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Validation and calibration for embedding rating of perceived exertion into high-intensity interval exercise in adolescents: a lab-based study

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RUNNING HEAD: RPE validation and calibration in HIIE

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ABSTRACT

Purpose: Rating of perceived exertion (RPE) is a convenient and cost-effective tool that can be used to monitor high-intensity interval exercise (HIIE). However, no methodological study has demonstrated the validity of RPE in this context. Therefore, the aim of this study was to validate and calibrate RPE for monitoring HIIE in adolescents. ***Methods:*** RPE, heart rate (HR) and oxygen uptake ($\dot{V}O_2$) data were retrospectively extracted from three lab-based crossover studies, with a pooled sample size of 45 adolescents, performing either cycling-based or running-based HIIE sessions. Within-participant correlations were calculated for RPE-HR and RPE-$\dot{V}O_2$, and receiver operator characteristic curve analysis was used to establish RPE cut-points. ***Results:*** The results showed that RPE-HR demonstrated acceptable criterion validity ($r = 0.53 - 0.74$, $p < 0.01$), while RPE-$\dot{V}O_2$ had poor validity ($r = 0.40 - 0.48$, $p < 0.01$), except for HIIE at 100% peak power ($r = 0.59$, $p < 0.01$). RPE cut-points of 4 and 5 were established in corresponding to HR/$\dot{V}O_2$ based thresholds. ***Conclusion:*** RPE has some utility in evaluating intensity during lab-based running or cycling HIIE in adolescents. Future studies should expand the validation and calibration of RPE for prescribing and monitoring HIIE in children and adolescents in field-based contexts.

INTRODUCTION

High-intensity interval exercise (HIIE) has emerged as a feasible and efficacious exercise modality for health promotion in adolescents (8, 10, 11, 18). It is espoused as an effective exercise which delivers similar, if not superior, benefits in cardiorespiratory fitness, body composition and cardiovascular disease biomarkers compared to moderate-intensity continuous training (8, 11). Meanwhile, recent studies have suggested that HIIE elicits improved cognitive function, mental health (18) and academic achievement (30) in children and adolescents.

Despite the potential health benefits of performing HIIE, no consensus has been reached in prescribing HIIE intensity, which ranges widely from 80% to 100% maximum heart rate (HR_{max}) (10, 11) or equivalent (e.g., 70% to 90% maximum oxygen uptake ($\dot{V}O_{2max}$)) (4, 8). Traditionally, heart rate (HR) monitoring is adopted as an objective means of intensity surveillance during HIIE (6, 10). In large scale, multi-site interventions however, this may not be practical or financially feasible (35). In addition, the utility of HR monitoring is not without limitations. For example, HR monitors are criticised for being inconvenient to use (12), that they require a large time commitment (32), and incur data loss (26). Thus, it seems a pragmatic alternative to HR is needed for alleviating the challenges of prescribing and monitoring HIIE.

In these circumstances, rating of perceived exertion (RPE) might be an attractive option to large-scale HIIE interventions given its simplicity and versatility (6). RPE is a psychophysiological scale used to assess the integrated sensations arising from multiple factors involving both the mind and body, such as disturbances to homeostasis, prior experience, awareness, and motivation (1). This scale allows individuals to subjectively estimate their degrees of exertion at any given timepoint during exercises, making it a promising tool for prescribing and monitoring HIIE. Indeed, some interventions have adopted RPE for HIIE intensity prescribing and monitoring in children and adolescents (12, 25). However, to our knowledge, no study has validated the use of RPE in monitoring HIIE and neither has it been calibrated for the purpose of estimating the attainment of HIIE intensity thresholds (e.g. 85% HRmax) in this cohort. Consequently, to achieve its practical utility, it is essential to determine the validity of RPE for monitoring HIIE across a range of settings, starting from well-controlled laboratory environments.

