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Research article

Predicting Changes in High-Intensity Intermittent Running Performance with Acute Responses to Short Jump Rope Workouts in Children

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Abstract

The aims of the present study were to 1) examine whether individual HR and RPE responses to a jump rope workout could be used to predict changes in high-intensity intermittent running performance in young athletes, and 2) examine the effect of using different methods to determine a smallest worthwhile change (SWC) on the interpretation of group-average and individual changes in the variables. Before and after an 8-week high-intensity training program, 13 children athletes (10.6 ± 0.9 yr) performed a high-intensity running test (30-15 Intermittent Fitness Test, V_{IFT}) and three jump rope workouts, where HR and RPE were collected. The SWC was defined as either 1/5th of the between-subjects standard deviation or the variable typical error (CV). After training, the large ~9% improvement in V_{IFT} was very likely, irrespective of the SWC. Standardized changes were greater for RPE (very likely-to-almost certain, ~30-60% changes, ~4-16 times >SWC) than for HR (likely-to-very likely, ~2-6% changes, ~1-6 times >SWC) responses. Using the CV as the SWC lead to the smallest and greatest changes for HR and RPE, respectively. The predictive value for individual performance changes tended to be better for HR (74-92%) than RPE (69%), and greater when using the CV as the SWC. The predictive value for no-performance change was low for both measures (<26%). Substantial decreases in HR and RPE responses to short jump rope workouts can predict substantial improvements in high-intensity running performance at the individual level. Using the CV of test measures as the SWC might be the better option.

Key words: Submaximal heart rate; rate of perceived exertion; OMNI scale; 30-15 Intermittent Fitness Test; progressive statistics.

Introduction

Monitoring athletes' fatigue, fitness and performance responses to training is paramount to adjust training load and contents in team sports (Borresen and Lambert, 2009). While the monitoring of saliva and blood variables (Cormack et al., 2008; Twist and Highton, 2013) can be useful, team sport coaches and supporting staff are looking for time-efficient, non-invasive, non-fatiguing and cheap tools (Twist and Highton, 2013). Therefore, the use of psychometric questionnaires (Hooper and Mackinnon, 1995; Buchheit et al. 2013a), jump tests (Cormack et al., 2008; Twist and Highton, 2013), rate of perceived exertion (RPE) and heart rate (HR) measures (Buchheit et al., 2012; Buchheit et al., 2013b) is becoming increasingly popular. Changes in HR and/or RPE responses to a 5-min submaximal run test, reflective of relative exercise intensity, have been shown to correlate largely with changes in high-intensity running performance (Buchheit et al., 2012; Buchheit et al., 2013b).

However, the use of a submaximal running exercise has still practical limitations in team sports, e.g., large area required, the need to tightly control running speed, difficulty to test a large number of players simultaneously. It may therefore be suggested that the HR and RPE responses to other type of exercises, such as jump rope workouts (Ozer et al., 2011), might be more practical to collect. The first advantage of rope jumping is that it can be performed within a limited space. Additionally, compared with cycling on an ergometer, rope jumping only requires a rope and is more exercise-mode specific to team sports. Nevertheless, the ability of HR and RPE responses to a jump rope workout to track changes in high-intensity running performance has not been examined yet.

In sports, significant changes (i.e., based on a null-hypothesis testing approach) in either performance measures or physiological variables may not be of practical importance, and conversely, non-significant changes can have meaningful effects (Hopkins, 2002). What actually matters to practitioners is whether the training-related changes could be important, i.e., whether their magnitude is actually greater than the smallest practical or meaningful change/effect (the so-called smallest worthwhile change, SWC) (Batterham and Hopkins, 2006; Hopkins et al., 2009). This magnitude-based approach of assessing training-induced changes can be supplemented with meaningful inferences about the observed magnitude, i.e., to assess whether the effect is substantially beneficial/detrimental (clearly greater than the SWC), trivial (clearly within the SWC) or eventually unclear (the confidence limits of the main effect overlap zero and/or the SWC) (Hopkins, 2006). In practice however, practitioners need to monitor each athlete in isolation to accurately interpret the possible changes in their training status, and make the correct decisions. Here, in addition to the SWC, the noise of measurement in each variable (i.e., the typical error arising from a test-retest study) needs to be considered (Hopkins 2004).

