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ORIGINAL INVESTIGATION

Impacts of Season Phases and Training Variables on Mental Fatigue in Real-World Elite Fencing

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Purpose: Mental fatigue (MF) is increasingly implicated in elite sports, yet its characteristics and impact in real-world fencing, a highly perceptual-cognitive demanding domain, are underexplored. ***Methods:*** A 4-week single-blind, longitudinal study monitored 31 (7 épée, 13 foil, and 11 sabre; 15 females) elite fencers' daily MF across training and competition phases before, during, and after a national championship. Subjective MF on a visual analog scale and reaction time (from 3-min Psychomotor Vigilance Test) were measured daily in the morning (baseline) and after training or competition. Self-reported individualized training variables (session rating of perceived exertion, duration, and detailed training workload demands) were collected posttraining. One-way repeated-measures analyses of variance assessed daily MF on a visual analog scale and reaction-time changes across phases. Linear mixed-effect models examined the impact of training load and specific training workloads on MF. ***Results:*** Analysis of 93 match days and 440 training days revealed that MF on a visual analog scale increased after fencing activities compared with baseline, peaking on match days (+19.34 AU, $P < .001$), which aligned with an impaired reaction time (+76.43 milliseconds, $P < .01$). On training days, overall training load (estimate = 0.02), as well as the contributions of tactical (estimate = 0.26) and physical (estimate = 0.12) workload demands, positively predicted the MF increase (all $P < .001$), whereas environmental demand (estimate = –0.13, $P = .022$) mitigated the MF elevation. ***Conclusions:*** The study highlights the prevalence of MF in elite fencers and its subsequent impact on reaction performance on competition days. The association with specific training structures provides insights for coaches and athletes to actively manage MF and optimize performance throughout a season.

Keywords: cognitive fatigue, longitudinal monitoring, reaction performance, training load, combat sports

Athletes, coaches, and support staff use evidence-based approaches to design and monitor athletic training.[1] Around competition periods, the goal is to enhance performance and minimize the risk of accumulating fatigue.[2] Fatigue is a multifaceted phenomenon with various underlying mechanisms[3] and can stem from physical and mental sources of exertion.[2] This physical component is researched extensively; but, despite a strong practitioner's acknowledgment of its importance, mental fatigue (MF) receives little to no attention.[4] MF is a psychobiological state induced during prolonged demanding cognitive activity.[5] It is commonly characterized by a subjective feeling of tiredness, decreased cognitive capacity, and/or altered brain activation.[5] Qualitative studies in athletic populations frequently report associated perceptions of disengagement and lower motivation and enthusiasm with MF.[6] Laboratory-based studies suggest that MF negatively impacts subsequent physical performance[7]; psychomotor performance including decision-making ability, reaction speed, and accuracy[5]; and key aspects of technical and tactical performance.[8] Reports from athletes and staff, combined with observational evidence, position MF as an important factor to be considered to actively monitor and manage in elite sports.[6]

Generally, in applied training and competition environments, researchers and practitioners utilize practically accessible subjective and behavioral approaches, including self-reported scales and questionnaires (eg, visual analog scale [VAS][9]) and short cognitive tasks (eg, 3-min Psychomotor Vigilance Test [PVT][10]) to evaluate MF. Studies have documented the presence, fluctuation, and persistence of MF across various sports, such as football,[11,12] netball,[13–15] rugby,[9] beach volleyball,[16] padel,[10] and orienteering.[17] Elevated MF is often observed posttraining and postcompetition.[9–17] It generally appears that MF fluctuates, with accumulation throughout consecutive tournament days and preseason training phases and peaks observed during later stages, and seasons.[10,12,14,15] For example, when comparing in-season soccer training sessions, higher MF was reported during the playoffs than in the regular season.[12] Despite the contextual difference and temporal variations, more acutely, open-skilled sports typically require rapid responses to unpredictable and dynamic environments, which impose high mental demands on athletes and are likely to lead to the onset of MF.[18]

Fencing (ie, épée, foil, and sabre), as an open-skilled combat sport, features sword fighting, which emphasizes the perceptual-

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cognitive skills and the allocation of mental rather than physical resources for performance maintenance and success.[19–21] Evidence suggests that the gradual subjective manifestation of fatigue is linked to a significantly increased mental demand.[20] Fatigue in real-world fencing activities may predominantly manifest as the mental component.[20] However, to the best of our knowledge, quantification of MF in the context of fencing is limited. As outlined above, from the perspective of fatigue management and training prescription, an essential MF profile across different phases of actual fencing training and competition is lacking. Furthermore, it is not known how different training sessions induce MF and what the potential impact on performance is. Therefore, this study aimed, first, to monitor and profile elite fencers' MF using subjective and behavioral indicators across different phases before, during, and after the Chinese National Championship Finals. Second, it sought to explore the relationship between fencing training variables and potential fluctuations in MF. We hypothesized that MF would accumulate with the progression of competition and postchampionship training, and the increased amplitude of daily MF would be affected by phases, training load (TL), and detailed training demands.

