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Published in:
European Journal of Sport Science

DOI:
10.1080/17461391.2022.2060136

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2023

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Houtmeyers, K. C., Brink, M. S., Helsen, W. F., Haelewijn, N., Hagen, M., Jaspers, A., & Vanrenterghem, J. (2023). A lab-based comparison of differential ratings of perceived exertion between a run and jump protocol involving low or high impacts on the lower extremities: Influence of impacts on differential RPE. *European Journal of Sport Science*, *23*(5), 746–754. Advance online publication. https://doi.org/10.1080/17461391.2022.2060136

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European Journal of Sport Science

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/tejs20

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To cite this article: Kobe C. Houtmeyers, Michel S. Brink, Werner F. Helsen, Nicolas Haelewijn, Michiel Hagen, Arne Jaspers & Jos Vanrenterghem (2023) A lab-based comparison of differential ratings of perceived exertion between a run and jump protocol involving low or high impacts on the lower extremities, European Journal of Sport Science, 23:5, 746-754, DOI: 10.1080/17461391.2022.2060136

To link to this article: https://doi.org/10.1080/17461391.2022.2060136

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EUROPEAN JOURNAL OF SPORT SCIENCE
2023, VOL. 23, NO. 5, 746–754
https://doi.org/10.1080/17461391.2022.2060136

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ORIGINAL INVESTIGATION

A lab-based comparison of differential ratings of perceived exertion between a run and jump protocol involving low or high impacts on the lower extremities

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ABSTRACT

The rating of perceived exertion method (RPE) allows to describe training intensity in a single value. To better understand the underlying components, the separate rating of perceived breathlessness (RPE-B) and leg-muscle exertion (RPE-L) has been proposed. Here we hypothesised that the separation between the two components may (partly) be determined by the impacts on the lower extremities. In this study, we aimed to experimentally evaluate the differential effect of high versus low impact running and jumping on RPE-B and RPE-L in team sport activities by manipulating the movement strategy (heel strike and passive landing pattern versus forefoot strike and active landing pattern). Eighteen recreational team sport players participated in two submaximal tests consisting of a sequence of running and jumping bouts, whilst ground reaction forces (GRF) were collected. RPE-B and RPE-L data were collected after each bout using the CR100 scale. Paired-samples *t*-tests were used to analyse between-session differences in these variables. GRF analysis showed that absorption mechanics differed considerably between the two sessions. RPE-L was on average 6.50 AU higher in the low impact session ($p = 0.006$). However, RPE-B was also increased by 4.96 AU with low impact ($p = 0.009$). We conclude that the extent to which the lower extremities are being exposed to high or low impacts does not explain a possible separation between the two RPE types.

KEYWORDS
Training; exercise; team sport; respiratory; musculoskeletal

Highlights

- The separate rating of the different underlying components of RPE (e.g. variables related to the cardiorespiratory and the muscular system) may provide more insight in the relationship between training load and training outcomes, which likely differs between these components.
- The findings of this study do not support the idea that the separation in rating between perceived breathlessness (RPE-B, cardiorespiratory) and leg-muscle exertion (RPE-L, muscular) is also rooted in the extent to which musculoskeletal structures in the lower extremities are being exposed to high or low impacts.

Introduction

The monitoring of training load is an important process within team sports (Impellizzeri, Marcora, & Coutts, 2019). Insights from load monitoring are used to optimise training with regard to players' performance and health. Training load is the product of training volume and intensity. While training volume can be easily monitored by registering the training duration, it is more challenging to monitor training intensity (Vanrenterghem, Nedergaard, Robinson, & Drust, 2017). Here, a distinction is made between external and internal variables of intensity (Impellizzeri et al., 2019). External variables describe facets of intensity that occur externally to the player and are related to the performance output (e.g. running speed and number of jumps within a given timeframe). The same external intensity does, however, induce a different psycho-physiological stress to the body for every player and context, known as the internal intensity. It is important to monitor the internal intensity because it ultimately determines the effect of training (i.e. adaptations).

