Load and fatigue monitoring in musicians using an online app: A pilot study

J. Matt McCrary[1,2]*, Sara Ascenso[3], Paola Savvidou[4], Séverine Schraft[5], Lesley McAllister[6], Emma Redding[7], Serap Bastepe-Gray[8] and Eckart Altenmüller[1]

[1]Institute of Music Physiology and Musicians' Medicine, Hanover University of Music, Drama and Media, Hanover, Germany, [2]Prince of Wales Clinical School, University of New South Wales, Sydney, NSW, Australia, [3]Royal Northern College of Music, Manchester, United Kingdom, [4]School of Music, Theatre and Dance, University of Michigan, Ann Arbor, MI, United States, [5]University of Music and Theatre Leipzig, Leipzig, Germany, [6]School of Music, Baylor University, Waco, TX, United States, [7]Faculty of Fine Arts and Music, University of Melbourne, Melbourne, VIC, Australia, [8]Peabody Institute of Johns Hopkins University, Baltimore, MD, United States

Background/aims: High occupational injury rates are reported in musicians, with a career prevalence of up to 89%. Fatigue and playing (over)load are identified as key risk factors for musicians' injuries. Self-report fatigue management strategies in sport have demonstrated preventive effects. A self-report fatigue management tool for musicians was developed based on a Delphi survey of international experts and hosted in an online app. The aims of this study are to evaluate the content validity and uptake of this new tool, and explore associations between collected performance quality, physical/psychological stress, pain, injury and fatigue data.

Methods: University and professional musicians were asked to provide entries into the online app twice per week for 1–6 months. Entries into the app were designed to take 2–3 min to complete and consisted of the following: 6 questions regarding playing load over the previous 72 h; 5 questions regarding current levels in key physical/psychological stress domains (sleep, recovery, overplaying, pain, fitness); one question self-rating of performance quality over the previous day; one question regarding current musculoskeletal symptoms; a reaction time task to evaluate psychomotor fatigue.

Results: $N = 96$ participants provided an average of 2 app entries (range 0–43). Increased playing time, rating of perceived exertion (RPE), and feelings of having to "play too much" were consistently associated with increased self-rated performance quality ($p \leq 0.004$; $6.7 <| t |< 2148.5$). Increased ratings of feeling fit and recovering well were consistently associated with reduced pain severity ($p < 0.001$; $3.8 <| t |< 20.4$). Pain severity was increased (6.5/10 vs. 2.5/10; $p < 0.001$) in participants reporting playing-related musculoskeletal disorders (PRMDs; symptoms affecting playing).

Conclusion: The prospective value of regular individual self-report playing load, stress, and performance data collection in musicians is clear. However, limited uptake of the online fatigue management app piloted in this study indicates that new approaches to the collection of these data are needed to realize their potential impact.

Introduction

The extremely high occupational injury rates of musicians are well-documented, with epidemiologic studies noting a career prevalence of playing-related pain and injuries of up to 89% (Ackermann et al., 2012; Steinmetz et al., 2015; Rotter et al., 2020). A substantial portion of musicians captured in these studies also indicated the presence of frequent or permanent painful symptoms [40% (Steinmetz et al., 2015)] and an injury requiring medical leave in the previous 18 months (Ackermann et al., 2012). Fatigue and playing (over) load have been identified as key risk factors for a range of injuries in epidemiologic studies of both professional and university student musicians (Davies and Mangion, 2002; Ackermann et al., 2012). Further, a heuristic model of musicians' injuries identifies motor fatigue as a foundational sensory-motor condition which, if poorly managed, can progress to medical conditions ranging from overuse syndromes to musician's dystonia and disability (Altenmüller et al., 2015).

In sport, strategies to manage fatigue have been developed and demonstrated to have preventive benefits (Owen et al., 2015; Hulin et al., 2016; Soligard et al., 2016). These strategies predominantly utilize consistent monitoring of individual playing/training load (*load = time × intensity of playing/training*) and key indicators of physical/psychological stress to provide a basis for the distinction between normal acute fatigue processes and fatigue and overload states (Halson, 2014). From these load and stress data, modifications to training and/or game activities can be judiciously prescribed to reduce injury risk and optimize performance (Owen et al., 2015; Hulin et al., 2016).