Methods

Subjects

The study took convenience sampling to recruit 39 active tiers 3 to 5 (from national to world-class[22]) senior fencers from Chinese fencing academy. After an interview (ie, health screening), 8 fencers were excluded due to injuries (n = 2), anti-influenza and melatonin medications (n = 4), or self-withdrawal (n = 2). Eventually, 31 (15 females and 16 males) participants from all 3 fencing disciplines were fully monitored and included in the analysis (see Table 1). Eighteen fencers competed in the World Juniors/Seniors Championships, and 3 were Olympians.

Study Design

This project used a longitudinal, single-blind observational approach. Fencers' subjective MF and real-time reaction performance on training and match days were collected across different phases before, during, and after the 2023 Chinese Fencing Championship Finals (hereafter referred to as "championship"). The monitoring period consisted of 4 phases: the preparation training week before the championship (P1), official match days (P2), a recovery training week (P3), and a regular training week (P4) after the championship, in sequence (see Figure 1). These fencers executed individualized training programs and match schedules under a shared, structured time frame. Because fencing was the primary daytime activity, the study treated each day as a whole, with measurements taken in the morning (baseline) and postfencing. The rest days, during which fencers did not train or compete (ie, no fencing), were excluded. Written informed consent from the participants was obtained before official participation, following Shanghai University of Sport's ethical approval (No. 102772023RT058). The observational project was retrospectively registered on Open Science Framework (osf.io/9jepv) after data collection.

Procedures

To provide context and enhance participants' understanding, standardized education on training and fatigue was conducted 1 week prior to the commencement of monitoring. The theoretical

Table 1 Demographic Information of the Participants, Mean (SD)

Discipline	Gender/n	Age, y	Height, cm	Weight, kg	Career, y	National experience, y
Sabre	Female/6	23.2 (1.6)	176.0 (3.8)	67.4 (5.4)	10.8 (1.3)	2.2 (2.6)
	Male/5	24.2 (1.5)	186.0 (3.4)	74.0 (3.7)	11.3 (2.7)	4.0 (2.5)
Foil	Female/5	23.6 (2.0)	168.1 (4.9)	59.0 (7.2)	10.6 (2.1)	2.2 (1.6)
	Male/8	21.9 (2.3)	185.5 (5.5)	75.4 (8.0)	9.5 (2.1)	1.4 (0.5)
Epée	Female/4	23.8 (2.1)	175.3 (3.9)	64.3 (1.7)	10.7 (1.2)	1.5 (0.6)
	Male/3	22.3 (2.6)	188.0 (8.1)	78.0 (11.6)	9.3 (2.1)	2.5 (2.0)

Note: Gender is recorded according to the information for the event.

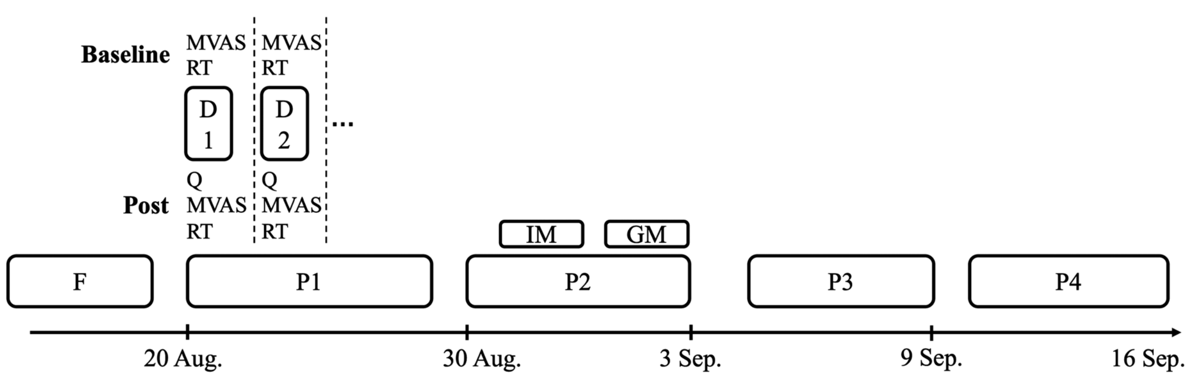

Figure 1 — Timeline of mental-fatigue monitoring. The ellipsis dots represent the repeated monitoring days. The blank space between blocks represents the rest days without fencing. D1 indicates monitoring day 1; D2, monitoring day 2; F, familiarization; GM, grouped match; IM, individual match; MVAS, subjective mental fatigue on visual analog scale; P1, preparation training week; P2, championship week; P3, recovery training week; P4, regular training week; Q, online questionnaire for training variables; RT, reaction time.

