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Joseph O. C. Coyne
Edith Cowan University

Aaron J. Coutts

Robert U. Newton
Edith Cowan University

G. Gregory Haff
Edith Cowan University

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The Influence of Mental Fatigue on Sessional Ratings of Perceived Exertion in Elite Open and Closed Skill Sports Athletes
Original Investigation

Joseph O.C. Coyne[1,2], Aaron J. Coutts[3,4], Robert U. Newton[1,5] & G. Gregory Haff[1,5,6]

[1]School of Medical and Health Sciences, Edith Cowan University, Joondalup, WA 6027, Australia
[2] UFC Performance Institute, Las Vegas NV 89118 United States
[3] Human Performance Research Centre, University of Technology Sydney (UTS), Moore Park Rd, Moore Park NSW 2021, Australia
[4] School of Sport, Exercise and Rehabilitation, University of Technology Sydney (UTS), Moore Park Rd, Moore Park NSW 2021, Australia
[5] Australian Centre for Research into Injury in Sport and its Prevention (ACRISP), Edith Cowan University, Joondalup, WA 6027, Australia.
[6] Directorate of Psychology and Sport, University of Salford, Salford, Greater Manchester, United Kingdom

CORRESPONDING AUTHOR: Joseph Coyne
MAILING ADDRESS: 18 Bondi Pl, Kingscliff NSW 2487, Australia
TELEPHONE: +61 411 529 390
EMAIL: coach@josephcoyne.com

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ABSTRACT

The main purpose of this investigation was to examine influence of mental fatigue on sessional ratings of perceived exertion (sRPE) over a training week in elite athletes in open (OS, i.e., more unpredictable and externally paced sports) and closed skill (CS, i.e., more predictable and internally paced) sports. Visual analogue scales (VAS) for mental fatigue, sRPE (CR-10 scale) and training duration were collected from an OS group (n=27) of basketball and volleyball athletes and a CS group (n=28) of weightlifting and track and field athletes during a typical training week five months prior to the 2016 Olympic Games. These variables were then examined using repeated measure correlations and linear mixed models with the level of significance set for the study at $p<0.05$. There was a small significant correlation between mental fatigue and sRPE in the OS group ($r=0.23$, $p<0.01$) but not in the CS group ($r=-0.07$, $p=0.38$). Mental fatigue had trivial influence on sRPE during individual sessions but had a moderate effect on total sRPE over a week ($p<0.001$, $f^2=0.265$) when accounting for type of sport, training duration and injury/illness burden. It seems mental fatigue may not significantly influence sRPE in individual training sessions but may potentially have a cumulative effect that may impact the sRPE over a training week. This suggests monitoring mental fatigue independently of other training load measures may be worthwhile for strength and conditioning specialists and sports coaches to manage their athletes and researchers conducting studies into training load and performance.

KEY WORDS

Cognition, Perception, Sports Performance, Training Load

INTRODUCTION

Mental fatigue is a psychobiological state induced by cognitively demanding activities (17) and its' negative influence on sports performance has been previously explained with a number of studies showing increased levels of mental fatigue impair sporting performance through a variety of mechanisms (e.g., decreased attentional focus, poorer decision-making, worse time-to-exhaustion endurance performance) (5, 6, 17, 27, 28). Although there has recently been an increasing amount of research focused on mental fatigue (24), it has been suggested that this research has limited applicability or transfer to elite sporting environments due to ecological validity concerns with how mental fatigue has been generated and the nature of both mental fatigue and performance assessments in previous research (24, 29). Measuring mental fatigue in athletes with subjective visual analogue scales (VAS) seems to be the most practical and evidence-based method currently available when compared to other methods (e.g., electroencephalography, heart rate variability) (24, 26).

As mental fatigue is induced by cognitively demanding activities, it is possible that an elite athletes' mental fatigue is influenced by the training they are exposed to. For example, it is plausible that longer or more intense training sessions may be more cognitively demanding than shorter or less intense training sessions. One method for quantifying training load is multiplying the training session's rating of perceived exertion (sRPE) and duration to give an overall training load (TL) for any given session (3). The sRPE is perhaps the most commonly used intensity factor in TL monitoring (18) and although not without its limitations (e.g., as a global score, its' sensitivity to account for biomechanical, cardiorespiratory and psychological responses to training stress may be compromised) (7), it may conceptually account for perceptions of mental fatigue from training sessions or competitions (7, 11). For example, as sRPE is a global score, learning a new skill or tactical strategy or competing against an unfamiliar opponent, which are both cognitively demanding activities for athletes, may stimulate an increase in mental fatigue and in turn sRPE. There have also been a number of studies reporting higher sRPE in subsequent physical performance tests across a range of activities (e.g., cycling, running, soccer) after an athlete is mentally fatigued (2, 5, 6, 16, 20, 27, 28). Alongside these studies, there was a moderate correlation between subjective mental and physical fatigue VAS (although not sRPE) in developmental netball athletes (23). However, to the best of our knowledge, there is no research examining this interaction with Olympic-level elite athletes.