While a small standardized change (based on Cohen's effect size principle, i.e., a fifth of the between-subject standard deviation, SD) is well admitted to be the best way to determine the SWC for group-average performance changes in team sports, whether the same approach could be used for physiological and perceptual markers, that only have an indirect link with performance,

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is still unclear. This approach to determine the SWC may also have limitations, since here the magnitude of the SWC is directly related to the homogeneity of the group (with the greater the homogeneity, the lower the SWC). Whether this approach should be used at the individual level is questionable, since the magnitude of meaningful within-athlete changes may not obligatory be linked with their group distribution. Another alternative to determine the SWC to track individual changes in physiological measures is to use a fraction of the within-athlete variations in the variable of interest (i.e., SWC = 0.5 (Le Meur et al., 2013) or 1 (Plews et al., 2013) × CV). In this case, the group-average of within-athlete CV may be used for group-average analyses, and individual within-athlete CVs, for individual monitoring (Buchheit, 2014). However, while changes twice greater than a CV may be interpreted as 100% clear, they might not obligatory be meaningful practically; the CV and the SWC being two different concepts (Hopkins, 2004). The SWC for non-performance measures could therefore also be defined as the change in the variable that relates to the actual SWC in performance (Barnes et al., 2013; Buchheit, 2014). To date however, the impact of these different approaches to determine a SWC on the interpretation of both group-average and individual changes has not been examined yet.

Therefore, the aims of the present study were to 1) examine whether changes in individual HR and RPE responses to jump rope workouts could be used to predict changes in high-intensity intermittent running performance in young athletes, and 2) examine the effect of using different methods to determine the SWC on the interpretation of both group-average and individual changes in the monitoring variables.

Methods

Participants

Thirteen children (age 10.6 ± 0.9 yrs, height 1.29 ± 0.02 m and body mass 32.4 ± 4.6 kg) participated in the study. They were training 4-5 times a week and were ranked first in the National Iranian U12 jump rope League at the time of the study. All players and their parents were informed of the experimental risks, and all signed an informed consent document before the investigation. The protocol was approved by the local research ethics committee and the study conformed with the Declaration of Helsinki.

Design

Data were collected during the preparation for the 7th Asian rope-skipping championships in Singapore in August 2013. The study involved a familiarization session for all tests, pre-tests, an 8-week training program and post-tests. The tests included a measure of high-intensity running performance and three jump rope workouts, with HR and RPE responses collected at the end of each. The training program consisted of 4 sessions per week. Twice a week, the athletes performed a high-intensity rope jumping session (Ozer et al., 2011): 6-8 sets of short jump rope intervals (10-20 s at maximal speed/2-3 min of passive rest) and 3 sets of long intervals (2 min at 120 $r\cdot min^{-1}$/3 min of passive rest). Finally, they participated in a 45-min general resistance training session (e.g., 3 x 15 reps, body mass or elastic-resistance squats, lateral rises, or lunges) and a 90-min technical session.

High-intensity intermittent running performance

The athletes performed the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$), with the final running speed noted as V_{IFT} (Buchheit, 2008; Buchheit et al., 2009a). The test presents a test-retest variation of 3-4%, and responds well to short high-intensity training blocks in young athletes (Buchheit and Rabbani, 2014).

Rope jump workouts

The athletes were requested to jump for 90 seconds at 100, 120 and 140 rotations per min ($r\cdot min^{-1}$), guided with a computer-based metronome. There was a 2-min passive recovery period between each workout. The acute HR (last 5 s of each workout, Polar FT60, Polar Electro, Kempele, Finland) and RPE (immediately after each workout, adapted OMNI Perceived Exertion Scale (Pfeiffer et al., 2002; Robertson et al., 2005), Figure 1) responses were recorded.

