attained at peak oxygen consumption (VO_2peak). There were no differences in VO_2peak (55.3 ± 8.2 cf. 54.4 ± 7.6 $mL \cdot kg^{-1} \cdot min^{-1}$) or maximal heart rate (202 ± 10 cf. 204 ± 8 $b \cdot min^{-1}$) between GXT_C and GXT_D, respectively ($P>.05$). Peak running speed (10.7 ± 0.9 cf. 12.1 ± 1.3 $km \cdot h^{-1}$) and respiratory exchange ratio (1.04 ± 0.05 cf. 0.92 ± 0.05) were however different between tests ($P<.001$). Although similar peak physiological values were revealed between GXT_C and the corresponding verification test ($P>.05$), VO_2peak (53.3 ± 7.3 $mL \cdot kg^{-1} \cdot min^{-1}$) and heart rate (197 ± 13 $b \cdot min^{-1}$) were significantly lower in the GXT_D verification test ($P<.05$). In conclusion, a discontinuous GXT is an accurate measure of VO_2peak in children aged 8 to 10 years and may be a valid alternative to a continuous GXT, despite its longer duration.

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INTRODUCTION

Maximal oxygen uptake (VO_2max) denotes the highest rate of oxygen uptake and utilisation within the body, and is an important marker of aerobic fitness and endurance performance [1-3]. Although VO_2max testing is commonly undertaken with paediatric groups, there is no consensus as to which incremental protocol is the most accurate for use with pre-pubertal children [4-10].

Eston and Parfitt [11] suggest that a discontinuous, incremental exercise test may elicit a more appropriate indication of maximal functional capacity in children compared to a continuous exercise test. Although limited, the pilot data from the aforementioned study demonstrated a higher peak heart rate and a lower perception of exertion for a given heart rate during a discontinuous versus continuous exercise test. In addition, the discontinuous test was shown to be preferential. As children's natural activity patterns are highly intermittent in nature, and characterised by rapid changes from rest to vigorous physical activity, discontinuous exercise tests may be considered ecologically valid for this population group, possibly more so than exercise of a continuous nature, if administered in the correct manner [12,13]. Skinner et al. [14] have previously demonstrated similar physiological responses between a continuous and discontinuous exercise test. However, during the discontinuous exercise protocol, the gradient of movement was altered rather than speed of movement, which does not necessarily demonstrate ecological validity [14]. Similarly, a prolonged rest period between bouts of intermittent exercise has been used in some studies, which may also limit the generalisability of study findings in relation to children's natural patterns of physical activity behaviour [14,15]. More recent research has tried to account for such differences by administering a discontinuous graded exercise test (GXT) protocol, which incorporates short recovery periods between bouts of increasing exercise [6,7,11,16]. For example, with pre-pubertal children, a number of studies have utilised repeated bouts of exercise (1-min duration) interspersed with passive recovery periods (1-min duration) [6,7,16]. However, a more comprehensive comparison of the physiological and perceptual responses between discontinuous and continuous testing procedures is needed to determine the validity of such protocols with children. Historically, the term VO_2max denotes a limit in VO_2 despite increased muscular work [17], and is characterised by a plateau in VO_2 in response to increasing exercise intensity [18]. However, it has often been shown that individuals can achieve their maximal aerobic capacity despite no observable plateau in their VO_2 response (i.e., VO_2peak) [19-21]; a finding commonly associated with maximal exercise testing in children [5,22,23]. As the use of secondary criteria (i.e., achievement of a maximum heart rate within 10 b·min-1 of age-predicted maximum) has also been questioned [2,24-26], a verification test, whereby an individual completes a supramaximal bout of exercise on completion of a maximal exercise test, has been recommended [19]. During continuous exercise testing, this ensures that an accurate VO_2peak has been attained in children [5]. However, as previous research has not yet implemented verification tests during discontinuous exercise testing procedures [6,7,16], further research is necessary to assess their efficacy following this type of exercise protocol.

The purpose of this study, therefore, was to compare the VO_2peak ascertained from a continuous and discontinuous exercise test in children aged 8 to 10 years. The study was also interested in identifying the importance of the verification test during both continuous and discontinuous exercise testing. It was hypothesised that a discontinuous GXT would elicit a higher VO_2peak than that achieved from a continuous GXT.