It is also notable that mental fatigue experienced by athletes may differ based upon whether or not they compete in open (OS) or closed (CS) skill sports. Open skill sports (e.g., basketball, table tennis) require athletes to react in an unpredictable and changing externally paced environment, whilst CS sports are performed in an environment that is relatively predictable, consistent and internally paced (e.g., weightlifting, shot put, swimming) (8). For instance, athletes in OS sports may develop better visual attention, action-execution and decision-making skills compared to CS sport athletes (19, 33). As attention and decision-making seem to be influenced by mental fatigue (5, 6, 17, 27, 28), the development of these different cognitive qualities in OS and CS sports (19, 31, 33) may be related to the amount of mental fatigue in these different sports. However, it is unknown whether OS or CS sports expose athletes to different levels of mental fatigue at an elite level.

In light of the limited applicability of previous research and lack of research on elite athletes, the primary purpose of this study was to examine the influence of mental fatigue on sRPE over a training week in elite athletes. Exploring this relationship is important for practitioners considering the widespread use of sRPE, the limited knowledge about how an elite athlete's mental fatigue and sRPE interact with one another and the negative impact mental fatigue has on performance in athletes. This exploration is also necessary considering sRPE may inherently assess perceptions of mental fatigue (7, 11). Due to this conceptual basis, the authors hypothesized that there would be a significant relationship between mental fatigue and sRPE. The secondary purpose of this study was to explore whether elite athletes may experience significantly different mental fatigue levels over a training week based on whether they participated in an OS or CS sport. This was deemed worthwhile considering OS sport athletes may experience higher levels of mental fatigue than CS sport athletes despite any habituation to the mental demands of the sport. We hypothesized that OS sport athletes would experience higher levels of mental fatigue than CS sport athletes despite any habituation to the mental demands of the sport and the potential for different TL between OS and CS sports.

METHODS

Experimental Approach to the Problem

This investigation used an observational study design. Mental fatigue VAS and sRPE were collected privately by the study's lead author within 30 minutes after training sessions during a full training week (i.e., a week that was not a scheduled reduction in training volume or intensity by the head coach of the team) within a three-week period five months prior to the 2016 Olympic Games. The athletes' individual training sessions' and total week's sRPE, session duration and mental fatigue VAS score were analysed primarily to determine if mental fatigue influences sRPE in individual training sessions and/or over a training week and secondarily, to see if any differences existed in mental fatigue VAS scores between OS and CS groups.

Subjects

Two groups of elite Olympic level athletes were analysed for this study: i) an OS sport group (n=32) and ii) a CS sport group (n=31). OS contained eleven female basketball (28 ± 3.7 years, 185.9 ± 10.1cm, 78.7 ± 11.5kg) and twenty-one female volleyball athletes (n=21, 26.4 ± 3.6 years, 187.5 ± 6.8cm, 75.5 ± 6.7kg). CS contained twenty-seven male (n=13) and female (n=14) weightlifting (27.0 ± 3.2 years, 162.2 ± 11.3cm, 72.2 ± 23.8kg) and four male track & field athletes (24.1 ± 1.3 years, 184.7 ± 1.5cm, 69.8 ± 5.6kg). All athletes were part of the senior national team for their respective sports with 78% of athletes in the OS group and 97% of the CS group having competed at the Olympic or World Championship level and had been on the national team for greater than one year. All subjects were informed of the benefits and risks of the investigation and all data for this study were collected within the athletes' training environment as part each national team's requirements of their athletes. This data was then released de-identified from the respective national Olympic committee who is the owner of the data. Approval for this investigation was granted by the Edith Cowan University Human Ethics Committee (Approval #19521) and conforms to the *Code of Ethics of the World Medical Association* (Declaration of Helsinki). Eight athletes (OS, n=5; CS, n=3) were excluded from any analysis due to either poor compliance with the data collection process (e.g., not able to record sRPE and mental fatigue VAS within 30 minutes of the training session completion) or were unable to complete all (i.e., 100%) of the planned training sessions in the week due to injury or illness.

Procedures

All subjects received a standardized education presentation on mental fatigue, including its definition (17), potential examples of mental fatigue along with the difference between mental and physical fatigue to improve metacognition (29). Subjects also received standardized instructions on the correct methods in recording mental fatigue and sRPE; and were also familiarised with these recording methods after one training session prior to the assessment week. Mental fatigue was assessed using validated 100mm VAS (26, 27) and sRPE was collected using the CR-10 scale (9, 10); both post-training. The TL was calculated as sRPE * training duration (sRPE-TL). Both fatigue VAS (Cronbach's α 0.91-0.98 (15)) and sRPE (coefficient of variation 8.5% (30)) are considered reliable measurement devices. The training week for both the OS and CS groups involved 8-10 technical training sessions (e.g., sports practice) and 3-4 non-technical training sessions (e.g., strength and power training, hypertrophy training, non-technical/games-based conditioning, recovery) from Monday to Saturday with Sunday off. Of note for the weightlifters in the CS group, due to the nature of the sport, was that any technical lifts and derivatives (e.g., snatch, front squat) were defined as technical training and any hypertrophy, rehabilitation or aerobic exercises were defined as non-technical training, which aligned with the sport coaches' definitions in this area. Although *not* compared with mental fatigue VAS scores, sRPE-TL was also collected from non-technical training sessions (as defined above) to assess if differences in the percentage of technical TL to total TL between OS and CS groups may have impacted the results.