A 2016 International Olympic Committee consensus statement outlines practical guidelines for such load and stress management strategies (Soligard et al., 2016):

1) Load must be monitored individually with a daily or weekly frequency for maximum benefit;
2) Both physiological and psychological stressors significantly impact injury risk and must be considered.

A range of monitoring techniques in sport meet the above guidelines, including evaluations of heart rate responses, power output, global positioning system data, and self-report data (Halson, 2014).

Fatigue management strategies thus provide a promising avenue for pain and injury prevention in musicians. However, the differing environments of athletes and musicians call for the adaptation and validation of fatigue management tools in musical contexts (McCrary and Altenmüller, 2020). While fatigue management programs in sport are aided by structured and/or team environments and more plentiful resources (Halson, 2014), the careers and physical demands of musicians are typically more individualized and resources more limited (Dick et al., 2013). Accordingly, self-report fatigue management tools from sport provide a particularly promising foundation for fatigue management in instrumentalists, as these tools require minimal resources and could be easily completed across a range of individual scenarios. Further, self-report tools in sport have been shown to be more sensitive to the development of fatigue states compared to objective measures (e.g., activity and heart rate monitoring) (Saw et al., 2016).

Based on a Delphi survey of international musicians' medicine experts (McCrary and Altenmüller, 2020), we developed a low-cost self-report fatigue management tool for musicians hosted in an online app. The aim of this study is to pilot this new fatigue management tool and evaluate its content validity and uptake in university/conservatoire and professional musicians. Secondary aims of this study are to explore relationships between playing-related musculoskeletal disorders (PRMDs), playing load, physical/psychological stress, and practice/performance quality to generate hypotheses for future research.

Materials and methods

Overview and participants

Study participants (*N* = 96) were university/conservatoire or full-time professional (i.e., primary income stream related to music performance) musicians who were recruited (*convenience sampling*) from February 2020 to December 2021 through emails and/or in-person presentations to university music schools and conservatoires in Germany,

FIGURE 1
Overview of study procedures.
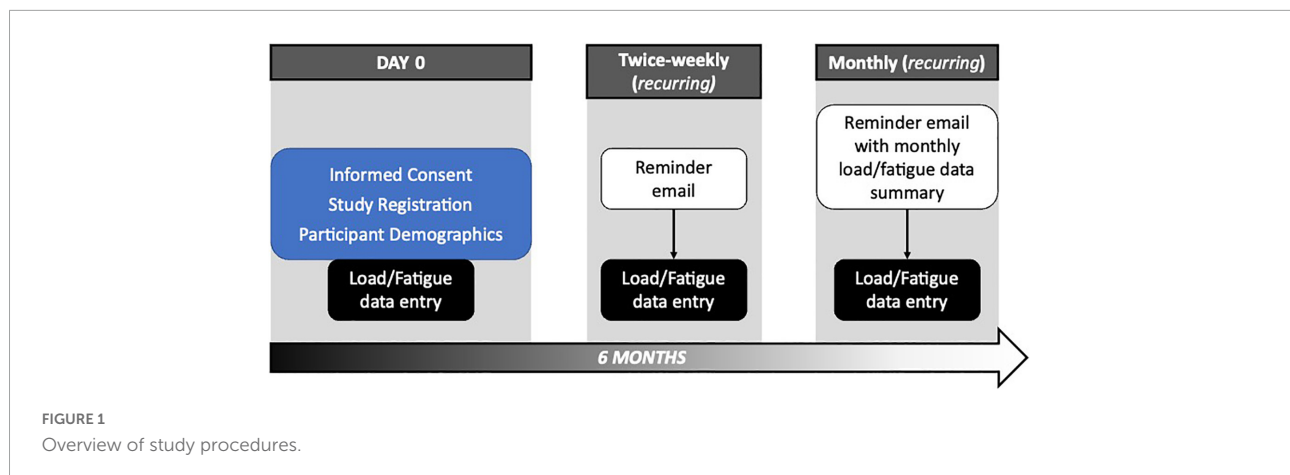
Austria, the United Kingdom, and the United States. Exclusion criteria were the presence of pain or other symptoms that interfered with playing, not being fluent in English or German, and being younger than 18 years of age. All prospective participants enrolled in the study by accessing the online app through a link provided in all recruitment documentation: musiciansfatigue.formr.org. The online app was hosted by formr, a study framework designed to host complex longitudinal studies (Arslan et al., 2020).