Perception of exertion (PE) is one of the most frequently used indicators to monitor internal intensity (Starling & Lambert, 2018; Weston, 2018). It is generally defined as the conscious sensation of how hard and strenuous a physical task is Marcora, 2010; Halperin &

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Emanuel, 2020). Over the last decades, different scales such as the Borg's CR10 and CR100 scale were developed to allow players to assign a numerical value to their PE, known as the rating of perceived exertion (RPE) (Arney et al., 2019). RPE is considered a gestalt measure of internal intensity (Halperin & Emanuel, 2020). This means that different components of PE are likely summarised in a single rating, which comes at the expense of losing information about the relative contribution of underlying components. In an attempt to better retain information about some underlying components, the differentiation between rating of perceived breathlessness (RPE-B, central component) and perceived leg-muscle exertion (RPE-L, peripheral component) has been proposed (Ekblom & Goldbarg, 1971). This method, known as differential RPE, may provide more insight into the relationship between training load and training adaptations, which likely differs between the two components (Vanrenterghem et al., 2017).

Although average differences in sport-specific training activities were rather small (Los Arcos, Mendez-Villanueva, Yanci, & Martinez-Santos, 2016; Maughan, MacFarlane, & Swinton, 2021; McLaren, Smith, Spears, & Weston, 2017; Weston, Siegler, Bahnert, McBrien, & Lovell, 2015; Wright et al., 2020), several observational studies have demonstrated that players are able to provide separate ratings for the two RPE types in distinct training activities such as aerobic fitness (higher sRPE-B[1]) and lower-leg resistance training (higher sRPE-L). To evaluate the utility of differential RPE, it is important to understand which variables relate differently to RPE-B and RPE-L. Differences in RPE-L between training activities have mainly been explained by markers of leg-muscle exertion such as blood lactate values and maximum counter movement jump height (McLaren, Graham, Spears, & Weston, 2016). sRPE-L also showed to be more strongly associated with high-speed and -power variables of external intensity (e.g. distance >14.4 km h^{-1}) than sRPE-B (Weston et al., 2015). Considering that high-speed running and high power activities involve higher impacts on the lower extremities suggests that the separation between both components may (also) be rooted in the extent to which the musculoskeletal structures in the lower extremities are being exposed to high impacts during certain activities. However, no study has examined this relationship yet. Therefore, the aim of our study was to explore and compare the relationship between impacts, RPE-B and RPE-L. For this, we experimentally compared RPE-B and RPE-L during a running- and jumping-based protocol for which we manipulated the impacts on the lower extremities for both activities. We manipulated the movement pattern of running and jumping activities to isolate the effect of impacts on RPE-B and RPE-L. We expected that RPE-L would be influenced by a change in impacts while RPE-B would remain unaffected.

Materials and methods

Participants

Eighteen recreational team sport players volunteered to participate in the study. The sample size was determined via an a priori sample size estimation based on statistical power. A previous study with a repeated measures design, comparing differential RPE between running and cycling, reported differences in RPE-L of around 15 arbitrary units (AU) on a CR100 scale (McLaren et al., 2016). Considering that running and cycling are considerably different activities, we estimated a smaller difference of only 5 AU in our study where participants performed the same activities (running and jumping) during both data collection sessions. Based on the standard deviation of differences observed in the aforementioned study (7 AU), a sample size of 18 was required to achieve 80% statistical power (using G*Power 3.1.9.7) (Faul, Erdfelder, Lang, & Buchner, 2007). Both male ($n = 13$, age: 22 ± 1.7 years, height 185 ± 5.1 cm, body weight 78 ± 6.7 kg) and female participants ($n = 5$, age: 23 ± 0.6 years, height 170 ± 2.0 cm, body weight 69 ± 6.5 kg) were included. All participants were recreationally active in an organised team sport, with at least one training session and one competitive match per week. Participants were recruited from different team sports such as football ($n = 9$), volleyball ($n = 5$) and basketball ($n = 4$). Before the start of the study, all participants confirmed that they had no lower limb injury and had not experienced low back pain in the six months prior to data collection. In addition, no participant had a major medical lower extremity intervention in the last 12 months. The study was approved by the local ethics committee of the KU Leuven (s62754). Before commencement, a written informed consent was obtained from all participants.

Design

A counterbalanced repeated measures design was used. Participants were asked to take part in three sessions on separate days. To avoid pre-session fatigue, a washout period of a minimum of two days was planned between subsequent sessions, and participants were asked to perform no training activities the day before the session (Skorski et al., 2019). During the first session, participants were familiarised with the protocol of the study. During the second and third session, participants performed the protocol in a condition of relatively high or low impacts. The order of conditions was randomly determined by the authors. Half of the participants first performed the condition of high impacts (i.e. session two) followed by the condition of low impacts (i.e. session three). This order was reversed for the other half of the participants.