Subjects also noted if any training sessions were burdened or modified in response to injury or illness post-training (i.e., subjects were able to train but may have required medical attention peri-training or had their training modified) (21). As mentioned, if subjects could not complete scheduled training sessions due to injury or illness, they were excluded from the study. This was also used to allow for any potential influence the amount of training burdened by injury or illness may have had on mental fatigue. Subjects were further instructed to avoid any changes from their normal athletic training, nutrition and recovery practices during the assessment week. Pre-training session mental fatigue VAS scores were not collected, and this was primarily due to the time allocation each national team allowed for access to athletes in this research project, which would seem a common constraint when working with elite athletes. However, the same factors that affect mental fatigue scores pre-training will also likely have some effect on sRPE scores in training, given sRPE's nature as a global score (7, 11). As such, the pre-training mental fatigue of the athlete was deemed to be partially controlled for in this study by using sRPE. Given the purpose of this investigation was to explore the influence of mental fatigue on sRPE and not necessarily the change in mental fatigue over a training session, only collecting mental fatigue and sRPE post-training (due to the conditions of the respective national teams) was deemed acceptable to continue the investigation.

Statistical Analysis

Statistical analyses were performed using statistical software (R statistics packages: *lmerTest, rmcorr, dabestr and performance;* https://www.r-project.org) or purposefully designed Excel spreadsheets (Microsoft Corporation, Washington, United States). All measures were summarized as mean ± standard deviation (SD). The alpha level for significance for all tests was defined as $p \leq 0.05$. To investigate the primary aim of the investigation (i.e., if there was any influence of mental fatigue on sRPE), repeated measures correlations with 95% confidence intervals were used to determine correlations between mental fatigue VAS scores, sRPE and training duration in both OS and CS groups. R-z transformations were applied to investigate if there were any significant differences in the correlations between OS and CS groups. Correlations were interpreted with r <0.10 defined as trivial, 0.1-0.29 as small, 0.3-0.49 as moderate, 0.5-0.69 as large and >0.7 as very large (12). To further examine the influence of mental fatigue on sRPE when considering other factors, a linear mixed model with the athlete as the random intercept was then created to examine the effects of skill (i.e., OS or CS), mental fatigue, duration and training burdened by injury as fixed effects on sRPE for individual training sessions. An additional multiple regression model was also completed for the sum of sRPE during the training week using the same fixed effects as above. Both models were checked for a) linearity, b) residual independence, normality and constant variance and c) high leverage points. The coefficients with their 95% confidence intervals along with marginal f^2 (1) were inspected for their contribution to sRPE. The marginal f^2 results were interpreted as trivial (<0.02), small (0.02-0.14), medium (0.15-0.34) and large (>0.35) (4).

To examine the secondary aim of this investigation (i.e., a potential difference in mental fatigue between OS and CS groups), linear mixed models (with the athlete as the random intercept) were used for the individual training session data with effect sizes of any differences calculated as marginal f^2 and interpreted as above. Meanwhile, for the training week totals, the data were first assessed for variance and normality and then the appropriate test (e.g., independent t-test (student's or Welch's) or Mann Whitney U test) were applied with effect sizes of any differences calculated as Hedge's g and interpreted as g <0.19 defined as trivial, 0.2-0.59 as small, 0.6-1.19 as moderate, 1.2-1.99 as large and >2 as very large (12).

RESULTS

The present study examined a total of 409 training sessions for all athletes combined. Descriptive statistics of the variables assessed in the training week for both OS and CS are presented in Table 1. Mental fatigue was significantly higher in the OS group when compared to CS in both individual training sessions (p=0.001, f^2=0.089) and over the training week (p<0.001, g=1.29). The differences are presented as estimation plots in Figure 1. The average sRPE was also significantly greater in the CS group than the OS group for individual sessions (p=0.01, f^2=0.037). Training burdened by injury or illness (p=0.79) and the percentage of technical TL to overall TL (p=0.25) were not significantly different between CS and OS groups.