MATERIALS AND METHODS

Participants

Twenty-one healthy children (9.6 ± 0.6 y, 1.47 ± 0.09 m, 45.0 ± 12.0 kg, 20.5 ± 3.9 kg·m^2) who completed, on average, two bouts of structured physical exercise each week outside of the school environment, volunteered for this study. To ascertain that children were asymptomatic of illness, disease and pre-existing injuries, parents/guardians completed a health screening questionnaire. Child assent and parent/guardian consent were obtained prior to participation in the research, which was conducted in agreement with the guidelines and policies of the institutional ethics committee and the requirements stipulated by the Declaration of Helsinki.

Procedures

Participants took part in two randomised laboratory-based exercise tests within a thermo-neutral environment (21.8 ± 1.9 ºC, 38.4 ± 7.0 % [humidity], 1005 ± 9 Nm^2); a discontinuous GXT (GXT_D) and continuous GXT (GXT_C) to VO_2peak. All tests were conducted in a randomised order on a treadmill (True 825, Fitness Technologies, St. Louis, USA) set at 1% grade to parallel the oxygen cost of running outside (Jones & Doust, 1996), with a minimum 72 h recovery period between tests. Standing and seated height (measured to the nearest 0.1 cm; SECA, Hamburg, Germany) and body mass (measured to the nearest 0.1 kg; InBody Biospace 230, Los Angeles, USA) were obtained on the initial visit to the laboratory. The online respiratory gas analysis was undertaken continuously using a breath-by-breath automatic gas exchange system (Sensormedics Corporation, Yorba Linda, CA, USA). Respiratory variables (oxygen uptake [VO_2], carbon dioxide [VCO_2], minute ventilation [V_E], respiratory exchange ratio [RER]) were measured continuously. Heart rate (HR) was measured using a paediatric wireless chest strap telemetry system (Polar Electro T31, Kempele, Finland), and stride frequency (SF) was recorded throughout each exercise test. The Eston-Parfitt (EP) Scale was used to provide an indication of a child's perception of exertion on completion of each stage of the exercise test [7]. All physical and physiological data were concealed from the participants during each test. At the end of the study children were asked to indicate (tick box) whether they preferred the discontinuous or continuous exercise test.

Discontinuous graded exercise-test (GXT_D)

Children were firstly familiarised and habituated to a range of treadmill speeds (4, 6 and 8 km·h^{-1}) and testing equipment (facemask, HR monitor). The GXT_D followed a discontinuous exercise protocol to ascertain VO_2peak and maximal heart rate (HRmax) [7,16]. Children commenced the test by walking at 4 km·h^{-1} for 1-min. The treadmill speed was then stopped (0 km·h^{-1}) to allow a 1-min recovery before the treadmill speed was increased to 6 km·h^{-1} for a further minute of exercise. Increments of 1 km·h^{-1} continued with this protocol until a speed of 8 km·h^{-1} was accomplished. Thereafter, the treadmill speed was incremented by 0.5 km·h^{-1} (8.5, 9.0, 9.5, 10.0 km·h^{-1}, etc.) every minute, with a 1-min recovery period between stages, until volitional exhaustion. During the final 10 s of each increment of the GXT, participants reported their overall perception of exertion.

Verification test

Following a 15-minute recovery period, participants completed a VO_2peak verification test whereby speed was gradually increased over a 30 s period to a running speed which was 105 % of the velocity attained at VO_2peak. Participants then exercised at this running speed until volitional exhaustion. Physiological variables were measured throughout.

Continuous graded exercise-test (GXT_C)

The GXT_C followed a similar protocol to that implemented in GXT_D, except that no recovery periods were employed between each stage of the exercise test. A comparable verification test was utilised 15-minutes following GXT_C.