Procedures

Protocol

The protocol consisted of running and jumping activities that were performed in alternation (Frank et al., 2019). After a warm-up of two minutes, participants were asked to run for 5 minutes on a treadmill at a speed that corresponded to a steady-state heart rate (HR) between 80% and 90% of the maximal HR. After running, participants performed 20 jumps to a jump height of 80% of their maximum. At the end of each running and jumping bout, participants indicated their RPE-B and RPE-L using the Borg's CR100 scale (Arney et al., 2019). The running and jumping sequence was repeated until the participants reached either >95% maximal HR, RPE (-B or -L) >85 or failed in reaching 80% of their maximum jump height.

Familiarisation session

The maximum jump height and running speed were determined during the familiarisation session. Following a 10-minute warm-up, existing of 5 minutes running at a preferred speed, stretching, and a few repeated jumps, the maximum jump height was tested by subtracting the height of tapping a wall with the fingertips at the highest possible point in the apex of the jump by the reaching height during standing (i.e. Sargent jump test) (de Salles, Vasconcellos, de Salles, Fonseca, & Dantas, 2012). To determine the speed that corresponded to a steady-state HR between 80% and 90% of the maximal HR, participants subsequently performed an incremental running protocol starting at 6 km h^{-1} and increasing every two minutes with 1 km h^{-1} until the participant reached a HR above 90% of their maximum. HR was monitored using a Polar H10 HR sensor. Maximal HR was determined based on age prediction ($207 - 0.7 \times$ age) (Gellish et al., 2007). Before the incremental running test, participants received verbal instructions on the meaning and procedures of the differential RPE method (McLaren, Coutts, & Impellizzeri, 2021). Participants were accustomed to using the scale by providing ratings after each stage of the incremental running protocol. Questions were randomised in order and were formulated as: "how intense is the effort in terms of breathlessness (RPE-B) and leg-muscle exertion (RPE-L). One of the authors always asked the question while showing the scale to the participants on an A4 sheet. Participants also responded verbally by indicating the numerical value that matched their PE.

Test sessions

In the two test sessions, participants performed the running and jumping protocol. HR was monitored using a Polar H10 HR sensor (Polar, Kempele, Finland). After each running and jumping bout, participants were asked to provide RPE-B and RPE-L using the same procedures as in the familiarisation session. The two test sessions differed from each other through the running and jumping style involving high or low impacts on the lower extremity. One of the sessions consisted of relative higher body impacts by instructing participants to run in a heel strike pattern and to perform jumps with a passive landing by keeping their legs in extension. In the other session, participants were instructed to run in a forefoot strike pattern and to perform jumps with an active "softer" landing by performing an eccentric squat movement during landing. We highlight that we only manipulated the movement patterns to elicit different impacts, and possibly separate responses in terms of RPE-B and RPE-L. We do not focus on the relationship between these movement patterns and the overall training load or performance and health benefits. To identify the alteration in impacts between both sessions, ground reaction forces (GRF) were recorded by force sensors built into the instrumental treadmill (Motek Medical, The Netherlands) on which both running and jumping activities took place (Aarts, Papegaaij, Steenbrink, & Martens, 2018).

Data analysis

GRF data of running and jumps in the first sequence (i.e. 5′ running + 20 jumps) of each session were collected using Vicon Nexus software (v2.4, Vicon Inc., Oxford, UK) and exported into Visual3D (v6, C-Motion, Germantown). The signal was filtered at 18 Hz using a fourth order recursive Butterworth low-pass filter. For running, at least 20 contact phases were analysed. For jumps, the landing phase of at least 5 jumps was analysed for the first 500 ms after touch down. These temporal profiles were then time normalised to 101 data points, averaged per individual and per session, and normalised to the participant's body weight (body mass × 9.81). We used one-dimensional Statistical Parametric Mapping (SPM) (SPM1D version M.0.4.7, www.spm1d.org) to run paired-samples t-tests on the time normalised GRF profiles (start to end of each foot contact) in order to avoid unjustified data reduction. Specifically, the use of SPM avoids the problem of multiple comparisons within a time series by calculating a test statistic profile based on each time node and modelling the behaviour of random time-varying signals with a similar smoothness as the recorded data for inference calculations (Pataky, 2012).