After being informed about study procedures and privacy policies, participants were assigned a study ID number and asked to provide basic demographic information—age; primary instrument; course of study; years playing their primary instrument; height; weight; estimated weekly hours spent playing musical instrument(s). Participants were then instructed to complete the first day's entry into the fatigue monitoring portion of the app and reminded that entries should be completed bi-weekly for a minimum of one and up to 6 months (Figure 1). Reminder emails were sent to each enrolled participant on Sunday and Wednesday of each week, although participants were able to complete entries at any time throughout the week. Sunday reminder emails also contained general information relevant to musicians' health and wellbeing, as well as monthly data reports as applicable. To maximize accessibility, the app was available in English and German language versions and equally functional when accessed from computers and mobile devices. Further, participants completing at least 8 entries (i.e., 4 weeks of bi-weekly entries) were entered into a prize drawing. This study was approved by the Leibniz University Hannover Central Ethics Committee (EV LUH 12/2019) and Conservatoires UK Ethics Committee (CUK/TL/2019/20/9).

Fatigue monitoring tool

The pilot musicians' fatigue monitoring tool was designed in consultation with 28 international musicians' medicine experts via a Delphi survey process (see McCrary and Altenmüller, 2020 for full details regarding the theoretical approach and development process). The tool is designed to capture, in brief 2–3 min data entries, fatigue-related symptoms, music performance quality, playing/practice load, psychomotor performance, and symptoms/illness interfering with playing (see Figure 2 for a screenshot of the primary user interface).

Fatigue-related symptoms

Five key indicators of fatigue-relevant physical and psychological stress identified the aforementioned Delphi survey (McCrary and Altenmüller, 2020) assessed using visual analog scales (0–10 scale): *I had pain; I did not get enough sleep; I recovered well physically; I had to play too much; I felt physically fit*. Studies in sport have indicated that self-report physical and psychological stress data are linked to and, in many cases, predictive of fatigue and related performance decrements (Saw et al., 2016; Ten Haaf et al., 2017).

Music performance quality

Music performance quality was self-assessed for the previous 24 h using a 0–10 visual analog scale in response to the question "*Please rate the overall quality of your musical performances over the past 24 h.*" Self-ratings of performance quality have been demonstrated to be significantly correlated to performance ratings by outside assessors in prior research (Ritchie and Williamon, 2012).

Playing/practice load

Playing and practice load was evaluated for each of the previous 3 days (*i.e., 0–24 h, 25–48 h, and 49–72 h prior to each entry*) using the session rating of perceived exertion (sRPE) (Borresen and Lambert, 2008). sRPE is a commonly used metric for monitoring training and playing load in sport, and is equal to the product of daily music practice/performance duration (min) and a rating of perceived exertion (RPE) representative of the overall difficulty of the entire playing day [6–20 scale (Borg, 1998)]. RPE and self-report diaries have been