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definition of TL and general understanding of physical and MF from broader athletic perspectives were given based on Halson[1] and Russell et al.[6] To ensure that participants remained blinded to the specific aim and focus on MF, the study was presented as routine fatigue monitoring, thereby minimizing the risk of bias reporting. Participants were instructed to download the application on which they could complete the PVT task (PVT Research Tool, Texas A&M University System) and a survey platform (wjx.cn, Wenjuanxing) onto their personal smartphones. During a 1-week familiarization period, participants practiced completing the online questionnaires delivered on their terminal platform. This questionnaire included reading background materials and answering training-related questions by sliding the digital scales or selecting options. Following this, participants were redirected to complete the 3-minute PVT (brief PVT [PVT-B]) as quickly and accurately as possible. Real-time feedback was provided only after each familiarization session, not during or after the official trial. Within 30 minutes of waking up in the morning (baseline) and 30 minutes after the last training session or competition of the day (post), the subjective MF on VAS (MVAS) and reaction time (RT) on PVT-B were collected via the participants smartphones. In addition, participants self-reported their training variables on the questionnaire at the end of each training day. Verbal and message reminders were provided to the participants individually if no data was input into the online system within 30 minutes of the questionnaire being activated to improve compliance.

Subjective MF

The digital VAS was set on the questionnaire to measure MVAS as previously adopted.[23] The participants moved the marker on the electronic scale to answer "How mentally fatigued do you feel right now?" Two ends of the line were anchored from 0 to 100 indicating "not at all" and "maximum" levels of MF, respectively. The backend of the online system recorded the MVAS for analysis by converting it into a 0 to 100 digital form.

Reaction Time

The PVT-B has been previously validated and adapted as a smartphone-compatible application.[24] Participants were instructed to focus their gaze on a gray cross located at the center of a black screen and tap the screen as soon as a red, solid circular stimulus appeared. They were required to respond as promptly as possible but were cautioned against reacting too quickly (ie, anticipation if RT < 100 ms). The interstimulus intervals were randomly varied between 1000 and 4000 milliseconds.[24] The average RT (in milliseconds) of valid touches across the 3-minute trial was calculated for subsequent analysis.

Training Variables

On training days, the online questionnaire regarding the completed training structure and activities was released 30 minutes after the training through the system to the participants' terminal survey platform. The questionnaire collected session-rating of perceived exertion (sRPE), training duration (TD), and participants' rated contributions of 5 workload factors to the training day. Evaluated on the digital Borg CR-10 scale, session-rating of perceived exertion is a simple yet validated approach to quantifying TL (*TL = session-rating of perceived exertion × training duration*) in fencing sports.[25] The study defined the overall workload on the training day as physical (PHY), technical (TEC), tactical (TAC), psychological (PSY), and environmental (ENV) demands. Specifically, PSY represented the workload from the dynamic process of stress appraisal, coping, and emotion,[26] and ENV represented external workload input in addition to the routine training itself. Participants slid the VAS each time from 0 (none at all) to 100 (maximum) to indicate the contribution of each factor based on the current experience of the training day. This allowed for describing the individualized training demands and exploring the potential influence on MF changes from different workload aspects.

Statistics

Data cleaning, analysis, and visualization were conducted in MATLAB 2023. All measures were presented as mean (SD). The significance level was defined as $P < .05$. The Shapiro–Wilk normality test checked the normal distributions for MVAS and RT at different times (post vs baseline) and phases. One-way repeated measure analyses of variance analyzed time changes of MVAS and RT in each phase, as well as the differences in baseline levels of MVAS and RT across the phases. Mauchly test assessed the assumption of sphericity in the repeated measure analyses of variance. If sphericity was violated, the Greenhouse–Geisser correction adjusted the F ratios. The Levene test checked the variance homogeneity across different times and phases. Welch analysis of variance was used when the assumption of homogeneity of variances was violated. Bonferroni post hoc tests were chosen for pairwise comparisons in which the main effects of time were observed. Effect sizes of the daily MVAS and RT changes were calculated, with a partial eta squared (η_p^2) of ≥.01 indicating small, ≥.06 medium, and ≥.14 large effects.[21]

Thereafter, training days were analyzed to explore the potential influences of different training variables on MF by establishing linear mixed-effects models. The Variance Inflation Factor for each factor was checked below the threshold of 10 to avoid multicollinearity. Phase, discipline, and TL were set as 3 independent variables for the fixed effects. In particular, $MVAS_{baseline}$ was set as a covariate due to its natural fluctuation with athletes' wellness.[11] Participants' identifier code (ID) was the random-effect factor for possible intraindividual effects.[27] The collecting day in numerical order (date) was also set as the random-effect factor considering the inconsistent measurement time and days.

$$MVAS_{post} \sim 1 + phase + discipline + TL + MVAS_{baseline} + (1|ID) + (1|date).$$

Finally, a separate model was established to explore the potential influences of the 5 general workload factors (ie, PHY, TEC, TAC, PSY, and ENV) during the training day on daily MVAS changes ($MVAS_{diff} = MVAS_{post} - MVAS_{baseline}$), and ID and date were the random effects.

$$MVAS_{diff} \sim 1 + PHY + TEC + TAC + PSY + ENV + (1|ID) + (1|date).$$

Results

A total of 533 days, among which 440 were training days, were fully analyzed for the 31 participants.