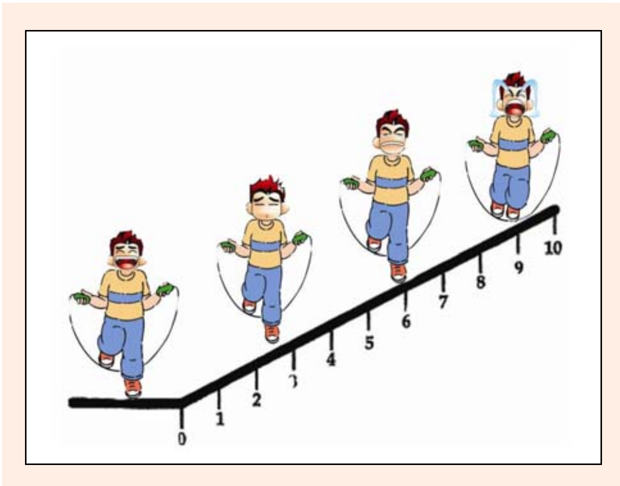

Figure 1. OMNI Perceived Exertion Scale adapted for jump rope exercise.

Statistical analyses

Data in the text and figures are presented as means with standard deviations (SD) and 90% confidence intervals (CI), respectively. All data were first log-transformed to reduce bias arising from non-uniformity error. The group-average ΔV_{IFT}, ΔHR and ΔRPE were standardized and expressed as a factor of the SWC, which was based either on 1) the typical error of measurement of each variable based on the literature (expressed as a CV; 3.5, 3 and 4% for V_{IFT} (Buchheit, 2008; Buchheit et al., 2009a), HR (Buchheit et al., 2010a) and RPE (Pfeiffer et al., 2002), respectively), 2) a small standardized effect based on Cohen's effect size principle (0.2 x between-athletes standard deviation, SD) (Hopkins et al., 2009) or 3) the actual ΔHR and ΔRPE that corresponded to a small standardized (0.2 x between-athletes SD) ΔV_{IFT} (Barnes et al., 2013). Probabilities were used to make a qualitative probabilistic mechanistic inference about the true changes: if the probabilities of the effect being substantially greater and smaller than the SWC were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value. The scale was as follows: 25−75%, possible; 75−95%, likely; 95−99%, very likely; >99%, almost certain (Hopkins et al. 2009).

The value of individual ΔHR and ΔRPE to predict substantial individual ΔV_{IFT} was examined as true positive / (true + false positive) changes (predictive value of changes) and true negative / (true + false negative) changes (predictive value of no change) (Griner et al., 1981). The sensitivity of the variables changes was assessed as true positive / (true positive + false negative) changes; the specificity of the variables changes, as true negative / (true negative + false positive) changes (Griner et al., 1981). Individual ΔV_{IFT}, ΔHR and ΔRPE were assessed using a specifically designed spreadsheet (Hopkins, 2000), where both the group-average CV of each measure (i.e., 3.5, 3 and 4% for V_{IFT} (Buchheit, 2008; Buchheit et al., 2009a), HR (Buchheit et al., 2010a) and RPE (Pfeiffer et al., 2002)) and the SWC were considered. Only changes rated as at least likely (>75%) were considered as substantial. The methods used to determine the individual SWC were the same as for group-average changes.

Finally, the relationships between individual ΔV_{IFT}, ΔHR and ΔRPE were examined using Pearson's correlation coefficients. The magnitude of the correlation (*r,* 90% CI) was interpreted quantitatively (Hopkins et al., 2009). If the 90% CI overlapped small positive and negative values, the magnitude was deemed unclear.