FIGURE 2
Screenshot of main user interface of online app.
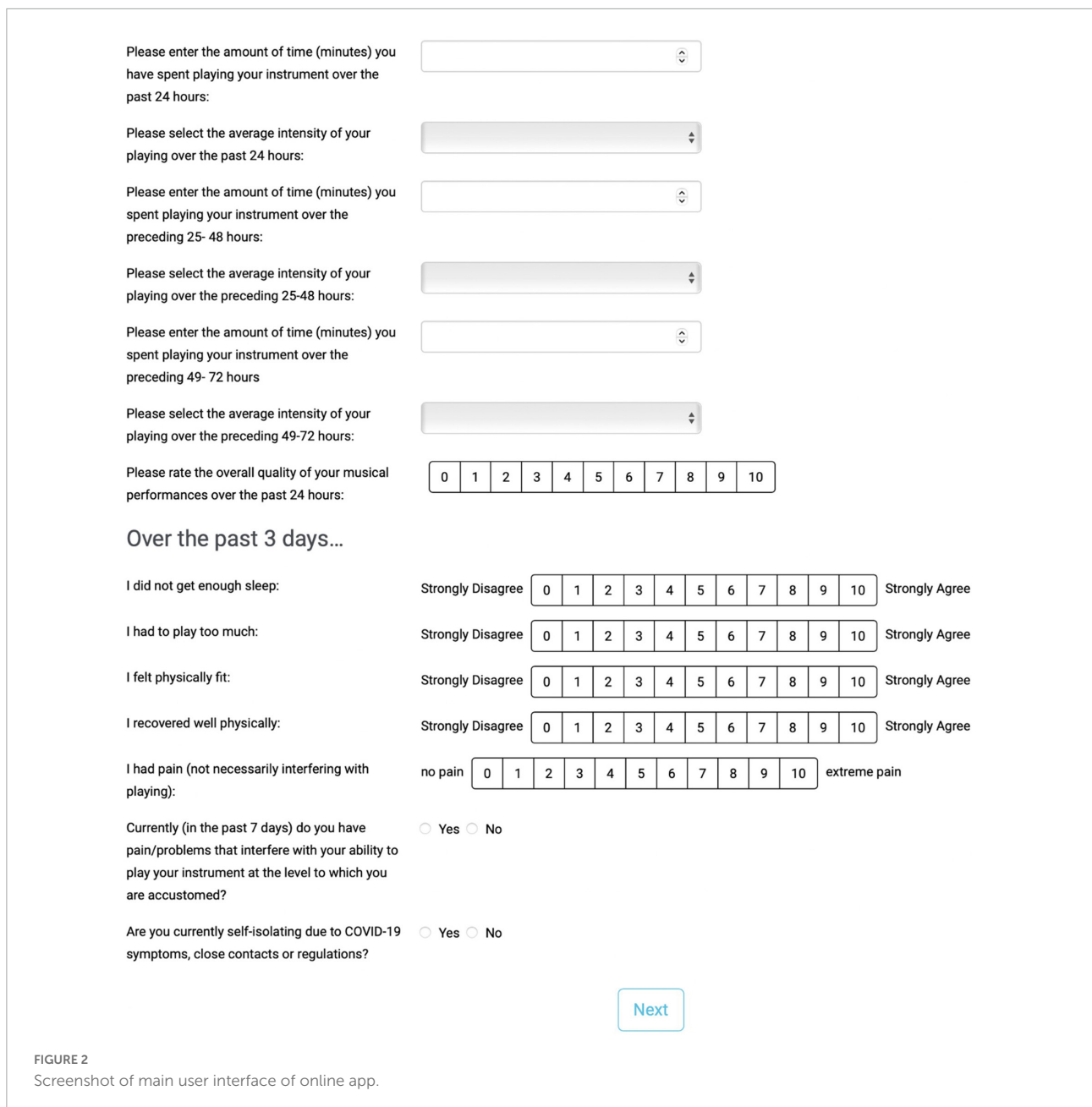
effectively used to quantify intensity and daily playing duration, respectively, in instrumentalists (Ritchie and Williamon, 2007; Ackermann et al., 2012; McCrary et al., 2016b). Further, sRPE has demonstrated retrospective recall reliability for up to 3 days in sport athletes (Christen et al., 2016).

Psychomotor performance

Psychomotor performance, assessed using complex reaction time tasks, has been demonstrated to be impaired in fatigue states in sport athletes (Rietjens et al., 2005; Dupuy et al., 2014). The fatigue monitoring tool in the present study included a complex "recognition reaction time" task. This task functioned by presenting participants with three of the first six letters of the alphabet (e.g., a, c, e) as "go" letters and instructing participants to click (computer version) or tap (mobile version) as fast as possible when "go" letters appeared, but not when "no go" letters (e.g., b, d, f) appeared. Twenty trials were completed with each entry into the online app, with the number of correct responses and average reaction time of correct responses recorded. "Go" and "no go" letters were randomly presented; the overall ratio of "go": "no go" letters across trials was 50:50, but was variable within each trial. Each trial lasted up to 1 s, with a 1 s pause between trials, for a maximum total task duration of 40 s. The reaction time task was programmed and hosted in lab.js, which

has demonstrated good validity and reliability in accurately capturing reaction time online (Henninger et al., 2022).

Symptoms interfering with playing-related musculoskeletal disorders

The incidence of pain and/or injury interfering with playing over the previous week was assessed by a single yes/no question, utilizing introductory text from the Musculoskeletal Pain Intensity and Interference Questionnaire for Musicians (MPIIQM) Zaza and Farewell (1997) definition (Berque et al., 2014): "*Playing-related musculoskeletal problems are defined as pain, weakness, numbness, tingling, or other symptoms that interfere with your ability to play your instrument at the level to which you are accustomed. This definition does not include mild transient aches and pains. Currently (in the past 7 days) do you have pain/problems that interfere with your ability to play your instrument at the level to which you are accustomed?*" (Berque et al., 2014).