Data Analysis

A series of paired-samples *t*-tests were used to compare the maximal physiological (VO_2peak, HRmax, $V_E$peak, terminal RER) and perceptual data between the GXTs. A similar analysis was used to compare VO_2peak data between the GXT and the respective verification stage for both GXT_D and GXT_C. Effect sizes were established using Cohen's *d*, where 0.2, 0.5 and 0.8 represent a small, moderate and large effect, respectively [27]. Pearson's correlation coefficients (*r*) were used to quantify the similarity of the maximal physiological criteria between the two tests (GXT_D and GXT_C) and between each GXT and their respective verification data. A Bland and Altman 95% Limits of Agreement (LoA) analysis quantified the agreement (bias ± random error [1.96 x SD]) between the measured VO_2peak from GXT_D and GXT_C [28]. Alpha was set at 0.05 throughout all analyses, and adjusted accordingly. All data were analysed using the statistical package SPSS for Windows, PC software, Version 21.

RESULTS

GXT data

The maximal values reported on completion of GXT_D and GXT_C are shown in Table 1. Significant differences in RER and peak speed were observed between tests ($P < .001$). There were no differences between tests for VO_2peak, HRmax, $V_E$peak and perceived exertion (all $P > .05$).

Pearson's *r* from GXT_D and GXT_C revealed moderate to strong correlations for all values reported on completion of the tests (0.49-0.80; Table 1). For the VO_2peak reported from the GXT_D and GXT_C, the corresponding 95% LoA were 0.91 ± 11.69 $mL·kg^{-1}·min^{-1}$ (Figure 1). Representative data for VO_2 taken from one participant during GXT_D and GXT_C are shown in Figure 2.

Verification data

Significant differences were observed for VO_2peak ($P < .05$), HRmax ($P < .01$) and peak speed between GXT_D and its corresponding verification test ($P < .001$). As demonstrated in Table 2, although participants were running at a significantly faster speed, a lower VO_2peak and HRmax were reported during the verification test. A significant difference was only observed for RER between GXT_C and the verification test, with a lower value reported during the verification test ($P < .01$; Table 3). Moderate to strong correlations were reported for all physiological, physical and perceptual responses between GXTs and their corresponding verification tests (GXT_D: Table 2; GXT_C: Table 3).

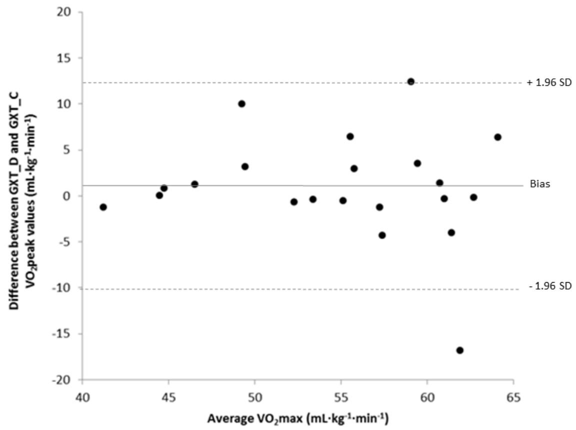

FIG. 1. Narrowest 95 % limits of agreement (bias ± [1.96 x SD_{diff}], $mL·kg^{-1}·min^{-1}$) between the GXT_D and GXT_C VO_2peak values.

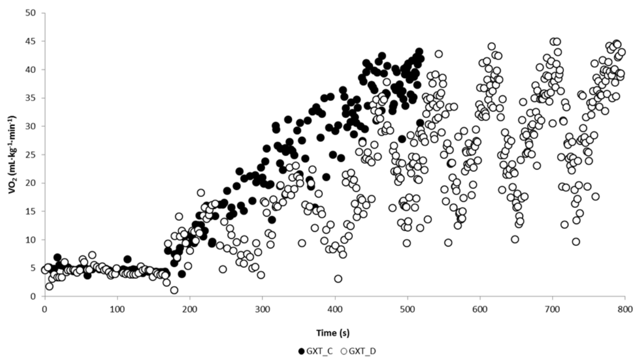

FIG. 2. Representative subject data for VO_2 from GXT_C (dark circles) and GXT_D (open circles). The figure includes a 3-minute baseline VO_2 measure.

TABLE 1. Mean (± SD) physiological, perceptual and physical values on completion of GXT_D and GXT C.