Results

After training, V_{IFT} increased from 13.4 ± 1.4 to 14.6 ± 1.0 $km \cdot h^{-1}$. Hear rate decreased from 184 ± 13 to 180 ± 11 $b \cdot min^{-1}$ at 100 $r \cdot min^{-1}$, from 184 ± 12 to 174 ± 18 $b \cdot min^{-1}$ at 120 $r.min^{-1}$ and from 180 ± 13 to 174 ± 11 $b.min^{-1}$ at 140 $r \cdot min^{-1}$. The RPE decreased from 4.5 ± 1.7 to 3.2 ± 1.6 at 100 $r \cdot min^{-1}$, from 5.8 ± 1.4 to 3.0 ± 1.7 at 120 $r \cdot min^{-1}$ and from 6.4 ± 2.0 to 2.8 ± 2.4 at 140 $r \cdot min^{-1}$.

The SWC based on between-subjects SD was 2% for V_{IFT}. The SWCs based on between-subjects SD were 1.5, 1.5 and 1.6% for HR at 100, 120 and 140 $r \cdot min^{-1}$, respectively. For RPE, the values were 8.7, 5.9 and 7.2%, respectively. The average SWCs for all workout pooled together corresponding to a small standardized ΔV_{IFT} were 1 and 8% for HR and RPE, respectively.

The ΔV_{IFT}, ΔHR and ΔRPE, using different SWC, are shown in Figure 2. After training, the large ~9% improvement in V_{IFT} was very likely, irrespective of the SWC. With the CV as the SWC, 3 athletes did not improve substantially their V_{IFT}, and one showed a decreased V_{IFT}. When using 0.2 x between-subject SD as the SWC, 4 athletes did not improve substantially their V_{IFT}, and one showed a decreased V_{IFT}. The ΔRPE (very likely to almost certain ~30-60% changes, ~4-16 times >SWC) were greater than ΔHR (likely to very likely ~2-6% changes, ~1-6 times >SWC), with the greater the jumping speed, the greater the magnitude of the changes. Using the CV as the SWC lead to the smallest and greater ΔHR and ΔRPE, respectively.