MF Changes Across Different Phases

As shown in Figure 2, MVAS scores increased significantly after fencing training and competition within each phase, with a large effect observed in P2 (58.29 [22.41] vs 38.95 [16.97] AU, $P < .001$, $\eta_p^2 = .193$), moderate effects in P4 (47.11 [21.61] vs 32.85

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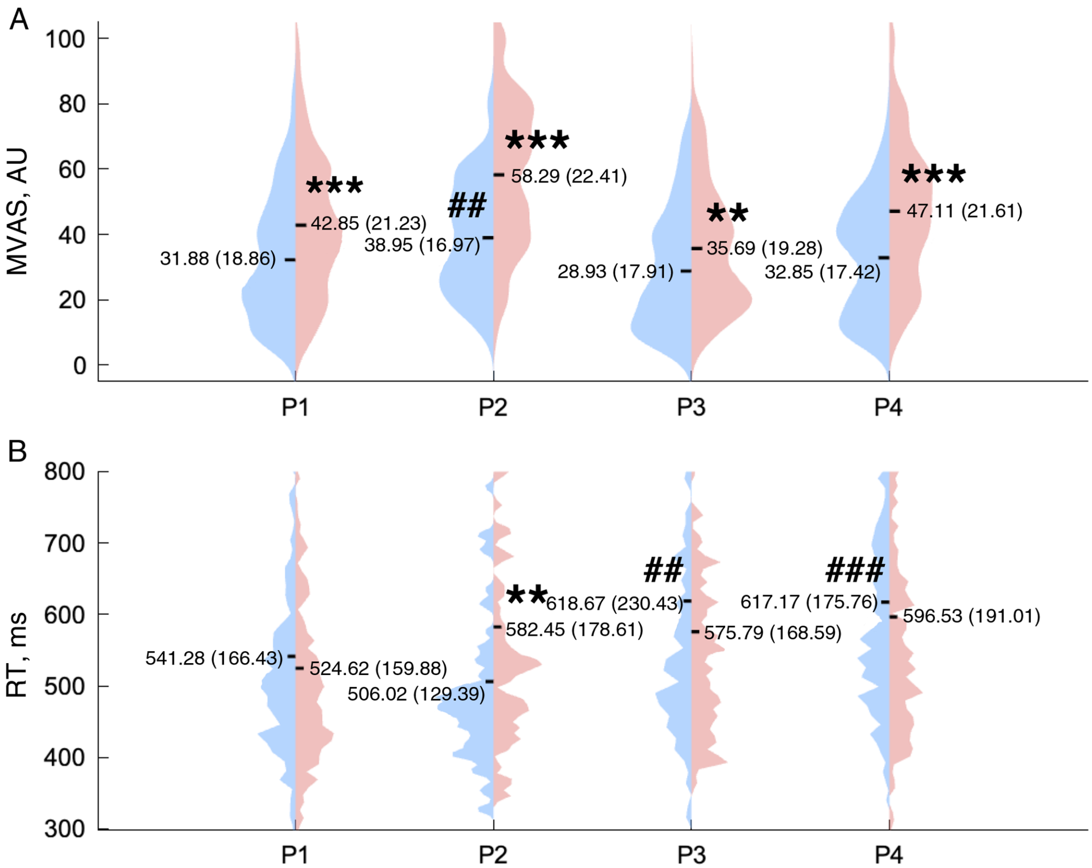

Figure 2 — (A) Violin plot of daily subjective mental-fatigue changes across different phases. (B) Violin plot of daily reaction-time changes across different phases. Left half part, baseline level; right half part, post level. The detailed value by the side and the black short dash represent mean (SD) in each measurement point. MVAS indicates subjective mental fatigue on a visual analog scale; P1, preparation training week; P2, the championship; P3, recovery training week; P4, regular training week; RT, reaction time (in milliseconds). $^{***}P < .001$ for post versus baseline within the phase. $^{**}P < .01$ for post versus baseline within the phase. ###$P < .001$ for baseline comparisons with preparation training week. ##$P < .01$ for baseline comparisons with preparation training week.