TABLE 1 ABOUT HERE

FIGURE 1 ABOUT HERE

Repeated measures correlations between the mental fatigue VAS scores, sRPE and training duration in the overall cohort and OS and CS groups are displayed in Table 2. The mental fatigue VAS scores were significantly correlated with sRPE only in the OS group (r=0.23, p=0.001) which was significantly different to the CS group (r-z p=0.002). When examining the interaction between sRPE and training duration, there was a small correlation between these variables in OS group (r=0.16, p=0.03) and a moderate correlation in the CS group (r=0.38, p<0.001).

TABLE 2 ABOUT HERE

The model summary for individual and total sRPE over a training week is displayed in Table 3. In this investigation, the effect of mental fatigue on sRPE was trivial for individual sessions with a one standard deviation increase in mental fatigue VAS in a session (~22mm) increasing sRPE by ~0.1 arbitrary units (~2%) when accounting for the effects of the other explanatory variables. However, for training week total sRPE, the effect of mental fatigue was moderate with a one standard deviation increase in total mental fatigue VAS over the training week (~125mm) increasing sRPE by 3.75 arbitrary units (~12%) over a week when accounting for the effects of the other explanatory variables. The effects of training durations on sRPE were small yet significant for individual sessions and were small and insignificant when assessed over a week. The predominant sporting skill (i.e., open versus closed) also demonstrated a significant impact on sRPE (p<0.001 and 0.04 for both models respectively) in this cohort.

TABLE 3 ABOUT HERE

DISCUSSION

To the best of our knowledge, this investigation is the first to compare mental fatigue and sRPE in a truly elite Olympic-level athlete population and in an ecological training setting. The primary purpose of this study was to investigate the influence of mental fatigue on sRPE over a typical training week performed by elite athletes with the hypothesis that there would be a significant relationship between mental fatigue and sRPE. In support of this hypothesis, there was a significant correlation between mental fatigue and sRPE in the OS group however, this correlation was small (r=0.23, p=0.001) with only ~5% of the variance in sRPE related to mental fatigue. This correlation is similar to previous research examining the relationship between mental and physical fatigue in an OS sport (r=0.37); with the difference in correlation strength being potentially due to different measures used (i.e., a subjective 100mm VAS physical fatigue scale compared to sRPE) and the level/experience of the athletes (e.g., developmental athletes versus Olympic level athletes) (23). In regard to the CS group, there was no significant correlation between sRPE and mental fatigue. Further, it seemed that mental fatigue had only a trivial influence on sRPE levels when examining the individual training sessions in this investigation based on the results of the linear mixed model. Both of these findings are in opposition to the hypothesis that there would be a significant relationship between mental fatigue and sRPE. One interpretation of these findings is that mental fatigue may not significantly impact sRPE in an individual training session for elite athletes and sRPE is more related to physical, rather than mental, exertion; which is supported by some of the previous research on sRPE (11). However, as the week's total mental fatigue had a moderate effect on the week's total sRPE ($p<0.001$, $f^2 = 0.265$) in this investigation, it is also possible that mental fatigue has more of a chronic, rather than acute, influence on sRPE. If this is supported by future research, a chronic influence of mental fatigue on sRPE could hypothetically moderate training outcomes in various sports (e.g., TL-performance relationships), depending on whether the sports are OS or CS (7).

The secondary purpose of this investigation was to examine whether there may be different levels of mental fatigue in an elite athlete's training week based on whether they participated in an OS or CS sport. This appeared to be evident in this investigation with the CS group having significantly lower levels of mental fatigue than the OS group in both individual training sessions ($p<0.01$, $f^2=0.089$) and over the training week ($p<0.001$, $g=1.29$). It is of interest that this difference also appeared despite the CS group having significantly higher ratings of training intensity i.e., higher sRPE scores ($p=0.01$, $f^2=0.037$). Although mental fatigue may be influenced by a number of different factors that are extremely hard to control for with elite athletes (e.g., professional commitments outside of training), both of these findings are interesting. Although more investigation is needed in this area, the higher mental fatigue levels yet lower sRPE in the OS group would seem to support the hypothesis that mental fatigue may be higher for OS sports than CS sports at an elite level. This finding also raises the possibility that even elite athletes of OS sports may not become accustomed to mental fatigue. Both of these suggestions would seem to warrant future research, especially for practitioners in OS sports.

A potential explanation for these differences in mental fatigue between the OS and CS groups is the differences in the preparation and training practices of the OS and CS sports in this study.

For example, in general, weightlifting and track & field training sessions may focus more on physical preparation whereas basketball and volleyball may focus more on technical and tactical preparation; based on their respective sport demands. The OS group having higher mental fatigue yet lower sRPE would also appear to be dissimilar to previous research on mental fatigue that has generally noted greater levels of sRPE in a mentally fatigued condition (2, 5, 6, 20, 27, 28). However, these differences with previous research may be explained by the experimental design. For instance, in this investigation, for ecological validity reasons, we did not give the athletes a mentally fatiguing task before training sessions and then examine sRPE response (as has been done in previous studies (2, 5, 6, 20, 27, 28)).