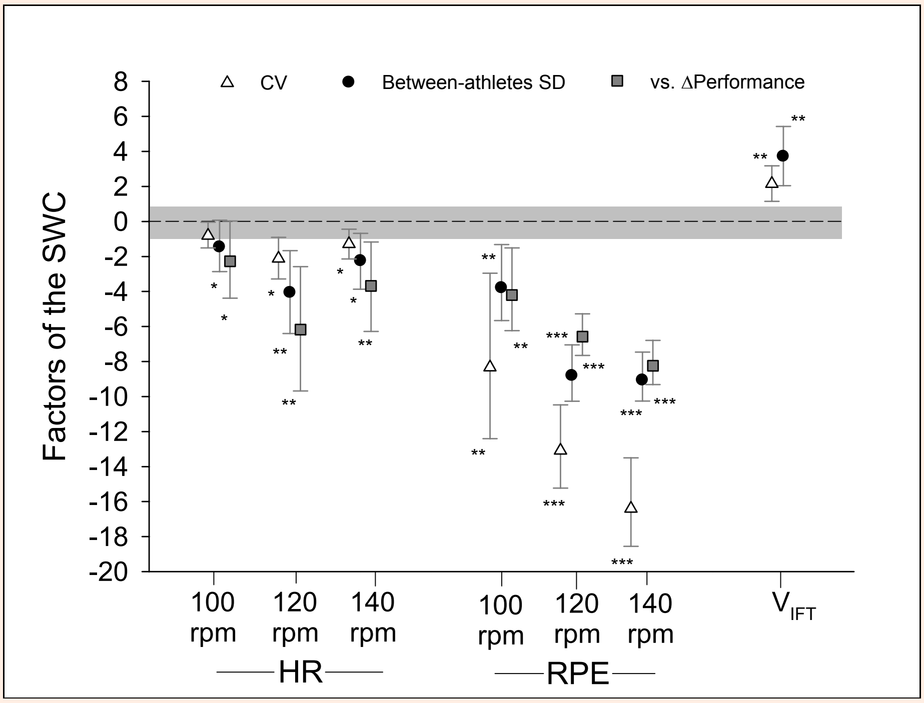

Figure 2. Standardized changes in acute heart rate (HR) and rate of perceived exertion (RPE) responses to three jump rope workouts (at 100, 120 and 140 rotations per min, rpm), and high-intensity intermittent running performance (V_{IFT}) after the training intervention. The changes are expressed as a factor of the smallest worthwhile change (SWC), which is based either on 1) the typical error of measurement of each variable (expressed as a CV), 2) a small standardized effect based on Cohen's effect size principle (0.2 x between-athletes standard deviation, SD) or 3) the actual changes in HR and RPE response that relate to a small standardized (0.2 x between-athletes SD) change in V_{IFT}. *: likely change, **: very likely change and ***: almost certain change.

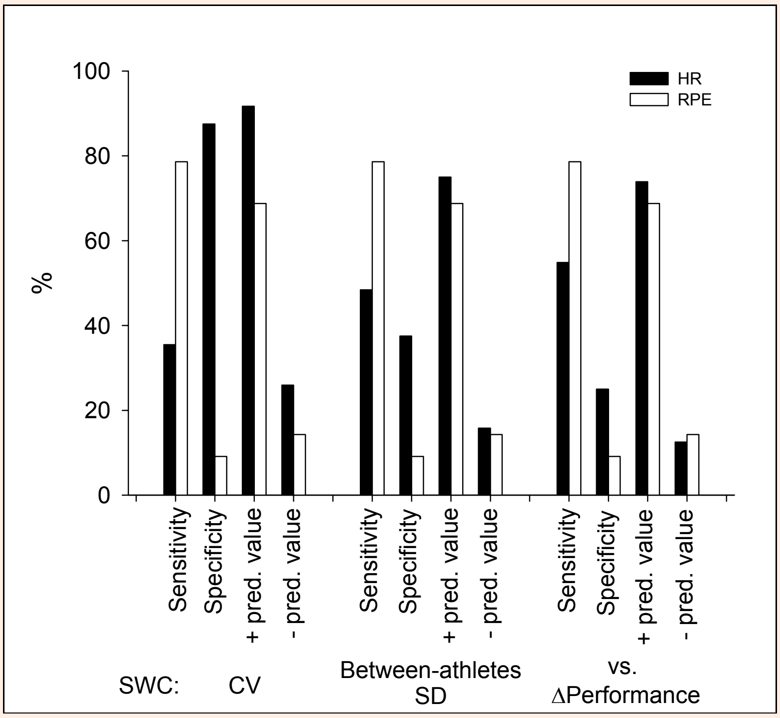

Figure 3. Performance (predictive value of change [+] and no-change [-]) of acute heart rate (HR) and rate of perceived exertion (RPE) responses to three jump rope workouts (at 100, 120 and 140 rotations per min, rpm) to predict changes in high-intensity intermittent running performance (V_{IFT}) after the training intervention, while using different approach to determine the smallest worthwhile change (SWC): either 1) the typical error of measurement of each variable (expressed as a CV), 2) a small standardized effect based on Cohen's effect size principle (0.2 x between-athletes standard deviation, SD) or 3) the actual changes in HR and RPE response that relate to a small standardized (0.2 x between-athletes SD) change in V_{IFT}.

The performance value of individual ΔHR and ΔRPE to predict individual ΔV_{IFT} are shown in Figure 3 (average of the 3 workouts). The predictive value for individual changes tended to be better for HR (74-92%) than RPE (69%), and greater when using the CV as the SWC. The predictive value for no-performance change was low for both measures (<26%).

All correlations between the changes in the different variables were unclear.