	GXT_C	GXT_D	r	Cohen's d
$\dot{V}O_2$peak ($mL·kg^{-1}·min^{-1}$)	55.3 ± 8.2	54.4 ± 7.6	.64	.12
$\dot{V}_E$ ($L·min^{-1}$)	79.9 ± 22.8	77.6 ± 16.9	.49	.11
RER	1.04 ± 0.05	0.92 ± 0.05*	.68	2.49
HR ($b·min^{-1}$)	202 ± 10	204 ± 8	.63	-.21
Perceived exertion	9.2 ± 1.3	9.9 ± 0.4	-.30	-.69
Peak speed ($km·h^{-1}$)	10.7 ± 0.9	12.1 ± 1.3*	.80	-.14
Duration (min)	7.4 ± 1.6	21.5 ± 5.0*	.52	3.80

Note: GXT_C - Continuous graded exercise-test ;GXT_D - Discontinuous graded exercise-test; r - Pearson's correlation coefficients; * Significant difference between GXT_D and GXT_C (P < 0.05).

TABLE 2. Mean (± SD) physiological, physical and perceptual values on completion of the verification stage to GXT_D.

	GXT_D_VER	GXT_D_DIFF	r	Cohen's d
$\dot{V}O_2$peak ($mL·kg^{-1}·min^{-1}$)	53.3 ± 7.3	-1.2 ± 2.3*	.98	.14
$\dot{V}_E$ ($L·min^{-1}$)	76.1 ± 19.9	-2.5 ± 7.8	.95	-.18
RER	0.92 ± 0.11	0 ± 0.11	.37	0
HR ($b·min^{-1}$)	197 ± 13	-7 ± 8*	.83	.64
Perceived exertion	9.6 ± 0.7	-0.2 ± 0.9	-.41	.52
Peak speed ($km·h^{-1}$)	12.5 ± 1.2	0.5 ± 0.2*	.99	-.31
Duration (min)	1.2 ± 0.4			

Note: GXT_D_VER - the verification values from GXT_D; GXT_D_DIFF - the difference in values between GXT_D and the corresponding verification test; r - the Pearson's correlation coefficients; * Significant difference between GXT and verification test (P < 0.05).

TABLE 3. Mean (± SD) physiological, physical and perceptual values on completion of the verification stage to GXT_C.

	GXT_C_VER	GXT_C_DIFF	r	Cohen's d
V̇O$_2$peak (mL·kg^{-1}·min^{-1})	55.3 ± 7.0	0.02 ± 4.4	.91	.0
V̇$_E$ (L·min^{-1})	82.6 ± 17.4	2.7 ± 21.2	.62	-.13
RER	1.01 ± 0.05	0.03 ± 0.05*	.71	.20
HR (b·min^{-1})	204 ± 7	3 ± 9	.61	-.23
Perceived exertion	9.2 ± 1.3	0 ± 1.3	.66	.0
Peak speed (km·h^{-1})	10.7 ± 0.8	11.2 ± 0.8	1.00	-.55
Duration (min)	2.6 ± 1.1			

Note: GXT_C_VER - the verification values from GXT_C; GXT_C_DIFF - the difference in values between GXT_C and the corresponding verification test; r - the Pearson's correlation coefficients. * Significant difference between GXT and verification test ($P < 0.05$).

GXT preference

Of the 21 participants, 19 participants indicated that they preferred GXT_D compared to two participants who preferred GXT_C.

DISCUSSION

This study demonstrated no statistical differences in the VO$_2$peak values obtained from either a discontinuous or continuous GXT, in contrast to our study hypothesis which suggests that GXT_D may elicit a higher measure of maximal functional capacity in pre-pubertal children. However, a significantly lower VO$_2$peak and HRmax were observed during the verification test of the discontinuous GXT. No differences were observed between the GXT and verification data from the continuous exercise test.

