Mental Fatigue in Sport—From Impaired Performance to Increased Injury Risk

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The literature describing the effects of mental fatigue (MF) has grown tremendously. This is accompanied by identification of a host of performance-determining parameters affected by MF. MF results from prolonged cognitive effort and predominantly affects physical, technical, tactical, and perceptual–cognitive dimensions of sport, while physiological parameters (eg, heart rate, lactate) and physical aspects of maximal and supramaximal efforts are predominantly unaffected. The aim of this paper was to provide an overview of the parameters described in the literature as influenced by MF. By identifying the different parameters, we not only see how they affect the performance of athletes but also raise concerns about the potentially increased injury risk due to MF. Preliminary evidence suggests that subsequent disturbances in balance, motor skills, and decision-making processes could potentially increase the vulnerability to injury. An abundance of lab-based studies looked into the effects of MF on performance; however, many questions remain about the mechanisms of origin and neurophysiological causes of MF, and only small steps have been taken to translate this knowledge into practice. Thus, there is a need for more research into the underlying mechanisms of MF and the role of the brain, as well as more applied research with a high ecological validity that also takes into account the potential increased risk of injury due to MF.

**Keywords:** cognitive fatigue, performance-determining parameters, injury susceptibility

Mental fatigue (MF) has gained significant attention in the scientific literature in recent years, resulting in new insights and updates to existing perspectives in this domain. This calls for an overview of the current state of the art and prompts considerations for future directions in both fundamental and applied research.

MF manifests as a result of sustained and demanding cognitive activities.1–3 A prolonged Stroop task is most often used in scientific studies to induce MF,4,8 while in everyday activities, prolonged exposure to screens9,10 (eg, use of smartphone apps or playing videogames), as well as endurance exercises at low intensity over an extended duration (eg, cycling), especially combined with an additional cognitive load9,11 have been identified as important causes of MF. Additionally, in the daily lives of elite athletes, media engagements, study and work commitments, as well as competition or tournaments and high internal training load are reported as triggers of MF.12–14 Within sports science, this psychobiological state of fatigue has become a focal point due to its impact on physical performance. A fundamental exploration of the influence of MF on physical abilities was presented in the systematic review by Van Cutsem et al.3 This review, dating back to 2017, has since inspired ongoing research, helping us better understand how MF affects performance in sports. In turn, this has led to several new review papers on different aspects of sports performance and the identification of a whole realm of physiological and other parameters affected by MF. Yet, in this expanding field of research, one vital aspect remains relatively unexplored: the potential link between MF and injury risk in sports. Injuries are common in the sporting population and constitute a real burden both in the short and long term, even potentially resulting in permanent disability.15 Given the significant impact of MF on multiple sports parameters, the question arises whether the effects of MF extend to an increased risk of injuries.

The goal of this paper is to build upon the established knowledge, on the one hand by offering an updated overview of performance-related parameters affected by MF and on the other hand by identifying future pathways for scientific research and practical applications by shedding light on the possible relationship between MF and sports injuries.

**MF in Sport, From 2017 to Present**

The much-cited review by Van Cutsem et al.3 has set in motion a discussion on the impact of MF on physical performance. While some studies fail to offer conclusive support for this claim,16–18 most recent studies are consistent with the perspective that MF has profound negative effects on physical performance.10,13,19–22 However, these studies further emphasize the importance of recognizing significant variations among different types of activities.23 Given the numerous studies on the impact of MF on various performance-related parameters, the complexity of the impact of MF becomes apparent.3,10,17,20–22,24,25 Recognizing this complexity, there is need for an overview of the parameters proven to be influenced by this phenomenon. A literature search, focusing on all systematic reviews that were conducted on this topic,3,10,17,20–22,24,25 yielded 106 articles describing the influence of MF on one or more performance-related parameters. An overview of the parameters shown to be affected by MF can be found in Table 1.