COVID symptoms

To control for the potentially confounding impacts of COVID symptoms and mandatory quarantine, participants were asked to indicate if they were "currently self-isolating due to COVID-19 symptoms, close contacts, or regulations?" Entries in which participants answered "yes" were excluded from analyses.

Statistical analyses

Data for all parameters were categorized as "3-day"—i.e., single app entry—or "weekly"—i.e., average of multiple app entries by the same participant over a 9-day period. Changes in 3-day data were calculated by subtracting values from two app entries occurring within 5 days of each other. Changes in weekly data were calculated by subtracting average weekly values from 2 consecutive weeks.

Fixed-effects repeated-measures generalized mixed models were used to analyze relationships between three target parameters—self-reported performance quality, pain severity (*i.e., "I Had Pain"*) ratings, and reaction time (*i.e., as an indicator of psychomotor fatigue*)—and all other investigated parameters. Links between 3-day and weekly data ("Values") and 3-day and weekly change data ("Change") from target and all other parameters were analyzed. Additionally, potential predictive relationships between 3-day and weekly Change data and Values of the corresponding time-period were analyzed. The Satterthwaite (1946) approximation was used to account for unevenly distributed data, linear and non-linear models were used as appropriate to analyze normal and non-normally distributed target parameter data, and the Bonferroni-Holm correction was used to account for multiple comparisons (Ludbrook, 1998). Additionally, exploratory independent samples *t*-tests, with the Bonferroni-Holm correction, were used to analyze differences in parameters when a PRMD was, compared to was not, reported. All statistical analyses were performed in SPSS v.27.0 (IBM, Armonk, NY).

Study registration and ethics approval

This study was prospectively registered in the Australian New Zealand Clinical Trials Registry (ACTRN12619001108101).

Results

Participants and data entries

N = 96 participants (*N* = 86 university/conservatoire students; *N* = 10 full-time professionals) enrolled in the study, providing a total of 478 data entries (median app entries per participant = 2; maximum participant entries = 43; minimum participant entries = 0). *N* = 14 participants (*N* = 12 students; *N* = 2 professionals) provided informed consent and enrolled in the study but did not complete any valid data entries. Valid reaction time data were available for 417 data entries. Student participants were from universities in the United States (*N* = 31), Germany (*N* = 29), the United Kingdom (*N* = 22), Austria (*N* = 2), Canada (*N* = 1), and Ireland (*N* = 1). Participants

TABLE 1 Participant (*N* = 96) demographics.

Mean age (standard deviation; range)	24 (6; 18–55)
Full-time students: Full-time professionals	86: 10
Mean years music performance experience (*standard deviation; range*)	14 (*7; 4–47*)
Gender	
Male	38
Female	58
Instrument	
Keyboard	25
Upper strings	23
Woodwinds	16
Brass	8
Vocalists	8
Lower strings	5
Percussion	5
Harp	3
Accordion	2
Guitar	1

practiced and played for, on average, 480 min (*SD = 365; minimum = 0; maximum = 2,160*) over the preceding 3-day period, with an average RPE of 12 (*SD = 2; minimum = 6; maximum = 17*) (see **Table 1** for participant demographics).

Correlates of performance quality

Increased playing time, RPE, and feelings of having to "play too much" were consistently associated with increased self-rated performance quality across 3-day and weekly comparisons ($p \leq 0.004$; $6.7 <| t |< 2148.5$; **Table 2**). Further, Changes (*increases*) in RPE and feelings of having to "Play too much" over the prior 3 days and week were both associated with higher self-rated performance quality ($p \leq 0.001$; $4.3 <| t |< 10.2$; **Table 2**). Reaction time, playing load, and ratings of feeling fit, recovering well, not getting enough sleep, and pain severity were also less consistently associated with self-rated performance quality ($p < 0.01$; $2.6 <| t |< 2217.6$; **Table 2**).