HR and RPE data were collected immediately after each running and jumping bout. All data were exported from Microsoft Excel (Version 2016, Microsoft Corporation, Washington, USA) into SPSS (Version 27, IBM Corp, Armonk, USA). Extreme outliers were removed from the analysis based on visual inspection of the raw between-condition differences via boxplots in SPSS (7 of 108 RPE observations, no HR observations). The Shapiro-Wilk Test of Normality indicated that data assumptions of normality were met. Therefore, differences between the sessions of high and low impacts were examined via paired-samples t-tests. Because the differences in RPE were compared based on data from the first sequence, last sequence and the average of the entire protocol, Bonferroni correction for multiple testing was applied. This was achieved by dividing the statistical significance level by three ($P < 0.017$). Practical equivalence was tested by visual inspection of the 90% confidence intervals (CI) of the mean difference (Lakens, Scheel, & Isager 2018). Between-session differences were deemed equivalent when the 90% CI was located completely inside the region of practical equivalence (ROPE). This region was determined in line with previous research that suggested a minimum practically important difference for HR and RPE of 2 bpm and 8 AU, respectively (Buchheit, 2014; Wright et al., 2020).

Results

Between-session differences in impact

The paired comparisons of vertical GRF between the high and low impact session showed significant differences in impact absorption mechanics as shown in Figure 1. Both for running and jumping, the high impact session involved significantly higher GRF during the initial phase of the landing (approximately the first 200 ms), while the low impact session involved increased forces during the later phase (250–500 ms after touch down).

Between-session differences in HR

Figure 2 shows the between-session differences in HR. On average, no significant difference was found between the session of high and low impacts ($t(17)$: 0.177, $p = 0.861$) and the mean difference seemed to be practically equivalent, as the 90% CI (−1.613–1.314) was located completely within the ROPE. We were thus successful in manipulating the impacts during both sessions without affecting the overall HR-based intensity of the sessions significantly.

Between-session differences in RPE-B and RPE-L

Figure 3 provides an illustrative example of the trend in RPE-B and RPE-L throughout the entire study protocol for one session of one participant. Figure 4 shows the between-session differences in RPE-B and RPE-L. In general, both RPE-B and RPE-L were higher in the low impact session compared to the high impact session. While no significant differences in RPE-B were found based on data collected during the first ($t(17)$: −2.219, $p = 0.040$) and last sequence ($t(16)$: −2.276, $p = 0.037$), a significant higher RPE-B in the low impact session was observed based on the average value of all collected data ($t(16)$: −2.949, $p = 0.009$). However, because the 90% CI of this difference falls completely within the ROPE, the practical relevance of this difference may be limited. For RPE-L, no significant difference was found based on data collected during the first sequence ($t(13)$: −2.489, $p = 0.027$). A significant higher RPE-L was observed in the low impact session based on data collected during the last sequence ($t(16)$: −3.272, $p = 0.005$) and during the entire protocol ($t(16)$: −3.159, $p = 0.006$).

Discussion

The aim of our study was to examine how different impacts on the lower extremities during running and jumping influence RPE-B and RPE-L. Although the between-condition differences were rather small in magnitude, our main finding was that RPE-B and RPE-L were both increased in the session involving lower impacts. Therefore, our findings do not provide evidence that the separation between RPE-B and RPE-L is also rooted in the extent to which musculoskeletal structures in the lower extremities are being exposed to high or low impacts.

In this study, we created a running- and jumping protocol to manipulate the loading in terms of impacts on the lower extremities without eliciting considerable differences in the overall cardiorespiratory stress. Figure 1 shows that we succeeded in manipulating the impacts of both the running and jumping activities. Different impact absorption mechanics were observed between the two sessions. We expect that these