[17.42] AU, $P < .001$, $\eta_p^2 = .117$) and P1 (42.85 [21.23] vs 31.88 [18.86] AU, $P < .001$, $\eta_p^2 = .070$), and a small effect in P3 (35.69 [19.28] vs 28.93 [17.91] AU, $P < .01$, $\eta_p^2 = .032$). The RT significantly increased after the competition (in P2; 582.45 [178.61] vs 506.02 [129.39] ms, $P < .01$, $\eta_p^2 = .058$), with no significant changes observed after the training (P1: $P = .265$; P3: $P = .088$; P4: $P = .279$). Compared with the baseline level in P1, $MVAS_{baseline}$ was significantly higher only in P2 ($P < .01$), whereas $RT_{baseline}$ was significantly higher in P3 ($P < .01$) and P4 ($P < .001$).

Influence of Training Variables on MF Changes

On training days, the model identified significant positive effects of TL (estimate = 0.02, $P < .001$) and $MVAS_{baseline}$ (estimate = 0.48, $P < .001$) on the $MVAS_{post}$. For discipline and phase, no significant fixed effects were found ($P > .05$; Table 2).

Regarding the contributions from different workload factors on training days and their potential influences on MF changes (see Table 3), TAC (estimate = 0.26, $P < .001$) and PHY (estimate = 0.12, $P < .001$) showed significant positive effects on $MVAS_{diff}$, whereas ENV (estimate = –0.13, $P = .022$) showed a substantial negative impact. TEC ($P = .136$) and PSY ($P = .057$) did not affect $MVAS_{diff}$.

Table 2 Influence of Different Training Variables on Mental Fatigue

	Est.	P	95% CI
Fixed-effect coefficients			
Intercept	5.38	.113	−1.28 to 12.03
Discipline_Foil	4.50	.107	−0.98 to 9.98
Discipline_Sabre	0.30	.918	−5.41 to 6.01
Phase_P3	1.00	.680	−3.74 to 5.73
Phase_P4	0.99	.636	−3.12 to 5.11
TL	0.02	<.001	0.01 to 0.02
$MVAS_{baseline}$	0.48	<.001	0.40 to 0.56
Random-effect covariance parameters			
ID	4.82		3.23 to 7.17
Date	2.81		1.52 to 5.22
Residuals	14.34		13.46 to 15.27

Abbreviations: Date, collecting day in numerical order; Est., estimate; ID, participants' identifier code; $MVAS_{baseline}$, the baseline level of subjective mental fatigue on a visual analog scale; TL, calculated overall training load.

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Table 3 Influence of Specific Training Workload on Mental-Fatigue Changes

	Est.	*P*	95% CI
Fixed-effect coefficients			
Intercept	−8.18	.001	−13.15 to −3.21
PHY	0.12	<.001	0.06 to 0.20
TEC	0.08	.136	−0.02 to 0.18
TAC	0.26	<.001	0.16 to 0.36
PSY	0.10	.057	−0.003 to 0.20
ENV	−0.13	.022	−0.25 to −0.02
Random-effect covariance parameters			
ID	7.61		5.40 to 10.72
Date	2.22		0.87 to 5.66
Residuals	14.59		13.60 to 15.65

Abbreviations: Date, collecting day in numerical order; ENV, environmental workload; Est., estimate; ID, participants' identifier code; PHY, physical workload; PSY, psychological workload; TAC, tactical workload; TEC, technical workload.

Discussion

The main purpose of the longitudinal study in elite fencers was to profile MF across different training and competition phases and explore the potential relationship of training variables with MF changes. The main findings are as follows: (1) MF was elevated after all fencing training and competitions, peaking on match days and coinciding with an impaired RT. (2) On training days, the increased subjective MF was not accompanied by a change in the behavioral indicator. (3) Increasing the overall TL, particularly the TAC and PHY, elicited a higher MF increase. By contrast, increasing the contribution of ENV in routine training mitigated the elevation of MF.

The Presence of Perceived MF in Fencing Athletes

After fencing, national to world-class fencers perceived higher MF in all phases, independent of the fencing discipline in which they participated. This finding is consistent with field-based MF monitoring studies across different open-skilled sports. In these studies, athletes self-reported MF after various events, such as semiprofessional soccer training days between the weekly matches,[12] elite rugby league games,[9] national orienteering races,[17] national beach volleyball tournament matches,[16] world padel eliminatory matches,[10] and national netball league competitions.[13] Fencing is a highly technical and tactical sport with an "open-skilled" specificity[28] that imposes significant cognitive loads, without any weapon (ie, discipline) or sex-related differences.[20] Perceptual-cognitive skills are essential to executing fast, coordinated, and accurate movements during fencing combats.[29] The prolonged utilization of the mental resources and intense mental workload induces a state of MF in all fencers and first manifests as elevated subjective perceptions.[20] Athletes and coaches need to recognize the prevalence of MF and its potential impact on performance, necessitating proactive MF management in fencing practice.