Thus, the primary aim of this study was to retrospectively analyse data from three laboratory-based HIIE studies in adolescents (21, 22, 24) to assess the validity of RPE in monitoring HIIE. The second aim was to determine RPE cut-points for estimating HIIE intensity threshold attainment. A range of calibrations were made in corresponding to the commonly adopted intensity thresholds and for upholding to the broad definition of HIIE intensity in the literature. It is hypothesized that RPE is valid to be used as a monitoring tool for HIIE in laboratory settings in adolescents.

METHODS

Participants

This study combined data from three crossover studies (21, 22, 24), with a pooled sample of 45 adolescents (16 females, 13.0 ± 0.9 y). Of the pooled sample, sixteen participants (8 females, 12.0 ± 0.3 y) performed cycling-based HIIE sessions at 70%, 85% and 100% peak power (PP), sixteen participants (8 females, 12.5 ± 0.8 y) performed a cycling-based HIIE session at 85% PP only, while another thirteen males (14.0 ± 0.5 y) completed two running-based interval exercise sessions at the intensity of 90% maximal aerobic speed (MAS) and 90% ventilatory threshold (VT). Data from the three studies were initially used to investigate adolescents' perceptual and enjoyment responses during interval training with no attempt to verify the validity of RPE in monitoring exercise intensity. The studies obtained ethical approval from Sport and Health Sciences Ethics Committee, University of Exeter. Potential risks and benefits of the experimental studies were explained to participants and their parents/guardians and informed assent and consent was obtained.

Incremental Tests

Participants in the cycling-based HIIE performed a ramp-incremental test on a cycle ergometer (Lode Corival Pediatric, Groningen, The Netherlands) to determine HR_{max} and $\dot{V}O_{2max}$ (2). After familiarisation, participants started with a 3-min unloaded warm-up, followed by 15 W increments every 1 min until exhaustion which was defined as failing to keep up a cadence of 75-85 revolutions per minute for 5 consecutive seconds despite strong verbal encouragement. The test is culminated with a 5 min cool down at 25 W.

In line with the study by Thackray and colleagues (31), participants in the running-based sessions completed an incremental test to establish HR_{max} and $\dot{V}O_{2max}$ using a treadmill (Woodway PPS 55 Sport slate-belt treadmill; Woodway GmbH, Weil am Rhein, Germany). Familiarisation was provided before a standard warm up (3 min at 4.0 $km.h^{-1}$). Subsequently, participants completed an incremental test started at 6.0 $km.h^{-1}$ with the speed increased by 0.5 $km.h^{-1}$ every 30 s until volitional exhaustion. By the end of the test, a 5 min cool down at 4.0 $km.h^{-1}$ was completed. Throughout the entire test, the treadmill gradient was set at 1%.

Throughout the incremental tests, HR and $\dot{V}O_2$ were constantly measured via telemetry system (Polar Electro, Kempele, Finland) and calibrated metabolic cart (Cortex Metalyzer III B, Leipzig, Germany). The data were subsequently averaged over 10 s intervals. HR_{max} was taken as the highest HR achieved whereas $\dot{V}O_{2max}$ was determined as the highest $\dot{V}O_2$ elicited on 10 s average (28). In addition, MAS (the maximum speed attained) and VT (the first disproportionate increase in CO_2 production compared to $\dot{V}O_2$) were determined during the treadmill test, while PP was taken as the maximum work power generated during the ramp test.

Experimental Protocols

The cycling-based HIIE consisted of three cycling sessions that were performed at 70%, 85%, or 100% PP for 8 work bouts (1 min each). The running-based interval exercises comprised of two running sessions: (1) 8 x 1 min work bouts at 90% MAS; and (2) 9 to 12 x 1 min work bouts at 90% VT, which was distance matched with 90% MAS. The work bouts were interspersed with 75 s active recovery at 20 W or 4.0 $km.h^{-1}$ for cycling or running, respectively. Each session included a 3 min warm-up and 2 min cool-down at 20 W or 4.0 $km.h^{-1}$ for cycling and treadmill exercise, respectively. The cycling/running sessions were performed at least three days apart and in a counterbalanced order for controlling for an order or learning effect.