A strength of this exploratory investigation is the level of the athletes involved (e.g., Olympians) and its applied nature. However, there are a number of potential limitations with this investigation. The first potential limitation was that there was no collection of mental fatigue VAS scores prior to training beginning, which was primarily due to the time allocation each national team allowed for access to athletes in this research project. However, as the same factors that affect mental fatigue scores pre-training will also likely have some effect on sRPE scores from training (given its nature as a global score) (7), the pre-training mental condition of the athlete may have been controlled for to some degree in this study. Regarding the global nature of sRPE, it may also have been that using differential RPE (32) instead of sRPE in this study to monitor TL may have provided stronger associations with mental fatigue. This association between differential RPE and mental fatigue is recommended to be explored in the future. Another potential limitation was that there was no physiological marker of mental fatigue (e.g., electroencephalography) incorporated in this investigation. However, VAS have been shown to be more sensitive than electroencephalography and heart rate variability to the mental fatigue from cognitive tasks in recent research (26) and electroencephalography seems currently impractical for use within an applied sporting environment (24, 29). Alongside physiological markers of mental fatigue, another limitation of this study was there was no formal recording of athlete subjective wellness measures, blood analysis (e.g. glucose) or hydration tests which have been recommended as reasonable measures involving mental fatigue research (24). A further limitation of this study was that although both groups were five months from competing at the Olympic Games, we were unable to recruit any elite male athletes for the OS group due to training and competition schedules of the respective national teams involved in this study. However, the available literature suggests that in an athletic population, mental fatigue increases perceived effort and reduces performance in a time-to-exhaustion test similarly in both sexes (p=0.98) (16). Further, there does not appear to be any significant sex effects on ratings of mental fatigue using 100mm VAS (13) or sRPE, at least at relative physiological intensities (14, 22). Given these limitations, the duration of the study period (i.e., one week) and the exploratory nature of this research, we suggest practitioners interpret these results at the level of a case study.

PRACTICAL APPLICATIONS

Although sRPE may theoretically encompass mental fatigue, it has not been designed to measure mental fatigue independently and many other factors exert an influence on sRPE scores (e.g., mechanical and/or physiological work). As such and also supported by the results of this study, sRPE does not seem to be an appropriate independent measure of mental fatigue. Therefore, it is recommended practitioners use VAS to monitor the mental demands of training, especially for OS sports, due to the negative impact mental fatigue has on performance outcomes in elite sport (24, 26). By also measuring sRPE and training duration at the same time, practitioners can decrease the impact of any response bias in mental fatigue VAS scores and reduce the number of variables that may confound the true biological and performance impact of mental fatigue (24, 29). To decide on if, how and when to implement mental fatigue or sRPE measures practically (e.g., frequency and timing of collection), readers are advised to consider the number of different factors presented by Saw et al (25). Practitioners are also encouraged to consider the impact of mental fatigue on any TL monitoring relationships with performance/injury, as well as the context of the sport and individual athlete situation. For instance, individual athletes *within the same sport* whose mental fatigue levels are relatively high compared to the group (e.g., a newcomer to a team trying to learn a playbook and/or establish themselves as a regular selection by coaches) as well as being under high TL at the same time may be of particular concern for strength & conditioning professionals or sports coaches.