The Contextual Difference in MF Between Training and Competition

The study concluded that the baseline MF fluctuated throughout the period and peaked on the match days. The contextual difference of MF between training and competition was also reflected in the varying magnitudes of daily changes observed in MVAS and RT. The present study demonstrated that day-long competitions cause the highest MF perception, with a concomitantly impaired RT. Indeed, competition is known to have higher mental demands and emotional strain than training courses or simulated fights.[19,26] In prior research in which MF is experimentally induced, the manipulation length of continuous cognitive tasks determined the inducement effectiveness.[7] Typically, an international match day lasts 9 to 11 hours,[30] whereas the unified timeframe for this national fencing base was approximately 3 hours per training day. With the highly intermittent nature of about 10% net worktime, relatively shorter exposure of fencing-specific combats in training context may have mitigated the amplitude of acute elevation in MF.

MF could also accumulate between matches throughout the match day.[10] By simulating the 5-bout direct elimination stage of an international fencing competition, Varesco et al[20] found that perceived fatigue, which had a strong cognitive component and thus was referred to as cognitive fatigue, increased by 12% for each successive bout.[20] It is reasonable to assume that in the real-world championship with higher competition demands,[26] a fencer's MF accumulated continuously along the rounds to a higher magnitude, consequently impairing reaction speed.[10,21] The contextual difference in MF suggests that more attention should be given to cognitive components in training environments. Interventions such as brain endurance training[31] and ecological match scenarios[32] can be implemented during fencing practice.

The Inconsistency of Subjective and Behavioral MF Indicators

The inconsistent indicator changes were only observed on training days. Specifically, daily MF perceptions elevated after training whereas RT remained unchanged. MF can manifest subjectively, behaviorally, and physiologically, but changes in these indicators may not always align.[7] Diaz-Garcia et al[10] utilized PVT-B after the actual matches to indicate the synchronous increase of subjective MF with RT in mentally fatigued padel players.[10] The finding is consistent with the current research on fencers after competitions.

By contrast, in our study, the behavioral indicator remained unchanged in all training phases. Multiple explanations and theoretical reasoning may justify this observation. First, the compensatory effect may exist (eg, as a result of high motivation[33]) in prechampionship preparation to alleviate the decline of reaction performance caused by MF. Second, the increased postchampionship baseline RT might have already masked the impairment after the fencing training, resulting in the unchanged reaction performance. Without the competition demands, lower motivation has been reported in national-level orienteering athletes.[17] It is plausible that these fencers experienced decreased motivation after the final station of this year's championship, leading them to become more distracted and less engaged with the daily behavioral measurements.[33] In elite individual sports for which the standardization of training and competition is challenging, maintaining athletes' active engagement in fatigue monitoring requires linked feedback to their individualized performance goals and recovery strategies. Field-based longitudinal research should prioritize sensitive assessment tools, combining baseline subjective perceptions with practical behavioral measures for multidimensional MF tracking.

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The Influence of Specific Training Demands on Daily MF Changes

The current study innovatively quantified the individualized training activities by collecting self-reported contributions of 5 general workloads to explore the relationship between these workloads and daily changes in MF. We observed that increasing the overall TL elicited a subsequent greater MF elevation. Findings further indicated a positive relationship between tactical/physical demands, a negative moderating effect of environmental demand, and no effect of technical and psychological demands, with the higher level of MF increase after training. Costa et al[16] found that 47% of the variation in subjective MF after a beach volleyball match was explained by the technical–tactical effort value.[16] The present study also identified a significant variation in the daily MF perception that could be attributed to the TAC, whereas the TEC was at a nonsignificant level. The PSY from stress appraisal, coping, and emotion on fencing training days was considered to be an independent perception in the present model. This is consistent with Russell et al[14] in that the MF of netballers across seasons was a different construct from other concurrently assessed psychological indicators such as stress and mood. Interestingly, the present study also revealed that the appropriate perception of environmental demand, distinct from the fencing training routine itself, can help mitigate the increase of MF on training days. Therefore, it is important to modulate TL and structures, with the strategic focus among tactical, physical, and environmental demands, for active MF management. It is also worth exploring which concurrent activities could best aid in the alleviation of MF.

Limitations

Due to the heterogeneity of daily activities, this study excluded nonfencing weekends and off days during daytime monitoring. However, the influence of intervals and nighttime activities may have masked other contributors to MF beyond fencing practice, as well as the potential persistence of MF. Future research should include continuous, whole-day monitoring across various real-life scenarios. Although diverse training variables have been explored in the national to world-class fencers across all disciplines, significant individual differences persist. This highlights the need for further investigation into more individual factors and performance metrics associated with MF changes among varying athletic levels of fencers.