We identified 4 categories of interest in parameters influenced by MF: physical performance, technical and tactical performance, physiological parameters, and perceptual–cognitive parameters. Within the category of physical performance, MF seems to negatively impact endurance performance, with time to exhaustion,26–57...
Table 1  Overview of the Performance Parameters Shown to Be Influenced by MF in Current Research, Showing the Proportion of Studies Investigating Each Parameter (%), and the Reported Effects of MF

<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>% Effect of MF</th>
<th>Reference numbers</th>
<th>Parameter</th>
<th>% Effect of MF</th>
<th>Reference numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical performance</strong></td>
<td>Time to failure</td>
<td>~37% Negative effect (↑): ~78% No effect: ~22%</td>
<td>26–57 33, 30, 117–123</td>
<td>Jump height</td>
<td>~4% No effect: ~100%</td>
<td>62, 86, 90, 124</td>
</tr>
<tr>
<td></td>
<td>Completion time</td>
<td>~17% Negative effect (↓): ~56% No effect: ~44%</td>
<td>9, 61, 66, 68–74 4, 64, 86, 113, 125–128</td>
<td>Total work</td>
<td>~3% Negative effect (↑): ~67% No effect: ~33%</td>
<td>129, 130 60</td>
</tr>
<tr>
<td></td>
<td>Distance covered</td>
<td>~14% Negative effect (↓): ~69% No effect: ~25% Positive effect (↑): ~6%</td>
<td>5, 58–67 6, 59, 90, 92 131</td>
<td>Peak torque</td>
<td>~3% No effect: ~100%</td>
<td>47, 89, 124</td>
</tr>
<tr>
<td></td>
<td>Speed</td>
<td>~10% Negative effect (↓): ~50% No effect: ~50%</td>
<td>59, 60, 62, 69, 70, 78 4, 41, 58, 59, 63, 85</td>
<td>Critical power</td>
<td>~2% No effect: ~100%</td>
<td>48, 124</td>
</tr>
<tr>
<td></td>
<td>Power output</td>
<td>~9% Negative effect (↓): ~55% No effect: ~45%</td>
<td>55, 59, 71, 74, 132, 133 59, 73, 134–136</td>
<td>Physical performance index</td>
<td>&lt;1% No effect: ~100%</td>
<td>137</td>
</tr>
<tr>
<td></td>
<td>Peak force</td>
<td>~6% Negative effect (↓): ~17% No effect: ~83%</td>
<td>138 7, 30, 47, 89, 124</td>
<td>Revolutions per minute</td>
<td>&lt;1% Negative effect (↑): ~100%</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td>Replots</td>
<td>~4% Negative effect (↓): ~50% No effect: ~50%</td>
<td>140, 141 137, 142</td>
<td>Time on task</td>
<td>&lt;1% Negative effect (↑): ~100%</td>
<td>142</td>
</tr>
<tr>
<td><strong>Technical performance</strong></td>
<td>Motor accuracy</td>
<td>~13% Negative effect (↓): ~67% No effect: ~33%</td>
<td>4, 6, 7, 75–81 81, 83, 92, 103, 143</td>
<td>Involvement in the game</td>
<td>~2% Negative effect (↑): ~50%</td>
<td>6 6</td>
</tr>
<tr>
<td></td>
<td>Reaction time</td>
<td>~7% Negative effect (↑): ~43% No effect: ~57%</td>
<td>77, 82, 83 5, 63, 76, 103</td>
<td>Movement duration</td>
<td>~2% Negative effect (↑): ~100%</td>
<td>144, 145</td>
</tr>
<tr>
<td></td>
<td>Points</td>
<td>~5% Negative effect (↓): ~67% No effect: ~33%</td>
<td>5, 7, 61, 64 63, 64</td>
<td>Sprint start accuracy</td>
<td>~2% Negative effect (↓): ~50% No effect: ~50%</td>
<td>146 82</td>
</tr>
<tr>
<td></td>
<td>Passing</td>
<td>~5% Negative effect (↓): ~43% No effect: ~43% Positive effect (↑): ~14%</td>
<td>4, 5, 63 5, 63, 78 6</td>
<td>Interceptions</td>
<td>&lt;1% Negative effect (↑): ~100%</td>
<td>91</td>
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<tr>
<td></td>
<td>Errors</td>
<td>~4% Negative effect (↑): ~100%</td>
<td>4, 7, 73, 103</td>
<td>Turnovers</td>
<td>&lt;1% Negative effect (↑): ~100%</td>
<td>87</td>
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<tr>
<td></td>
<td>Tackling</td>
<td>~4% Negative effect (↓): ~40% No effect: ~60%</td>
<td>6, 91 6, 78, 92</td>
<td>Ball lost</td>
<td>&lt;1% Negative effect (↑): ~50% No effect: ~50%</td>
<td>81 81</td>
</tr>
<tr>
<td></td>
<td>Ball possessions</td>
<td>~3% Negative effect (↓): ~33% No effect: ~67%</td>
<td>6 6, 78</td>
<td>Dribbling</td>
<td>&lt;1% Negative effect (↑): ~50% No effect: ~50%</td>
<td>78 78</td>
</tr>
<tr>
<td></td>
<td>Control errors</td>
<td>~3% Positive effect (↑): ~33% No effect: ~67%</td>
<td>6 78, 92</td>
<td>Ball control</td>
<td>&lt;1% No effect: ~100%</td>
<td>85</td>
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<tr>
<td></td>
<td>Decision-making index</td>
<td>~3% Negative effect (↓): ~100%</td>
<td>88, 101, 102</td>
<td>Players efficiency</td>
<td>&lt;1% No effect: ~100%</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Ball speed</td>
<td>~2% Negative effect (↓): ~100%</td>
<td>5, 7</td>
<td>Shooting</td>
<td>&lt;1% No effect: ~100%</td>
<td>78</td>
</tr>
</tbody>
</table>