Measurement and Extraction

Anthropometry

Stature and body mass were measured to the nearest 0.01 m and 0.1 kg using standard procedures. Body mass index (BMI) was calculated using body mass (kg) divided by stature (m) squared. Weight status was determined according to the age and sex specific BMI cut-points determined by Cole et al. (7).

Heart rate and oxygen uptake

Throughout the exercise protocols, HR and $\dot{V}O_2$ were continuously measured and averaged every 10 s. Subsequently, HR and $\dot{V}O_2$ data were extracted at 16 time-points for later analysis: 20 s before the end of the work (8 bouts) and rest (7 bouts) intervals and immediately post each session.

Rating of perceived exertion

RPE was taken at the same 16 time-points to match with the analysis of the HR and $\dot{V}O_2$ data. The OMNI-cycling scale (27) and OMNI-walk/run scale (33) were used to estimate the perceived exertion during cycling and running sessions, respectively. To ensure the accurate use of the scale, anchoring was giving at integer level, ranging from 0 (not tired at all) to 10 (very, very tired), before the commencement of each session.

Data extraction

Descriptive data of all the 45 participants in the three studies were extracted and pooled together. The RPE, HR and $\dot{V}O_2$ data, with respect to work and rest intervals, were categorised in terms of intensity sessions (e.g., 70% PP), which were extracted from the original three studies. specifically, data related to 90% VT and 90% MAS were sourced from study (22), data for 70% PP and 100% PP sessions were obtained from study (24), while data for 85% PP session were obtained from studies (21, 24).

Statistical Analyses

All the statistical analyses were performed using SPSS (version 28.0; IBM Corporation, Armonk, NY, USA) with a significance level set at 0.05. Descriptive characteristics were presented as mean and standard deviation and was compared between running and cycling groups using independent samples t-tests. Hierarchical multiple regression was employed to assess the correlation between RPE-HR and RPE-$\dot{V}O_2$ by regressing RPE scores against HR and $\dot{V}O_2$ across different sessions separately (i.e., 70% PP, 85% PP and 100% PP, 90% VT and 90% MAS). It is worth mentioning that despite 90% VT being initially classified as moderate intensity in the original study, it was still incorporated into the data analysis. This inclusion was deemed significant as it allowed for a meaningful comparison with the 90% MAS, which facilitates the examination of whether a higher intensity enhances the correlation between RPE and HR/$\dot{V}O_2$ in running-based interval training. To control for individual differences (3), within-participant correlations were applied by creating dummy variables for each participants. In addition, where applicable, age, sex and study design were also included in the model as confounders. The criterion validity was considered as good if correlation coefficient (r) > 0.75, while 0.50 to 0.75 acceptable and < 0.50 poor (16).

Prior to the Receiver Operator Characteristic (ROC) curve analysis, HR and $\dot{V}O_2$ data were converted into percentages of HRmax and $\dot{V}O_{2max}$ achieved, respectively, according to the HR_{max} and $\dot{V}O_{2max}$ values. These percentages were subsequently coded into binary indicator variables (0 or 1) specific to the intensity thresholds (80%, 85%, 90%, 95% and 100% HR_{max} and 70%, 75%, 80%, 85% and 90% $\dot{V}O_{2max}$) for calibration, with “0” represented fail to reach the target thresholds, whereas “1” achieved. ROC curve analysis was then conducted and RPE cut-points for HR/$\dot{V}O_2$ based thresholds were established whereby maximising the Youden index (J = sensitivity + specificity - 1) (36). The area under the ROC curve (AUC) ≥ 0.71, 0.64-0.71 and 0.56-0.64 were adopted to demarcate high, moderate, and low accuracy, respectively (13).

RESULTS

The descriptive data of 45 participants from the three studies were combined and presented in Table 1. Participants in the running-based sessions (13 males) exhibited significantly higher age, body mass, HR_{max} and $\dot{V}O_{2max}$ compared to those in the cycling-based sessions (16 males and 16 females). It is worth noting that, on average, participants achieved 58% of $\dot{V}O_{2max}$ and 79% of HRmax at VT. The session RPE, HR and $\dot{V}O2$ data, with respect to work and rest intervals, were presented in Table 2. Overall, work intervals generated higher mean RPE, HR and $\dot{V}O_2$ in comparison to rest intervals, while the means increased with intensity irrespective of exercise modality.