Practical Implications

- Athletes and coaches should recognize the prevalence of MF in fencing activities and its subsequent impact on reaction performance, particularly in-season competitions.
- The effects of specific training variables support daily active MF management through modulating TL and structures, with the strategic focus among TAC, PHY, and ENV demands.
- Field-based MF monitoring suggests combining daily subjective perceptions with practical, individualized behavioral indicators for an optimal assessment in elite athletes.

Conclusion

The study highlights the prevalence of mental fatigue (MF) after fencing activities and its fluctuation over a 4-week national championship period. There was a peak during competitions, and a subsequent impact on reaction performance on match days was observed. The association with specific training structures provides insights for coaches and athletes to actively manage MF and optimize performance throughout a season. Field-based MF monitoring in elite athletes suggests the integration of daily subjective perception and practical, individualized behavioral assessments.

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References

1. Halson SL. Monitoring training load to understand fatigue in athletes. *Sports Med*. 2014;44:139–147. doi:10.1007/s40279-014-0253-z
2. Kellmann M, Bertollo M, Bosquet L, et al. Recovery and performance in sport: consensus statement. *Int J Sports Physiol Perform*. 2018; 13(2):240–245. PubMed ID: 29345524 doi:10.1123/ijspp.2017-0759
3. Meeusen R, Van Cutsem J, Roelands B. Endurance exercise-induced and mental fatigue and the brain. *Exp Physiol*. 2021;106(12):2294–2298. PubMed ID: 32176398 doi:10.1113/EP088186
4. Russell S, Johnston RD, Stanimirovic R, Halson SL. Global practitioner assessment and management of mental fatigue and mental recovery in high-performance sport: a need for evidence-based best-practice guidelines. *Scand J Med Sci Sports*. 2024;34(1):e14491. doi: 10.1111/sms.14491
5. Habay J, Van Cutsem J, Verschueren J, et al. Mental fatigue and sport-specific psychomotor performance: a systematic review. *Sports Med*. 2021;51(7):1527–1548. PubMed ID: 33710524 doi:10.1007/s40279-021-01429-6
6. Russell S, Jenkins D, Rynne S, Halson S, Kelly V. What is mental fatigue in elite sport? Perceptions from athletes and staff. *Eur J Sport Sci*. 2019;19(10):1367–1376. PubMed ID: 31081474 doi:10.1080/17461391.2019.1618397
7. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. *Sports Med*. 2017;47(8):1569–1588. PubMed ID: 28044281 doi:10.1007/s40279-016-0672-0
8. Smith M, Coutts A, Merlini M, et al. Mental fatigue impairs soccer-specific physical and technical performance. *Med Sci Sports Exerc*. 2016;48(2):267–276. PubMed ID: 26312616 doi:10.1249/MSS.0000000000000762
9. Mariano Y, Martin K, Mara J. Mental fatigue and technical performance in elite rugby league. *J Sports Sci*. 2023;41(6):584–595. PubMed ID: 37384834 doi:10.1080/02640414.2023.2228138
10. Diaz-Garcia J, Gonzalez-Ponce I, Lopez-Gajardo M, et al. How mentally fatiguing are consecutive world padel tour matches? *Int J Environ Res Public Health*. 2021;18(17):9059. doi:10.3390/ijerph18179059
11. Abbott W, Brownlee TE, Naughton RJ, Clifford T, Page R, Harper LD. Changes in perceptions of mental fatigue during a season in professional under-23 English Premier League soccer players. *Res Sports Med*. 2020;28(4):529–539. PubMed ID: 32602742 doi:10.1080/15438627.2020.1784176