Continuous, incremental exercise testing protocols are commonly applied in paediatric research [5,8-10,29,30). However, it has been suggested that continuous exercise testing protocols may limit athletic performance (i.e., VO$_2$peak) in individuals accustomed to intermittent exercise [31]. Past research has recommended that discontinuous GXTs may be appropriate when investigating the maximal exercise capacity of children [11] as it may better reflect children's normal patterns of physical activity [12,13]. In this study, a discontinuous GXT was shown to be a valid alternative to a continuous GXT when assessing maximal functional capacity in children aged 8 to 10 years, as shown by the statistical similarities and moderate to strong correlations (Table 1). However, it should be noted that the test duration of the discontinuous GXT was much greater than the continuous GXT, which would have practical implications associated with overheads, labour time and costs for clinicians and exercise practitioners.

In this study, 11 participants elicited a higher VO$_2$peak during the discontinuous GXT, while 10 participants elicited a higher VO$_2$peak during the continuous GXT. When considering the 95% LoA, a mean difference of 0.91 mL·kg^{-1}·min^{-1}, with a bias of ± 11.69 mL·kg^{-1}·min^{-1}, was observed between the VO$_2$max values of the GXT_D and GXT_C (Figure 1). Accordingly, due to the large bias, one test (GXT_D cf. GXT_C) may underestimate VO$_2$peak by as much as 23 % compared to the other. It is of interest to note, however, that when the two outliers are removed from the analysis (Figure 1), the potential variance is reduced to 15 % (95% LoA: 1.23 ± 7.17 mL·kg^{-1}·min^{-1}). As such, it is plausible that the inclusion of a more homogenous sample (e.g., matched for body mass, fitness) in a study such as this would likely reduce the observed differences in VO$_2$peak values between GXT_D and GXT_C. This should be considered in future research.

In keeping with previous research, a supramaximal bout of exercise (verification test) elicited statistically similar maximal values to those obtained from the GXT_C [5,25]. Although eight of the participants (38 %) elicited a higher VO$_2$peak in the verification test of GXT_C, only four participants (19 %) achieved a similar outcome for GXT_D. In this regard, the verification test for GXT_D elicited a significantly lower VO$_2$peak and maximal HR than that observed from the actual GXT, despite the observation of strong correlations (r = 0.98 and 0.83, respectively). As reflected in the duration of the GXT_D verification test (Table 3), it is evident that the supramaximal bout of exercise that was employed was not appropriate for the children in this study. Essentially, the higher peak speed and longer test duration of GXT_D compared to GXT_C (Table 1) resulted in a subsequent validation test speed that was, practically, too quick for the children. Thus, the children were unable to achieve VO$_2$peak before volitional exhaustion ensued or the test needed to be terminated due to safety concerns (uncoordinated gait due to exhaustion). Accordingly, a verification test of this nature may not be appropriate following a discontinuous GXT, and alternative protocols, if deemed necessary, should be considered if implementing discontinuous exercise protocols to assess VO$_2$peak in children.

It is important to recognise that this study implemented established and robust measures for determining VO$_2$peak from the GXTs (i.e., verification test, secondary criteria). Although the utility of secondary criteria has been questioned [2,24-26], in the current study, there were minimal differences between the two testing procedures as similar maximal heart rates and peak perceptions of exertion were reported for GXT_D and GXT_C (Table 1). However, recovery periods during intermittent exercise have been shown to result in improved exercise performance as a result of the ability to resynthesise PCr and by ensuring the sufficient removal of metabolites, CO_2 and the shuttling of blood lactate [32]. It is likely that such factors underpinned the achievement of a statistically higher peak speed and a lower RER on completion of the discontinuous GXT, as well as contributed to the children's preference with regards to the testing procedure (i.e., discontinuous vs. continuous GXT).

CONCLUSIONS

In conclusion, a discontinuous GXT provides a valid measure of maximal functional capacity in comparison to a traditional continuous

GXT. Despite the large differences in test duration, a discontinuous GXT may elicit similar VO_2 and heart rate responses, but higher peak speeds compared to a continuous test. Children also expressed preference for the discontinuous exercise protocol. A continuous protocol, however, would prove more time and cost efficient to administer. Although verification procedures have been recommended to confirm VO_2peak, our findings suggest that accurate measures of VO_2peak can be achieved through appropriate implementation of a single discontinuous or continuous GXT.

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