REFERENCES

1. Aiken LS, & West, S. G. *Multiple regression: Testing and interpreting interactions.* Newbury Park: Sage, 1991.
2. Badin OO, Smith MR, Conte D, and Coutts AJ. Mental Fatigue: Impairment of Technical Performance in Small-Sided Soccer Games. *Int J Sports Physiol Perform* 11: 1100-1105, 2016.
3. Bannister EW, Calvert, T.W., Savage, M.V. and Bach, T.M. A systems model of training for athletic performance. *Aust J Sci Med*: 57-61, 1975.
4. Cohen J. A power primer. *Psychol Bull* 112: 155-159, 1992.
5. Coutinho D, Gonçalves B, Travassos B, Wong DP, Coutts AJ, and Sampaio JE. Mental Fatigue and Spatial References Impair Soccer Players' Physical and Tactical Performances. *Front Psychol* 8: 1645-1645, 2017.
6. Coutinho D, Goncalves B, Wong DP, Travassos B, Coutts AJ, and Sampaio J. Exploring the effects of mental and muscular fatigue in soccer players' performance. *Hum Mov Sci* 58: 287-296, 2018.
7. Coyne JOC, Gregory Haff G, Coutts AJ, Newton RU, and Nimphius S. The current state of subjective training load monitoring—a practical perspective and call to action. *Sports Med Open* 4: 58, 2018.
8. Di Russo F, Bultrini A, Brunelli S, Delussu AS, Polidori L, Taddei F, Traballesi M, and Spinelli D. Benefits of sports participation for executive function in disabled athletes. *J Neurotrauma* 27: 2309-2319, 2010.
9. Ding W. The Validity and Reliability of Borg's 6-20 RPE Scale among Chinese Mandarin Speaking Young Healthy Adults, in: *Exercise and Health Science*. University of Massachusetts Boston, 2016.
10. Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, and Dodge C. A new approach to monitoring exercise training. *J Strength Cond Res* 15: 109-115, 2001.
11. Haddad M, Stylianides G, Djaoui L, Dellal A, and Chamari K. Session-RPE Method for Training Load Monitoring: Validity, Ecological Usefulness, and Influencing Factors. *Front Neurosci* 11, 2017.
12. Hopkins WG, Marshall SW, Batterham AM, and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-12, 2009.
13. Jaydari Fard S and Lavender AP. A comparison of task-based mental fatigue between healthy males and females. *Fatigue* 7: 1-11, 2019.
14. Laurent CM, Green JM, Bishop PA, Sjokvist J, Schumacker RE, Richardson MT, and Curtner-Smith M. Effect of gender on fatigue and recovery following maximal intensity repeated sprint performance. *J Sports Med Phys Fitness* 50: 243-253, 2010.
15. Lee KA, Hicks G, and Nino-Murcia G. Validity and reliability of a scale to assess fatigue. *Psychiatry Res* 36: 291-298, 1991.
16. Lopes TR, Oliveira DM, Simurro PB, Akiba HT, Nakamura FY, Okano AH, Dias ÁM, and Silva BM. No Sex Difference in Mental Fatigue Effect on High-Level Runners' Aerobic Performance. *Med Sci Sports Exerc* Publish Ahead of Print, 2020.
17. Marcora SM, Staiano W, and Manning V. Mental fatigue impairs physical performance in humans. *J Appl Physiol* 106: 857-864, 2009.
18. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, and Weston M. The relationships between internal and external measures of training load and intensity in team sports: A meta-analysis. *Sports Med* 48: 641-658, 2018.
19. Overney LS, Blanke O, and Herzog MH. Enhanced temporal but not attentional processing in expert tennis players. *PLoS One* 3: e2380, 2008.

20. Pires FO, Silva-Júnior FL, Brietzke C, Franco-Alvarenga PE, Pinheiro FA, de França NM, Teixeira S, and Meireles Santos T. Mental Fatigue Alters Cortical Activation and Psychological Responses, Impairing Performance in a Distance-Based Cycling Trial. *Front Physiol* 9, 2018.
21. Raysmith BP and Drew MK. Performance success or failure is influenced by weeks lost to injury and illness in elite Australian Track and Field athletes: a 5-year prospective study. *J Sci Med Sport* 19: 778-783, 2016.
22. Robertson RJ, Moyna NM, Sward KL, Millich NB, Goss FL, and Thompson PD. Gender comparison of RPE at absolute and relative physiological criteria. *Med Sci Sports Exerc* 32: 2120-2129, 2000.
23. Russell S, Jenkins D, Halson S, and Kelly V. Changes in subjective mental and physical fatigue during netball games in elite development athletes. *J Sci Med Sport*, 2019.
24. Russell S, Jenkins D, Smith M, Halson S, and Kelly V. The application of mental fatigue research to elite team sport performance: New perspectives. *J Sci Med Sport*, 2018.
25. Saw AE, Kellmann M, Main LC, and Gastin PB. Athlete Self-Report Measures in Research and Practice: Considerations for the Discerning Reader and Fastidious Practitioner. 12: S2-127, 2017.
26. Smith MR, Chai R, Nguyen HT, Marcora SM, and Coutts AJ. Comparing the Effects of Three Cognitive Tasks on Indicators of Mental Fatigue. *J Psychol* 153: 759-783, 2019.
27. Smith MR, Coutts AJ, Merlini M, Deprez D, Lenoir M, and Marcora SM. Mental Fatigue Impairs Soccer-Specific Physical and Technical Performance. *Med Sci Sports Exerc* 48: 267-276, 2016.
28. Smith MR, Marcora SM, and Coutts AJ. Mental Fatigue Impairs Intermittent Running Performance. *Med Sci Sports Exerc* 47: 1682-1690, 2015.
29. Thompson CJ, Fransen J, Skorski S, Smith MR, Meyer T, Barrett S, and Coutts AJ. Mental Fatigue in Football: Is it Time to Shift the Goalposts? An Evaluation of the Current Methodology. *Sports Med* 49: 177-183, 2019.
30. Wallace LK, Slattery KM, Impellizzeri FM, and Coutts AJ. Establishing the criterion validity and reliability of common methods for quantifying training load. *J Strength Cond Res* 28: 2330-2337, 2014.
31. Wang C-H, Chang C-C, Liang Y-M, Shih C-M, Chiu W-S, Tseng P, Hung DL, Tzeng OJL, Muggleton NG, and Juan C-H. Open vs. Closed Skill Sports and the Modulation of Inhibitory Control. *PLoS ONE* 8: e55773, 2013.
32. Weston M, Siegler J, Bahnert A, McBrien J, and Lovell R. The application of differential ratings of perceived exertion to Australian Football League matches. *J Sci Med Sport* 18: 704-708, 2015.
33. Yarrow K, Brown P, and Krakauer JW. Inside the brain of an elite athlete: the neural processes that support high achievement in sports. *Nat Rev Neurosci* 10: 585-596, 2009.