Relationships with pain severity

Increased ratings of feeling fit and recovering well were consistently associated with reduced pain severity ($p < 0.001$; $3.8 <| t |< 20.4$; **Table 3**). All other investigated parameters were less consistently associated with pain severity ratings ($p < 0.001$; $3.5 <| t |< 913.4$; **Table 3**). No changes in any parameter were consistently linked to pain severity values.

Relationships with reaction time (psychomotor speed)

No parameters were consistently associated with reaction time. Further, no changes in any parameter over the previous 3 days or week were significantly associated with reaction time ($p > 0.004$; $| t | < 3.1$; **Table 4**). Playing load, playing time, RPE, and ratings of feeling fit, recovering well, pain severity, and performance quality were intermittently associated with reaction time ($p < 0.002$; $3.2 <| t |< 10.6$; **Table 4**).

Symptoms interfering with playing playing-related musculoskeletal disorders

Symptoms interfering with playing (PRMDs) were reported by 23 participants [18 students/5 professionals; Primary instruments: piano (4), violin (3), vocal (3), accordion (2), bass (2), saxophone (2), viola (2), flute (1), guitar (1), horn (1), clarinet (1), oboe (1)] across 32 of the total 478 (6.7%) data entries. Pain severity was significantly greater when symptoms

interfering with playing were reported ($| t | = 8.9$; $p < 0.001$) (**Figure 3**). Additionally, several parameters trended toward significance in PRMD vs. No PRMD comparisons: increased 3-day RPE (PRMD (*mean ± standard deviation*): 12.6 ± 2.3; No PRMD: 11.5 ± 2.3; $p = 0.02$) and feelings of playing too much ($p = 0.049$; **Figure 3**); and decreased feelings of fitness ($p = 0.03$; **Figure 3**) and recovering well ($p = 0.02$; **Figure 3**). 3-day playing time (PRMD: 473.1 ± 363.6 min; No PRMD: 577.7 ± 379.3 min), 3-day playing load (PRMD: 6168.8 ± 4997.9; No PRMD: 7934.3 ± 5845.3), and reaction time (PRMD: 643.8 ± 88.7 ms; No PRMD: 674.7 ± 92.5 ms) did not significantly differ when PRMDs were vs. we're not reported ($p > 0.07$).

Discussion

This study demonstrates the potential of regularly collected self-report playing load and physical/psychological stress data to advance understanding of the complex influences of these parameters on performance, pain and injury outcomes in musicians. The piloted fatigue management tool appears to display good content validity. However, limited uptake of diminishes its prospective impact and raises questions regarding the feasibility of regular self-report data collection in high-level musicians.

Unexpectedly, increased RPE and feelings of having to "play too much" were strongly and consistently associated with *increased* self-rated performance quality. Increased playing time and playing load were also linked to *increased* self-rated performance quality, albeit slightly less consistently, in line with prior study (Ritchie and Williamon, 2012). Self-rated music performance quality has been shown to be significantly correlated with performance quality ratings of external assessors (Ritchie and Williamon, 2012). However, the only moderate strength of this prior association favors discussion focusing on associations between investigated parameters and *perceived* performance quality.

Links between increased performance quality and feelings of having to "play too much" indicate that musicians may benefit from a version of the post-activation potentiation response observed in athletes, where prior fatiguing activity leads to short-term gains in performance (Hodgson et al., 2005). Links between increased RPE and improved self-rated performance mirror prior study associating effort and performance outcomes (McPherson and McCormick, 2000). Increased RPE and playing load have been assumed to be a negative outcome for both performance and injury risk. Accordingly, this study adds to a growing body of evidence challenging assumptions that increased effort and playing load have a universally negative impact on injury and performance quality (Chan et al., 2014; McCrary et al., 2016b), instead suggesting more complex interactions between playing load,

TABLE 2 Associations between self-rated performance quality and all other parameters.