Discussion

The aims of the present study were to 1) examine whether changes in individual HR and RPE responses to short jump rope workouts could be used to predict changes in high-intensity intermittent running performance in children athletes, and 2) to examine the effect of using different SWCs on the interpretation of both group-average and individual changes in the different variables. The main results are as follow: 1) after training, the large ~9% improvement in V_{IFT} was very likely, irrespective of the SWC, 2) group-average changes in RPE were greater than in HR, 3) using the CV as the SWC lead to the smallest and greatest standardized ΔHR and ΔRPE, respectively, 4) the predictive value for individual performance changes tended to be better for HR (74-92%) than RPE (69%), and greater when using the CV as the SWC, and 5) the predictive value for no-performance change was low for both measures (<26%).

Responses to training

In the present study, the 8-week training program induced a large increase in high-intensity running performance, which was associated with moderately-to-very large decreases in HR and RPE responses to the jump rope workouts (Figure 1). The magnitude of the present V_{IFT} changes is consistent with that reported in adolescent team sports players after other types of high-intensity (run-based) training interventions, i.e., 5-10% (Buchheit et al., 2008; Buchheit et al. ,2009b; Buchheit et al., 2010b; Buchheit and Rampini, 2014). Similarly, the decreases in HR responses to the jump rope workouts are in agreement with the training-induced decreases in HR responses to submaximal runs reported in young athletes, i.e., 5% (Buchheit et al., 2008; Buchheit et al., 2012). Taken together, these data suggest that a high-intensity rope jumping program as the one implemented in the present study is an efficient means of substantially improving high-intensity intermittent running performance in children. They also suggest that HR responses to jump rope workouts may respond similarly to training than the HR responses to a submaximal running exercise, at least in children familiarized with this exercise mode. While the need to master jump rope technique may be seen as a limitation of the present testing approach, rope jumping is a common component of general conditioning methods and athletes become generally quickly proficient.

Another interesting finding of the present study is that both the magnitude of the training-induced changes in the different variables and the confidence (inferences) in these changes were affected by the method used to define the SWC. For example, the decrease in HR at 120 r·min^{-1} was rated as likely ~2, likely ~4 and very-likely ~6 times greater than the SWC, when using either the typical error (CV, 3%), 0.2 x between-athletes SD (1.5%) or the corresponding change in V_{IFT} (1%) as the SWC, respectively. These differences are directly related to the magnitude of the SWC, with the smaller the SWC, the greater the interpretation of the magnitude and the more likely the changes. The classical statistical model of null-hypothesis testing has now clearly shown its limitations to interpret changes in various fitness and health markers (Cummings and Koepsell, 2010; McCormack et al., 2013). The progressive approach (Batterham et al., 2006; Hopkins et al., 2009) used in the present study is clearly more appropriate for practitioners. Also, the null-hypothesis testing approach can't be used to assess individual changes (Hopkins 2004). Present results show nevertheless that the method used to determine the SWC may affect the final outcomes. It is therefore crucial that practitioners carefully consider the method they choose, and authors clearly report their approach in their manuscripts.

Predicting changes in high-intensity running performance

In contrast to previous studies (Buchheit et al., 2012; Buchheit et al., 2013b), there was no clear correlation between individual changes in V_{IFT}, HR or RPE. The reasons for these discrepancies may be related to participants' age and/or exercise mode. Nevertheless, the lack of a direct relationship between the changes in the variables did not limit the capacity of HR and RPE responses to predict changes in high-intensity running performance (Figure 2). A linear relationship can only be obtained when the changes in the two variables remain proportional, which was unlikely in the present study (Figure 1). When we used a prediction approach based on the assessment of substantial individual changes (considering both the CV and the SWC (Hopkins, 2004)), the ability of changes in HR and RPE responses to predict changes in V_{IFT} was high (Figure 2). Present data showed however that the predictive value for no performance change was limited (Figure 2). It is worth noting that in the context of the large fitness improvements observed in the present study (Figure 1), only 3-4 athletes (~30%) did not improve their test performance; this might explain the present results. Therefore, further studies involving a larger number of athletes presenting with a decreased performance capacity is warranted.