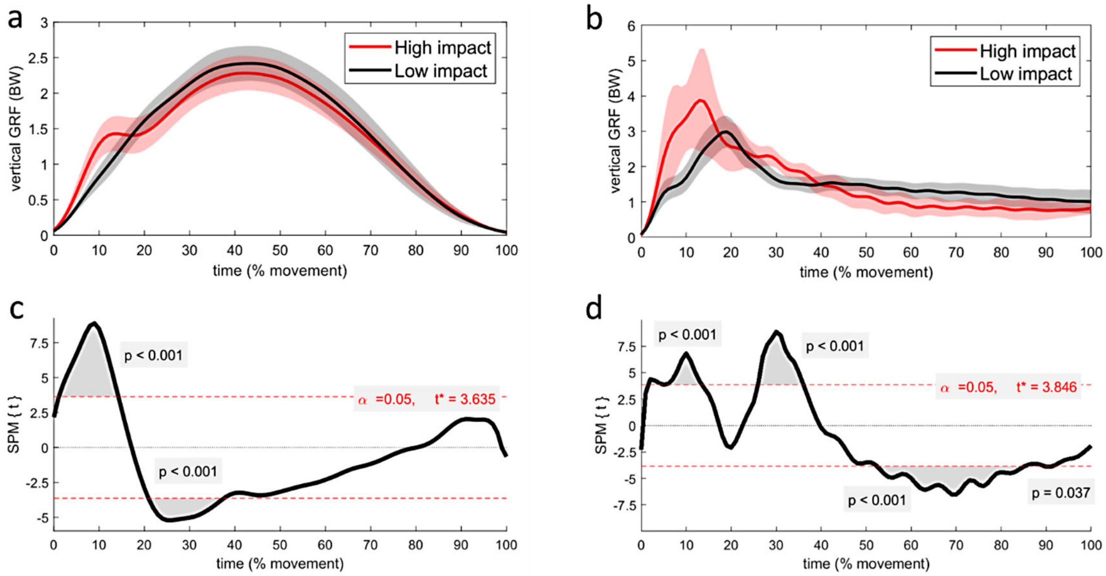

Figure 1. Comparison of vertical GRF profiles between high and low impact running (panels a & c) and jumping (panels b & d). Top panels: Means and SD clouds of the vertical GRF normalised to body weight (BW). Bottom panels: SPM output of the paired-samples t-test. If the t-curve (black line) crosses the critical threshold indicated as a red dashed line, then the null-hypothesis (no difference between conditions) is rejected. Both positive (high impact session has significantly higher forces than low impact session) and negative (high impact session has significantly lower forces) differences were found. Each period of significant difference is indicated by a light grey shaded area (so-called "threshold crossing cluster"), for which a separate cluster-specific probability value can be calculated (p-values with each cluster).

differences result from an increased reliance on either passive (i.e. high impact) or active musculoskeletal structures (i.e. low impact) (Swinnen et al., 2019; Yong et al., 2020; Yong, Silder, & Delp, 2014). The high impact session involved significantly higher GRF during the initial landing phase, indicating a higher impact absorption likely from a passively stiffened musculoskeletal system (Yong et al., 2014; Yong et al., 2020). The low impact session involved increased forces during the later phase at which we expect a more active (muscle-contraction driven) rebounding force generation to compensate for the reduced impact absorption over the first phase (Swinnen et al., 2019; Yong et al., 2014; Yong et al., 2020). Despite these mechanic differences, Figure 2 shows that there was no significant difference between sessions in the average heart rate, and thus the overall cardiorespiratory stress. Therefore, we are confident that we created two running and jumping conditions that mainly differed in terms of the impacts on the body.

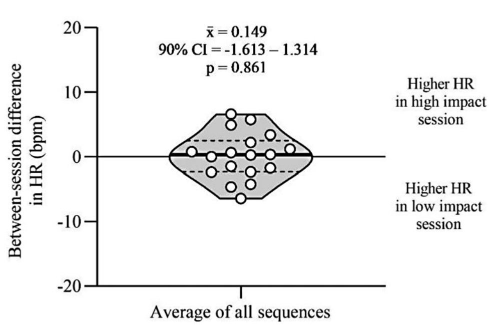

Figure 2. Between-session difference in HR based on data collected during the entire protocol. The solid and dashed black lines indicate the values corresponding to the median and the 25th or 75th percentile, respectively. CI: confidence interval, HR: heart rate, $\bar{x}$: mean difference, *: $p < 0.017$.