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FIGURE CAPTIONS

Figure 1A-B. Estimation Plots of the Differences in Individual Session Mental Fatigue (A) and Total Mental Fatigue (B) in a Typical Training Week Prior to the 2016 Olympic Games for a Group of Open and Closed Skill Sport Elite Athletes.

Table 1. Descriptive Statistics of the Mental Fatigue and Training Load Characteristics of Closed and Open Skill Sport Elite Athletes in One Training Week Prior to the 2016 Olympics.

	Closed Skill	Open Skill	*p*	*f2*
Individual Sessions				
MF	45.5 ± 23.2	59.0 ± 20.7	0.001**	0.089
sRPE	4.8 ± 2.1	4.1 ± 1.3	0.01**	0.037
t	99.3 ± 31.3	139.9 ± 63.6	<0.001***	0.182
sRPE-TL	469.6 ± 303.0	597.4 ± 362.4	0.04*	0.028
Weekly Totals				*g [95% CI]*
Total MF	302.1 ± 102.8	470.2 ± 153.7	<0.001***	1.29 [0.75, 1.82]
Total sRPE	32.1 ± 9.5	33.0 ± 7.3	0.71	0.10 (-0.43, 0.64)
Total t	659.6 ± 173.2	1114.4 ± 179.2	<0.001***	2.46 [1.72, 3.13]
Total sRPE-TL	3298.9 ± 1245.0	4757.8 ± 1185.4	<0.001***	1.12 [0.58, 1.65]
inj	0.50 ± 0.51	0.54 ± 0.51	0.79	0.07 [-0.49, 0.67]
% Technical TL	0.74 ± 0.12	0.71 ± 0.06	0.25	-0.31 [-0.85, 0.23]

Note: MF – mental fatigue, sRPE – sessional rating of perceived exertion, t – training duration, TL – training load, inj – training burdened by injury or illness, % Technical TL – percentage of total technical training load to total training load, *$p<0.05$, **$p<0.01$, ***$p<0.001$, f^2 – Cohen's marginal effect size, *g* – Hedge's effect size, *CI* – confidence interval

Table 2. Repeated Measure Correlations between Mental Fatigue and Training Load Variables from One Training Week Prior to the 2016 Olympic Games for Open and Closed Skill Sport Elite Athletes.

	Overall		Closed Skill		Open Skill		*R-Z*
	r [95% CI]	*p*	*r [95% CI]*	*p*	*r [95% CI]*	*p*	*p*
MF-sRPE	0.05 [-0.05, 0.16]	0.33	-0.07 [-0.22, 0.09]	0.38	0.23 [0.09, 0.36]	0.001**	0.002**
MF-t	0.09 [-0.01, 0.19]	0.09	0.11 [-0.05, 0.26]	0.16	0.09 [-0.05, 0.23]	0.21	0.84
sRPE-t	0.22 [0.11, 0.31]	<0.001***	0.38 [0.23, 0.50]	<0.001***	0.16 [0.02, 0.29]	0.03*	0.02*