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12. Díaz-García J, Filipas L, La Torre A, Gómez-Rivera J, Rubio-Morales A, García-Calvo T. Mental fatigue changes from regular season to play-offs in semiprofessional soccer: a comparison by training days. *Scand J Med Sci Sports*. 2023;33(5):712–724. PubMed ID: 36601789 doi:10.1111/sms.14301
13. Russell S, Jenkins D, Halson S, Kelly V. Changes in subjective mental and physical fatigue during netball games in elite development athletes. *J Sci Med Sport*. 2020;23(6):615–620. PubMed ID: 31883778 doi:10.1016/j.jsams.2019.12.017
14. Russell S, Jenkins DG, Halson SL, Juliff LE, Connick MJ, Kelly VG. Mental fatigue over 2 elite netball seasons: a case for mental fatigue to be included in athlete self-report measures. *Int J Sports Physiol Perform*. 2022;17(2):160–169. PubMed ID: 34583327 doi:10.1123/ijspp.2021-0028
15. Russell S, Jenkins DG, Halson SL, Kelly VG. Mental fatigue increases across a 16-week pre-season in elite female athletes. *J Sci Med Sport*. 2022;25(4):356–361. PubMed ID: 35027320 doi:10.1016/j.jsams.2021.12.002
16. Costa Y, Fortes L, Santos R, et al. Mental fatigue measured in real-world sport settings: a case study of world class beach volleyball players. *J Phy Educ Sport*. 2023;23:1237–1243. doi:10.7752/jpes.2023.05152
17. Lam HKN, Sproule J, Turner AP, Phillips SM. The impact of sprint, middle-distance, and long-distance orienteering races on perceived mental fatigue in national level orienteers. *J Sports Sci*. 2023;41(15):1423–1436. PubMed ID: 37885048 doi:10.1080/02640414.2023.2273097
18. Coyne JOC, Coutts AJ, Newton RU, Haff GG. The influence of mental fatigue on sessional ratings of perceived exertion in elite open and closed skill sports athletes. *J Strength Cond Res*. 2021;35(4):963–969. PubMed ID: 33752221 doi:10.1519/JSC.0000000000003980
19. Roi GS, Bianchedi D. The science of fencing: implications for performance and injury prevention. *Sports Med*. 2008;38(6):465–481. PubMed ID: 18489194 doi:10.2165/00007256-200838060-00003
20. Varesco G, Pageaux B, Cattagni T, et al. Fatigue in elite fencing: effects of a simulated competition. *Scand J Med Sci Sports*. 2023;33(11):2250–2260. PubMed ID: 37574844 doi:10.1111/sms.14466
21. Varesco G, Sarcher A, Doron J, Jubeau M. Striking a balance: exploring attention, attack accuracy and speed in fencing performance. *Eur J Sport Sci*. 2024;24(9):1278–1286. PubMed ID: 39073230 doi:10.1002/ejsc.12176
22. McKay A, Stellingwerff T, Smith E, et al. Defining training and performance caliber: a participant classification framework. *Int J Sports Physiol Perform*. 2021;17:317–331. doi:10.1123/ijspp.2021-0451
23. Thompson C, Noon M, Towlson C, et al. Understanding the presence of mental fatigue in English academy soccer players. *J Sports Sci*. 2020;38(13):1524–1530. PubMed ID: 32212903 doi:10.1080/02640414.2020.1746597
24. Basner M, Mollicone D, Dinges DF. Validity and sensitivity of a brief Psychomotor Vigilance Test (PVT-B) to total and partial sleep deprivation. *Acta Astronaut*. 2011;69(11–12):949–959. PubMed ID: 22025811 doi:10.1016/j.actaastro.2011.07.015
25. Turner AN, Buttigieg C, Marshall G, Noto A, Phillips J, Kilduff L. Ecological validity of the session rating of perceived exertion for quantifying internal training load in fencing. *Int J Sports Physiol Perform*. 2017;12(1):124–128. PubMed ID: 27140957 doi:10.1123/ijspp.2016-0062
26. Doron J, Martinent G. Dealing with elite sport competition demands: an exploration of the dynamic relationships between stress appraisal, coping, emotion, and performance during fencing matches. *Cogn Emot*. 2021;35(7):1365–1381. PubMed ID: 34323175 doi:10.1080/02699931.2021.1960800
27. Habay J, Uylenbroeck R, Van Droogenbroeck R, et al. Interindividual variability in mental fatigue-related impairments in endurance performance: a systematic review and multiple meta-regression. *Sports Med Open*. 2023;9:14. doi:10.1186/s40798-023-00559-7
28. Sorel A, Plantard P, Bideau N, Pontonnier C. Studying fencing lunge accuracy and response time in uncertain conditions with an innovative simulator. *PLoS One*. 2019;14(7):e0218959. doi:10.1371/journal.pone.0218959
29. Russo G, Ottoboni G. The perceptual–cognitive skills of combat sports athletes: a systematic review. *Psychol Sport Exerc*. 2019;44:60–78. doi:10.1016/j.psychsport.2019.05.004
30. Tarragó R, Bottoms L, Iglesias X. Temporal demands of elite fencing. *PLoS One*. 2023;18(6):e0285033. doi:10.1371/journal.pone.0285033
31. Roelands B, Bogataj Š. Optimizing athletic performance through brain endurance training. *Int J Sports Physiol Perform*. 2024;19(10):973–974. PubMed ID: 39209294 doi:10.1123/ijspp.2024-0278
32. Bian C, Ali A, Nassis G, et al. Repeated interval loughborough soccer passing tests: an ecologically valid motor task to induce mental fatigue in soccer. *Frontiers Physiol*. 2022;12:803528. doi:10.3389/fphys.2021.803528
33. Herlambang MB, Taatgen NA, Cnossen F. The role of motivation as a factor in mental fatigue. *Hum Factors*. 2019;61(7):1171–1185. PubMed ID: 30817228 doi:10.1177/0018720819828569

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