Table 1. Descriptive characteristics of the participants.

Variable	**Running-based sessions**	**Cycling-based sessions**			**Combined**		
	Males (n=13)	Males (n=16)	Females (n=16)	Overall	Males (n=29)	Females (n=16)	Overall
Age (year)	14.0 (0.5) *	12.4 (0.6)	12.7 (0.7)	12.6 (0.6)	13.2 (1.0)	12.7 (0.7)	13.0 (0.9)
Stature (m)	1.62 (0.11)	1.57 (0.08)	1.55 (0.08)	1.56 (0.08)	1.59 (0.10)	1.55 (0.08)	1.58 (0.09)
Body mass (kg)	49.6 (13.7) *	44.0 (6.1)	44.1 (9.0)	44.0 (7.6)	46.5 (10.5)	44.1 (9.0)	45.7 (9.9)
BMI ($kg.m^{-2}$)	18.6 (3.2)	18.5 (2.0)	18.6 (3.8)	18.6 (3.0)	18.6 (2.6)	18.6 (3.8)	18.6 (3.0)
HR_{max} ($beats.min^{-1}$)	197 (10) *	192 (7)	188 (6)	190 (7)	194 (9)	188 (6)	192 (9)
$\dot{V}O_{2max}$ ($L.min^{-1}$)	2.48 (0.52) *	1.61 (0.24)	1.54 (0.22)	1.57 (0.23)	2.00 (0.58)	1.54 (0.22)	1.83 (0.53)
MAS ($km.h^{-1}$)	15.3 (2.1)	NA	NA	NA	NA	NA	NA
PP (w)	NA	130 (16)	115 (16)	122 (17)	NA	NA	NA
VT_$\dot{V}O_2$ ($L.min^{-1}$)	1.72 (0.33)	0.87 (0.22)	0.72 (0.12)	0.79 (0.19)	1.25 (0.51)	0.72 (0.12)	1.06 (0.49)
% $\dot{V}O_{2max}$	69	56	47	50	63	47	58
VT_HR ($beats.min^{-1}$)	163 (10)	150 (8)	149 (9)	150 (8)	154 (10)	146 (9)	152 (10)
% HR_{max}	83	78	79	79	79	78	79
VT_RPE	3.9 (0.8)	4.7 (1.3)	5.0 (1.1)	4.8 (1.2)	4.3 (1.1)	5.0 (1.1)	4.6 (1.2)

BMI, body mass index; HR_{max}, maximum heart rate; $\dot{V}O_{2max}$, maximum oxygen uptake; MAS, maximum aerobic speed; PP, peak power; NA, not applicable; VT, ventilatory threshold; RPE, rating of perceived exertion; *, Running-based sessions vs Cycling-based sessions, $p < 0.05$.

Table 2. Mean and standard deviation of rating of perceived exertion, heart rate and oxygen uptake in terms of work and rest intervals for different sessions.

Modality	**Running-based sessions**		**Cycling-based sessions**		
Intensity	90% VT	90% MAS	70% PP	85% PP	100% PP
N	13	13	16	32	16
RPE work	2.4 (1.5)	4.3 (2.2)	3.5 (1.7)	4.4 (1.9)	5.8 (1.9)
RPE rest	1.6 (1.2)	2.4 (1.3)	2.5 (1.2)	3.2 (1.3)	3.7 (1.4)
HR work	143 (17)	177 (16)	156 (9)	172 (9)	176 (9)
HR rest	106 (19)	131 (18)	127 (12)	140 (9)	144 (9)
$\dot{V}O_2$ work	1.46 (0.36)	2.01 (0.44)	1.08 (0.18)	1.17 (0.16)	1.28 (0.14)
$\dot{V}O_2$ rest	0.77 (0.19)	1.04 (0.28)	0.64 (0.09)	0.72 (0.13)	0.78 (0.11)

VT, ventilatory threshold; MAS, maximal aerobic speed; PP, peak power; N, number of participants; RPE, rating of perceived exertion; HR, heart rate; $\dot{V}O_2$, oxygen uptake; work, work intervals; rest, rest intervals.