(continued)
<table>
<thead>
<tr>
<th>Category</th>
<th>Parameter</th>
<th>% Effect of MF</th>
<th>Reference numbers</th>
<th>Parameter</th>
<th>% Effect of MF</th>
<th>Reference numbers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological</td>
<td>Heart rate</td>
<td>~11% ↓: ~33% No effect: ~50% ↑: ~17%</td>
<td>4, 6, 132, 139 5, 60, 73, 85–87 41, 81</td>
<td>Blood glucose</td>
<td>~2% No effect: ~100%</td>
<td>60, 83</td>
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<td>Lactate</td>
<td>~5% No effect: ~80% Negative effect (↑): ~20%</td>
<td>60, 73, 86, 88 41</td>
<td>Oxygen consumption</td>
<td>&lt;1% No effect: ~100%</td>
<td>136</td>
</tr>
<tr>
<td></td>
<td>Oxygen volume</td>
<td>~4% Negative effect (↓): ~75% No effect: ~25%</td>
<td>60, 133, 147 55</td>
<td>Tidal volume</td>
<td>&lt;1% No effect: ~100%</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>EMG activity</td>
<td>~2% Negative effect (↓): ~50% No effect: ~50%</td>
<td>138 47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceptual-</td>
<td>RPE</td>
<td>~27% Negative effect (↑): ~59%</td>
<td>5–7, 28, 41, 47, 48, 59–62, 69–71, 81, 89, 90</td>
<td>Motivation</td>
<td>~11% Negative effect (↓): ~8%</td>
<td>91</td>
</tr>
<tr>
<td>cognitive</td>
<td></td>
<td>No effect: ~41%</td>
<td>46, 68, 73, 78, 86–88, 92, 101, 102, 128, 135</td>
<td>No effect: ~92%</td>
<td></td>
<td>4–6, 60, 61, 63, 64, 78, 83, 86, 91, 92</td>
</tr>
<tr>
<td>parameters</td>
<td></td>
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Abbreviations: EMG, electromyography; MF, mental fatigue; RPE, rating of perceived exertion.
distance, completion time being the main focus of MF research, while maximal strength, power, and anaerobic work remain largely unaffected. In the category of technical and tactical performance, accuracy and response time are the most studied. The majority of the included studies show a significant deterioration of accuracy while the effect of MF on response time is more diverse with 43% of the studies reporting a significant negative effect. Regarding the physiological parameters, most of the included articles indicate no clear effect of MF on peripheral metabolic and cardiorespiratory parameters, such as heart rate and blood lactate. Finally, MF research has paid much attention to rating of perceived exertion (RPE) and recently also to motivation. According to the majority of studies, MF has a significant negative effect on RPE, with the decline in endurance performance, resulting from MF, being primarily linked to this elevated perception of effort. Meanwhile, motivation remains largely unaffected under MF, as reported in over 90% of the articles that included a measure of motivation. However, it is important to note that the measures of motivation used in previous studies may be inadequate for analyzing motivation immediately prior to, during, and after MF and physical exercise. Motivation is a complex psychological construct influenced by various factors, including individual differences, task demands, and context characteristics. Traditional self-reported measures of motivation may not capture the dynamic motivational states experienced during periods of MF and exercise. More recently, it has been suggested that pupil diameter could serve as a more objective indicator of behavioral motivation in MF research. Future MF research should consider implementing such measures.