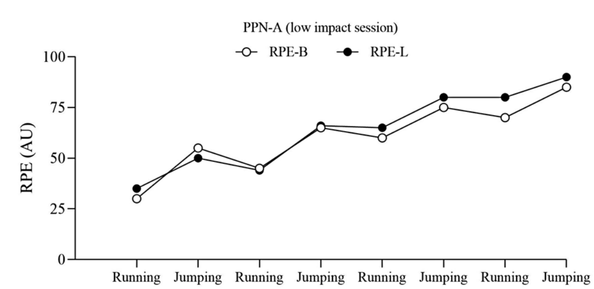

Figure 3. Illustrative example of the trend in RPE-B and RPE-L throughout the low impact session of one participant (PPN-A) that performed 4 sequences of running- and jumping bouts. RPE: rating of perceived exertion, RPE-B: rating of perceived breathlessness, RPE-L: rating of perceived leg-muscle exertion, AU: arbitrary units, PPN: participant.

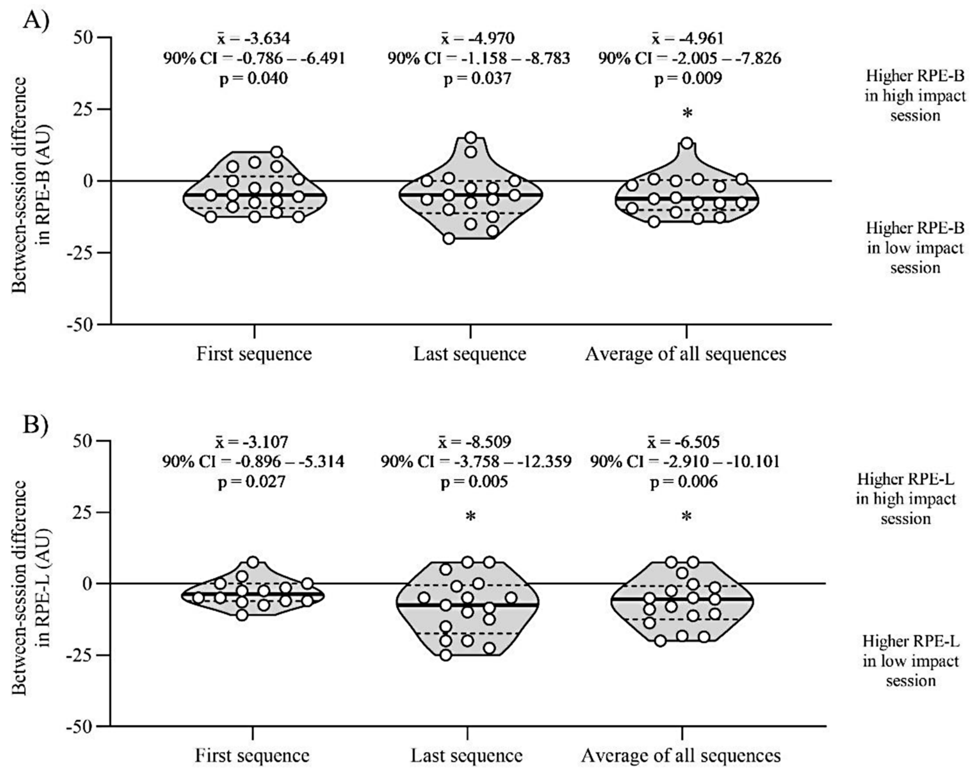

Figure 4. Between-session differences in (A) RPE-B and (B) RPE-L based on data collected during the first sequence, last sequence and the average of the entire protocol. The solid and dashed black lines indicate the values corresponding to the median and the 25th or 75th percentile, respectively. AU: arbitrary units, CI: confidence interval, $\bar{x}$: mean difference, *: $p < 0.017$.

Figure 4 shows that RPE-L was significantly higher in the low impact session. This could be explained by a higher muscular exertion resulting from the active (muscle-contraction driven) rebounding force generation. The fact that participants were instructed in the low impact session to actively soften their jump landings and foot contacts during running may have resulted in an increase in eccentric muscle contractions (e.g. quadriceps, gastrocnemius) and hence an increased perceived effort.

Yet, there might be a second reason for the higher RPE-L during the low impact session. The eccentric muscle contractions might have caused perceptions of discomfort or pain. Because participants were involved in different sports, they may differ in how familiar they were with the activities performed in the protocol (e.g. repeated jumping). In addition, participants were asked to perform non-habitual running- and jumping patterns on a surface they were not used to (i.e. treadmill). In result, the participants might not yet have been adapted to the larger eccentric muscle contractions during the low impact session, causing discomfort and pain. Although we instructed participants based on the most recent RPE definitions – highlighting the conceptual difference between perceived exertion and other sensations such as discomfort and pain (Halperin & Emanuel, 2020; Marcora, 2009; McLaren et al., 2021) – participants' limited experience in providing such ratings may have limited their ability to distinguish between these sensations.