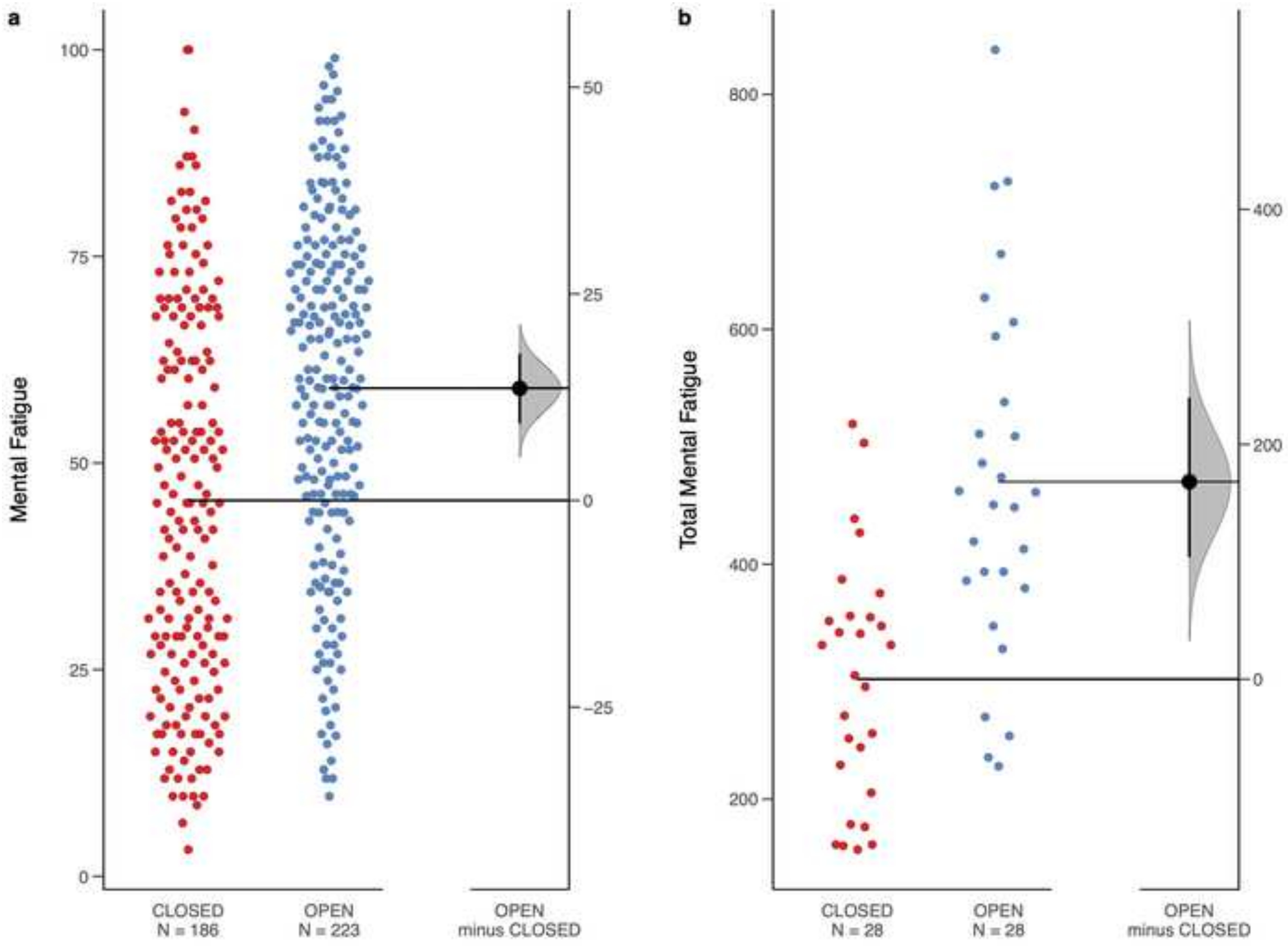
Note: MF – mental fatigue, sRPE – session rating of perceived exertion, t – training duration, TRIMP – training impulse, inj – training burdened by injury or illness, *$p<0.05$, **$p<0.01$, ***$p<0.001$, CI – confidence interval, *R-Z* – r-z transformation comparing open and closed skill correlations.

Table 3. Model Summary for Individual Session (linear mixed model) and Weekly Total (multiple regression model) Sessional Rating of Perceived Exertion During a Typical Training Week Prior to the 2016 Olympic Games for a Group of Open and Closed Skill Sport Elite Athletes.

	Estimate [95% CI]	Standard Error	Standardised Estimate	f^2	*Pr(>|t|)*	R^2	F statistic *p*-value
Individual Session Mental Fatigue							
(Intercept)	3.84 [3.19, 4.84]	0.33			<0.001***	0.29	N/A
Skill	-1.03 [-1.57, -0.49]	0.27	-0.59	0.055	<0.001***		
MF	0.01 [-0.00, 0.01]	0.00	0.07	0.002	0.20		
t	0.01 [0.00, 0.01]	0.00	0.22	0.043	<0.001***		
inj	0.06 [-0.45, 0.57]	0.26	0.02	0.001	0.82		
Weekly Total Mental Fatigue							
(Intercept)	17.0 [5.99, 28.0]	5.47			<0.01**	0.22	0.01*
Skill	-8.28 [-16.1, -0.42]	3.92	-0.99	0.087	0.04*		
Total MF	0.03 [0.01, 0.04]	0.01	0.57	0.265	<0.001***		
Total t	0.01 [-0.00, 0.02]	0.01	0.31	0.041	0.15		
inj	-0.96 [-5.32, 3.40]	2.17	-0.06	0.004	0.66		

Note: MF – mental fatigue, t – training duration, TRIMP – training impulse, inj – training burdened by injury or illness, *p<0.05, **p<0.01, ***p<0.001, g – Hedge's effect size, CI – confidence interval, f^2 – Cohen's marginal effect size, R^2 – proportion of variation in response variable explained by explanatory variables

Figure 1.


a
Mental Fatigue
100
75
50
25
0
50
25
0
−25
CLOSED
N = 186
OPEN
N = 223
OPEN
minus CLOSED
b
Total Mental Fatigue
800
600
400
200
400
200
0
CLOSED
N = 28
OPEN
N = 28
OPEN
minus CLOSED