RPE Validation

Table 3 provides the correlation coefficients of RPE-HR and RPE-$\dot{V}O_2$ across intensities and modalities. Overall, after controlling for age, sex and study design, RPE-HR showed an acceptable criterion validity across all intensities and modalities ($r = 0.53$ to 0.74, $p < 0.01$). By contrast, the validity of RPE-$\dot{V}O_2$ was acceptable only if the exercise was performed at 100% PP ($r = 0.59$, $p < 0.01$) whereas the others were poor ($r = 0.40$ to 0.48, $p < 0.01$). In addition, there was a clear trend that the magnitude of the within-subject correlations increased with intensity in both cycling- and running-based sessions.

Table 3. Correlations coefficients for rating of perceived exertion and heart rate and oxygen uptake across various sessions.

Sessions	RPE-HR				RPE-$\dot{V}O_2$			
	N	*r*	95% CI	*p*	*N*	*r*	95% CI	*p*
Cycling-based sessions								
70% PP	16	0.53	0.43, 0.61	< 0.01	16	0.43	0.32, 0.53	< 0.01
85% PP	32	0.61	0.55, 0.66	< 0.01	32	0.44	0.36, 0.51	< 0.01
100% PP	16	0.74	0.68, 0.80	< 0.01	16	0.59	0.50, 0.67	< 0.01
Running-based sessions								
90% VT	13	0.54	0.43, 0.63	< 0.01	13	0.40	0.28, 0.51	< 0.01
90% MAS	13	0.69	0.60, 0.75	< 0.01	13	0.48	0.36, 0.58	< 0.01

RPE, rating of perceived exertion; HR, heart rate; $\dot{V}O_2$, oxygen uptake; N, number of participants; CI, confidence interval; PP, peak power; VT, ventilatory threshold; MAS, maximal aerobic speed.

RPE Calibration

Table 4 displays the proportion of participants who met the commonly adopted HIIE intensity thresholds and the RPE cut-points in relation to the HR and $\dot{V}O_2$ thresholds. The proportion ranged from 1% (100% HR_{max}) to 41% (80% HR_{max}) in terms of threshold achievement. Cut-points were determined for all thresholds with high discriminations (all AUC > 0.71). An RPE of 4 was determined for the thresholds of 80% HR_{max}, 85% HR_{max}, 70% $\dot{V}O_{2max}$ and 75% $\dot{V}O_{2max}$, while an RPE of 5 for 90%, 95% and 100% HR_{max}, and 80%, 85% and 90% $\dot{V}O_{2max}$.

Table 4. Percentage of thresholds achieved, rating of perceived exertion cut-points and the corresponding sensitivity, specificity, and area under the curve.

Thresholds	Threshold achieved %	Cut-points	Sensitivity %	Specificity %	AUC (95% CI)
80% HR_{max}	41%	4	70.2	73.2	0.78 (0.75-0.80)
85% HR_{max}	31%	4	77.3	70.4	0.82 (0.79-0.84)
90% HR_{max}	20%	5	75.6	83.2	0.88 (0.86-0.90)
95% HR_{max}	7%	5	79.2	75.7	0.85 (0.82-0.89)
100% HR_{max}	1%	5	100.0	72.4	0.87 (0.83-0.91)
70% $\dot{V}O_{2max}$	23%	4	70.9	64.9	0.73 (0.70-0.76)
75% $\dot{V}O_{2max}$	20%	4	72.6	62.2	0.73 (0.70-0.77)
80% $\dot{V}O_{2max}$	13%	5	58.6	76.3	0.73 (0.69-0.77)
85% $\dot{V}O_{2max}$	9%	5	61.9	74.9	0.73 (0.68-0.77)
90% $\dot{V}O_{2max}$	4%	5	69.2	73.2	0.76 (0.69-0.83)

RPE, rating of perceived exertion; HR_{max}, maximal heart rate; $\dot{V}O_{2max}$, maximal oxygen uptake; AUC, area under the curve.