Finally, the method used to determine the SWC also affected the capacity of each variable to predict changes in V_{IFT} (Figure 2). In theory, a (too) small SWC may decrease the number of false negatives (no decision taken when you should), but may increase the number of false positives (decision taken when you should not). This could, in turn, improve the sensitivity of the test (the proportion of true cases that are diagnosed as cases), but decrease the specificity (proportion of true non-cases that are diagnosed as non-cases). In contrast, a (too) large SWC may increase the number of false negatives but decrease the number of false positive; the sensitivity may be decreased, but the specificity, increased. The magnitude of the SWC that improves the predictive value of changes and no-changes in performance is not straightforward, and is also likely related to the actual magnitude of the variable change (i.e., signal). In agreement with these assumptions, the sensitivity of HR changes to predict changes in V_{IFT} was decreased (35 vs. 55%), and the specificity, increased (88 vs. 25%), when using the CV (3%) as the SWC compared with the change related to a small substantial change in V_{IFT} (1%) (Figure 2). Importantly also, both the predictive value for changes and no-change in V_{IFT} were greater with the CV as the SWC, which suggests that this latter option should be preferred. With respect to RPE, the different SWC values had little effect on the predictions, probably because both of them were clearly smaller than the signal (4 and 8% vs. 30-60%). For consistency with HR measures, and since the change related to a small substantial change in V_{IFT} cannot be known *a priori*, we suggest using the CV as the SWC. Whether smaller fractions of the CV should be used warrants further researches. Importantly, the CVs used in the present analyses were extracted from the literature (i.e., 3 and 4% for HR (Buchheit et al., 2010a) and RPE (Pfeiffer et al., 2002), respectively). While it is intuitive that individually-based CVs may be more appropriate (Buchheit, 2014), their calculation requires repeated trials for each athletes, which were not available in the present study. Further studies using individual CVs are therefore also warranted to confirm the present results. Finally, it is worth noting that in the present study, the average SWCs for all workout pooled together corresponding to a small standardized ΔV_{IFT} were pretty small (i.e., 1 and 8% for HR and RPE, respectively). These small but important changes may therefore not always be detectable by many of the tests available (i.e. noise > signal), which may explain their lower predictive values (Figure 2).

Practical applications

Decreased HR and RPE responses to short jump rope workouts can be confidently used to track improvements in high-intensity intermittent running performance in children familiarized with this exercise mode. Rope jumping is a particularly convenient exercise, since it can be performed in a restricted space and allows the testing of a large number of athletes simultaneously. In practice also, we recommend using the CV of the measures (i.e., 3 and 4% for HR and RPE (OMNI scale) responses, respectively) as the SWC.

Conclusion

Decreases in HR and RPE responses to short jump rope workouts have a strong predicting capacity of substantial improvements in high-intensity intermittent running performance at the individual level. Their ability to predict a lack of performance change remains however unclear. Further research involving athletes presenting with different training status (e.g., overreached or overtrained) is therefore still warranted. Finally, when using progressive statistics, the method employed to define the SWC may affect the outcomes. Practitioners and researchers should therefore be mindful in their approach and clearly mention how/why they defined this important parameter. When assessing individual changes in the variables examined in the present study, using (a fraction of) the CV of the variables might be the best option. Whether using individual vs. group-based CVs may lead to different outcomes still needs to be examined.

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Key points

- Decreased HR and RPE responses to short jump rope workouts can be confidently used to track improvements in high-intensity intermittent running performance in children familiarized with this exercise mode. Rope jumping is a particularly convenient exercise, since it can be performed in a restricted space and allows the testing of a large number of athletes simultaneously.
- We recommend using the CV of the measures (i.e., 3 and 4% for HR and RPE (OMNI scale) responses, respectively) as the SWC.

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