Looking at the wide array of identified performance parameters affected by MF, it is clear that the impact extends across several physical and psychological domains. This underscores the need to explore the implications of MF beyond performance outcomes and consider how these compromised parameters might also elevate the risk of injuries.

**MF and Sport Injuries**

Injuries pose a significant concern in sports, with injury prevention research receiving considerable attention in sports science nowadays. Given the profound negative impact of MF on physical performance, there are concerns regarding whether the effects of MF extend to an increased risk of injuries.

First, MF has been reported to impair balance control and a significant relationship between the level of MF and the degree of balance disturbance has been identified. This impaired balance originates from compromised attentional processing due to MF, but also smaller recovery step length and larger trunk flexion following MF have been identified as possible causes for this balance disturbance. Additionally, delayed neuromuscular activation due to MF could explain the impaired balance control as electromyography onset times are longer in mentally fatigued individuals compared with controls. The compromised balance as a result of MF leads to an elevated risk of falls, which in turn increases the likelihood of sustaining injuries. Furthermore, slower and less accurate execution of sport-specific exercises, due to MF, could lead to dangerous game situations. In soccer, higher error rates and less successful tackles have been observed under conditions of MF. In addition, studies have documented reduced accuracy, increased response time, and poorer decision making as a result of MF. These findings raise the question whether such compromised performance metrics, including unsuccessful tackles and more errors attributed to heightened response times, impaired anticipation, and suboptimal decision making, could elevate the susceptibility to collisions during gameplay, potentially leading to injuries. In addition, MF has been proven to impair perceptual-cognitive performance as well as the ability to use environmental information and player’s positioning. This in combination with impaired decision making under MF may manifest in athletes making suboptimal strategic choices during critical game moments, potentially exposing themselves to higher injury probabilities. Finally, the elevated RPE experienced during MF contributes to an increased internal training load, as this is the combination of RPE and activity duration. In turn, this elevated internal training load amplifies the risk of injury.

Despite the absence of research on the direct link between MF and injury risk, the observed negative impact of MF on the aforementioned parameters suggests a potential scenario in which individuals are more prone to accidents and injuries during sports activities. This underscores the importance of advancing MF research to the next stage, where the focus is on elucidating the link between MF and injury risk.