DISCUSSION

This is the first study to validate and calibrate RPE for monitoring HIIE in adolescents in well-controlled laboratory conditions. The key findings are: (1) RPE is a valid means for HIIE intensity monitoring in adolescents performing running or cycling protocols; (2) the increase in exercise intensity strengthened the relationship of RPE-HR and RPE-$\dot{V}O_2$, irrespective of running or cycling modalities; (3) an RPE score of 4 or 5 can be adopted to meet the HR/$\dot{V}O_2$ based thresholds.

Criterion Validity

In line with previous study (17), there was no sex dependent differences in RPE validity, and therefore, data for males and females were pooled together. When using HR as the criterion, RPE was deemed acceptable for HIIE intensity evaluation in adolescents, with correlation coefficients ranging from 0.53 to 0.74 ($p < 0.01$) after controlling for age, sex and study designs. On the contrary, RPE-$\dot{V}O_2$ failed to reach the point of acceptable criterion validity, unless the exercises were performed at the intensity of 100% PP ($r = 0.59$, $p < 0.01$). The RPE-HR correlation in this study is consistent with Green et al. (14) where they demonstrated a RPE-HR correlation coefficient of 0.70 during high-intensity interval cycling, despite the different population (young adults) and RPE scale (Borg scale) in their study. However, the relationship between RPE and $\dot{V}O_2$ remains to be established in the context of HIIE. In the present study, the prolonged recovery periods (60:75 s work-to-rest ratio) and relatively low exercise intensity (e.g., 90% VT and 70% PP) may have contributed to the mismatch between participants' perceived exertion and objectively measured $\dot{V}O_2$ and therefore attenuated RPE-$\dot{V}O_2$ correlation. Hence, caution should be taken in interpretating the RPE-$\dot{V}O_2$ association. Collectively, RPE is valid (at least when HR is the criterion) to be embedded in HIIE for the purpose of assessing exercise intensity. Considering the potential disadvantages of using HR monitors, findings in the current study support the viable utility of RPE in alleviating the challenges of HIIE intensity surveillance.

Interestingly, the current study showed that exercise intensity had a significant impact on the correlation between RPE and both HR and $\dot{V}O_2$, irrespective of cycling- or running-based interval exercises. As the intensity increased from 70% PP to 90% PP and from 90% VT to 90% MAS, the correlation coefficient between RPE and HR increased from 0.53 to 0.74, and from 0.53 to 0.69, while the correlation coefficient between RPE and $\dot{V}O_2$ increased from 0.43 to 0.59, and from 0.40 to 0.48 for cycling- and running-based interval exercises, respectively. These findings are consistent with previous studies that have observed an increase in the correlation between RPE and physiological parameters (e.g., HR) with the increase in exercise intensity during both cycling-based (5) and running-based (29) exercises. Of note, these studies were conducted in adults using continuous exercise protocols. It has been shown that children tend to underestimate RPE when rating at a low intensity (19), which may explain the weaker correlation observed between RPE and physiological parameters (e.g., HR) at lower intensity. While the underlying mechanism for this phenomenon is yet to be fully understood, RPE is more accurate in monitoring higher intensity exercises appears tenable. Consequently, this finding further corroborated the validity of embedding RPE in HIIE protocols since it is innately performed at high intensities (e.g., ≥ 90% HR_{max} or 90% MAS).

RPE Calibration

According to the AUC data showed in table 4, RPE scores of 4 and 5 were determined to predict HR and $\dot{V}O_2$ thresholds in the current study. It is difficult to draw connections with previous studies in the literature since this is the first study to calibrate RPE for the purpose of demarcating HIIE thresholds. Although cut-points of 4 and 5 may seem low, they are supported by another empirical study from our laboratory (23). In this study, a similar protocol was adopted and the RPE score fluctuated between 4 and 6 while maintaining an overall intensity above 90% HR_{max}. Indeed, Viana et al. (34) have argued that the intensity at which HIIE is performed is not a very strenuous effort, which may yield a low RPE score and a high level of enjoyment. However, findings of the present study contradict a recent review that suggested a RPE ≥ 8 for prescribing HIIE interventions in the field (20), despite, to our knowledge, no empirical data exists to support this recommendation. Nonetheless, it is worth noting that variations in terms of HIIE protocols and contexts may result in significantly different physiological responses (34) and hence, nuanced RPE scores and cut-points.