Because RPE-B was also significantly higher in the low impact session, it remains unclear whether the between-session differences in RPE-L could be attributed to the impact absorption mechanics. A previous study showed that both RPE types were highly correlated in team sport activities such as football training sessions (Maughan et al., 2021). Therefore, participants may have had a tendency to increase their RPE-B in the low impact session in line with the increase in RPE-L (or vice versa). This tendency may be less present in training activities that elicit more distinct cardiorespiratory and muscular stresses, such as resistance training (Wright et al., 2020). In team sport activities, RPE-B and RPE-L may actually have a similar exponential relationship with exercise intensity because lactic acidosis during anaerobic work will both increase hyperventilation (RPE-B) and muscular exertion (RPE-L) (Meyer, Faude, Scharhag, Urhausen, & Kindermann, 2004). Therefore, limited differentiation between the two RPE types in these activities may not be surprising, which requires attention in the further development of this method.

Our study is not without limitations. As mentioned earlier, the limited experience of participants in rating (different types of) exertion may have influenced the outcome of the study. While we did demonstrate a difference in impact absorption mechanics, we were not able to distinguish conditions based on objective measurements of muscle activation or exertion. Although we evaluated the cardiorespiratory stress based on heart rate, and we assume that increased metabolic demands from increased eccentric muscle contractions in the low impact activities are negligible, we did not measure the respiratory rate or blood lactate levels during exercise, which might provide a more direct reference for perceived breathlessness or leg muscle exertion respectively.

In applied research topics such as load monitoring, a combination of experimental and observational studies is required to understand the mechanisms behind the methods that are used, which in turn helps assessing the usefulness of these methods. Previous research on differential RPE was mainly observational, or was not specifically related to the activities performed within team sports (Maughan et al., 2021; McLaren et al., 2016; Weston et al., 2015; Wright et al., 2020). Therefore, this study aimed to experimentally generate knowledge to better understand the mechanisms behind this method. In team sport practice, it is still difficult to quantify the running- and jumping-based impacts on the lower extremities (Verheul, Vanrenterghem, Robinson, & A, 2020). Because these impact forces likely have a considerable influence on the perceived musculoskeletal stress, our study design provided an interesting opportunity to examine the relationship between impacts and differential RPE more closely. Therefore, we consider our main finding, namely that RPE-B and RPE-L were similarly influenced by changes in impacts, a useful contribution to the knowledge base surrounding differential RPE, which needs to be further developed and refined to have a considerable impact on current sports practice.

Up to now, studies that examined the utility of differential RPE for monitoring training load in team sports have provided contrasting evidence and opinions (Los Arcos et al., 2016; Maughan et al., 2021; McLaren et al., 2016; McLaren et al., 2017; Weston et al., 2015). Differential RPE was initially developed to understand how the different psycho-physiological stresses vary in distinct exercise activities and settings (Pandolf, 1978). The method used for this purpose is directly translated to the domain of load monitoring in the absence of a reference framework defining the context-specific purposes and mechanisms behind the method. Therefore, we encourage future research to re-evaluate the concept of differential RPE for monitoring training load in team sports. Clarity must be provided in how differential RPE is expected to improve insights from load monitoring to evaluate and adapt the training process (i.e. purpose). For this, the constructs (e.g. RPE-B, RPE-L, …) and the underlying mechanisms need to be more clearly defined, including discussion of semantics, and taking into account current definitions of the general RPE method that distinguish RPE from other sensations such as pain and discomfort (Halperin & Emanuel, 2020).

To conclude, the findings of this study do not support the idea that the separation between RPE-B and RPE-L in running- and jumping activities can be attributed to the extent to which musculoskeletal structures in the lower extremities are being exposed to high or low impacts. Both RPE-B and RPE-L were increased in the low impact condition. Therefore, this study does not provide evidence in support of the separate rating of perceived breathlessness and leg-muscle exertion in team sport related activities.

Note

1. It is common in practice to ask players at the end of the training session to rate their perceived exertion for the entire session. This value reflects the average perceived exertion over the entire session and is described as the session rating of perceived exertion (sRPE).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by Agentschap voor Innovatie door Wetenschap en Technologie [grant number IWT HBC.2017.0569].

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