**A Way Forward**

The evolution in MF research since the 2017 systematic review by Van Cutsem et al raises new inquiries. Specifically, it raises the question whether the observed negative effects of MF on various performance parameters may contribute to an elevated risk of injuries. For example, impaired balance, compromised response time, accuracy, and decision making potentially increase the risk of falls and collisions in sports. Despite these recognized consequences of MF, a systematic examination of the role of MF in the occurrence of injuries remains absent from the literature. Considering that falls and collisions are identified as the most important causes of sports injuries in adolescents, this raises the need for research on the direct link between MF and injury risk in sports. Future research should focus on prospective studies investigating the relationship between individuals’ reported levels of MF and the occurrence of sports-related injuries over time. Additionally, randomized controlled trials investigating the effects of mental training in addition to regular sports training on injury occurrence among physically active individuals, as well as randomized controlled trials comparing injury rates between individuals who are engaging in mentally fatiguing activities (e.g., smartphone use) before sports, versus a control group, are important to identify potential injury prevention strategies.

Despite these advancements in MF research, there is still a significant gap between research findings and their application in practical settings. In most articles, MF is induced by a computerized cognitive task (e.g., Stroop, AX-Continuous Performance Task). This is a convenient and validated way to induce MF, but it is far removed from everyday life and does not allow us to directly translate the results into practice. Recently, sport-specific tests have been identified that are capable of inducing a similar level of MF as the Stroop task, but with a much higher ecological validity. For example, tasks such as imagery training sessions, a version of the Repeated Interval Loughborough Soccer Passing task, and prolonged tactical instructions have been demonstrated to effectively induce MF in athletes, offering alternatives to the Stroop task. Additionally, MF is clearly and variously experienced in sports context as athletes and staff do express the belief...
that MF has a negative impact on sports performance.\textsuperscript{12} This indicates an urgent need for more applied research to come up with countermeasures and preventive strategies that can be implemented in practice.

At the same time, fundamental research remains equally important since the underlying mechanisms of MF are still unknown. Fundamental studies have explored potential explanations for this phenomenon by using several techniques (such as brain encephalography and functional magnetic resonance imaging) to assess the role of the brain in the onset of MF. Van Cutsem et al\textsuperscript{3} used functional magnetic resonance imaging and reported an increased level of MF that was associated with a decrease in response inhibition-associated brain activity.\textsuperscript{114} Wiehler et al\textsuperscript{115} suggested a neurometabolic link: prolonged cognitive work results in glutamate accumulation in the brain, particularly in the lateral prefrontal cortex.\textsuperscript{115} This accumulation disrupts synaptic transmission and impairs cognitive processes, which could be a potential mechanism of MF. Further research into the neurophysiological mechanisms at play during MF episodes and, for example, brain neurotransmission is necessary to uncover the underlying mechanisms of this complex phenomenon.\textsuperscript{116}

**Conclusion**

Research on mental fatigue (MF) in sport has grown tremendously, which has led to identification of 43 performance-related parameters that are influenced by MF. These can be classified into 4 categories of interest: physical performance, technical and tactical performance, physiological parameters, and perceptual–cognitive parameters. The impact of MF mainly manifests itself in an impaired endurance capacity, mainly due to an increased rating of perceived exertion, while physiological parameters (eg, heart rate, lactate) and maximal and supramaximal efforts are predominantly unaffected by MF. Although our understanding of the effects of MF on sport performance has improved significantly, a critical gap remains in our understanding of the potential contribution of MF to injury risk. While research on the direct link between MF and injuries is lacking, impaired balance, compromised response time, and suboptimal decision making are identified as possible mechanisms by which MF might increase the risk of injuries. Future research should focus on unraveling this relationship between MF and sport injuries. Additionally, focus should be on translation of these findings into everyday practice to develop prevention strategies targeting both the decline in physical performance and the potential increased risk of injury due to MF. Finally, fundamental research to further explore the neurophysiological mechanisms underlying MF remains equally important to fully understand this complex phenomenon.

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**References**


**References**


Mental Fatigue in Sport Performance and Injury Prevention


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