Utilities and Recommendations

The current study serves as a foundation for validating and calibrating RPE with the purpose to embedding RPE into HIIE studies for intensity monitoring in adolescents. Previous studies have shown that children and adolescents are capable of regulating exercise intensity based on a prescribed RPE score, however, not in the context of HIIE (15). Therefore, the present study has timely filled this research gap by demonstrating the validity of using RPE for HIIE intensity monitoring and RPE cut-points have been established. Nevertheless, the expectation for children and adolescents to consistently maintain a given level of effort based on an RPE score throughout an entire session is presumably unrealistic. Considering this, rather than prescription, it may be better to be conservative at this stage and incorporate RPE in conjunction with other monitoring tools (e.g., HR monitor) for assessing and regulating intensity to enhance HIIE study fidelity. Furthermore, in accordance with the Bayesian brain theory, the ability for accurate perception of training load relies on constantly updating prior exercise experiences (9). Since our participants lacked prior experience with HIIE, we used the incremental tests to exhaustion for initial anchoring and encouraged the participants to recall and integrate their evolving exercise experiences throughout the experiment. Future studies are recommended to ensure the quality of anchoring and to familiarise participants with the RPE scale before using it in practice.

RPE score represents an integrated feedback from both the physiological and psychological systems (1). As such, the change of context may catalyse different RPE scores and thus different cut-points. The findings in the current study may be generalised to laboratory-based running or cycling HIIE with 60 s to 75 s work-to-rest ratio in adolescents. However, the valid use of RPE in other contexts such as school-based HIIE interventions, where resistance training or game-based exercises are commonplace (10), remains unknown. The utility of RPE in these settings may be maximised given its convenience and affordability, which warrants further methodological studies to confirm the validity of RPE in such context. Apart from the context and setting, it is worth mentioning that our ROC analysis was conducted specific to an adolescent population with a 0 to 10 RPE scale. Therefore, future studies are recommended to cross-validate and calibrate different RPE scales in various HIIE contexts, settings, and populations. With more cut-points established under different scenarios, the potential of RPE can be increased, which ultimately will facilitate the implementation of HIIE interventions.

Strengths and Limitations

Unlike previous studies, which used the estimating equations to predict HR_{max}, the current study adopted the gold standard measurement to establish HR_{max} and $\dot{V}O_{2max}$. Notwithstanding, several potential limitations should be noted. Although the sample size (n = 45) in the present study closely aligns with that of previous studies (15), it is important to highlight that no power calculation was performed due to this is a secondary data analysis of previous investigations. In addition, the data in this study originated from three crossover studies consisting only two to three HIIE sessions as opposed to long-term interventions, which may have limited its utility in long-term HIIE interventions. Furthermore, the data in this study were collected in highly controlled laboratory environments and with distinct experimental protocols. Therefore, the generalizability of the findings to other settings and populations may be limited. Lastly, although the cut-points have been established, RPE may be better to act as an adjuvant, rather than a substitution of HR and $\dot{V}O_2$ in monitoring HIIE intensity.

CONCLUSION

The present study is the first to validate and calibrate RPE for monitoring HIIE in adolescents. The results support the valid use of RPE in monitoring HIIE intensity and RPE cut-points were established to determine the attainment of intensity thresholds. However, the utility of these findings should be limited to well-controlled laboratory environments and until more evidence has emerged, RPE alone may not be a sufficient prescription tool. The findings of this study highlight the need for further validation and calibration of RPE under different circumstances for its effective integration into HIIE studies. Such efforts will ultimately enhance intervention fidelity and facilitate the implementation of future HIIE interventions.

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