Performance quality rating	3-day value		Weekly value		3-day change		Weekly change	
Parameter	Coeff.	p	Coeff.	p	Coeff.	p	Coeff.	p
Not enough sleep (value)	0.001	0.975	0.042	0.329				
Not enough sleep (change)	−0.028	0.441	0.020	0.744	−0.021	0.466	**0.093**	**0.002**
Play too much (value)	**0.192**	**0.004**	**0.21**	**<0.001**				
Play too much (change)	**0.155**	**<0.001**	**0.304**	**<0.001**	**0.165**	**<0.001**	**0.237**	**<0.001**
Felt fit (value)	**0.205**	**<0.001**	**0.400**	**<0.001**				
Felt fit (change)	−0.024	0.659	0.157	0.102	0.021	0.664	**0.142**	**0.009**
Recovered well (value)	**0.171**	**0.001**	**0.286**	**<0.001**				
Recovered well (change)	−0.119	0.032	−0.169	0.098	−0.013	0.557	0.018	0.229
Pain 0-10 rating (value)	−0.056	0.535	**−0.122**	**<0.001**				
Pain 0-10 rating (change)	0.069	0.123	0.040	0.718	0.023	0.656	<0.001	0.98
Playing load (value)	<0.001	0.016	**<0.001**	**<0.001**				
Playing load (change)	**<0.001**	**0.002**	<0.001	0.041	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Playing time (value)	**0.001**	**0.001**	**<0.001**	**<0.001**				
Playing time (change)	**0.001**	**<0.001**	<0.001	0.036	**0.003**	**<0.001**	**0.001**	**<0.001**
Rating of perceived exertion (RPE) (value)	**0.368**	**<0.001**	**0.520**	**<0.001**				
Rating of perceived exertion (RPE) (change)	**0.197**	**<0.001**	**0.432**	**<0.001**	**0.292**	**<0.001**	**0.526**	**<0.001**
Average reaction time (value)	−0.003	0.026	−0.003	0.017				
Average reaction time (change)	0.001	0.664	**<0.001**	**<0.001**	<0.001	0.783	<0.001	0.991
Reaction time, number correct (value)	−0.012	0.792	0.102	0.181				
Reaction time, number correct (change)	0.034	0.564	−0.097	0.475	0.079	0.262	0.063	0.268
Reaction time, time*correct (value)	<0.001	0.041	<0.001	0.130				
Reaction time, time × correct (change)	**<0.001**	**0.001**	0.002	0.431	**0.001**	**<0.001**	**<0.001**	**0.004**

Value vs. value and change vs. change comparisons display concurrent relationships. Value vs. change comparisons represent predictive relationships. Statistically significant associations are highlighted in bold and gray.

TABLE 3 Associations between pain severity (*"I Had Pain"*) ratings and all other parameters.

Pain severity rating	3-day value		Weekly value		3-day change		Weekly change	
Parameter	Coeff.	p	Coeff.	p	Coeff.	p	Coeff.	p
Not enough sleep (value)	−0.119	0.006	−0.667	<0.001				
Not enough sleep (change)	0.055	0.233	−0.237	0.007	0.151	<0.001	0.170	<0.001
Play too much (value)	−0.388	<0.001	−0.278	<0.001				
Play too much (change)	0.233	<0.001	−0.457	<0.001	<0.001	0.988	0.080	0.029
Felt fit (value)	−0.524	<0.001	−0.808	<0.001				
Felt fit (change)	−0.018	0.814	<0.001	0.998	−0.178	<0.001	−0.223	<0.001
Recovered well (value)	−0.529	<0.001	−0.715	<0.001				
Recovered well (change)	−0.127	0.052	0.129	0.413	−0.246	<0.001	−0.399	<0.001
Performance quality rating (value)	−0.868	<0.001	−0.625	<0.001				
Performance quality rating (change)	−0.027	0.661	−0.026	0.818	0.023	0.656	<0.001	0.989
Playing load (value)	>−0.001	<0.001	>−0.001	<0.001				
Playing load (change)	>−0.001	0.519	−0.002	0.170	<0.001	0.983	<0.001	<0.001
Playing time (value)	−0.001	<0.001	−0.002	0.318				
Playing time (change)	>−0.001	0.271	<0.001	0.998	<0.001	0.986	<0.001	0.001
Rating of perceived exertion (RPE) (value)	−0.431	<0.001	−0.423	<0.001				
Rating of perceived exertion (RPE) (change)	0.006	0.915	−0.127	0.248	<0.001	0.993	0.158	<0.001
Average reaction time (value)	<0.001	0.788	0.007	0.007				
Average reaction time (change)	−0.003	<0.001	−0.009	0.017	<0.001	0.999	0.001	0.078
Reaction time, number correct (value)	−0.223	0.036	−1.00	<0.001				
Reaction time, number correct (change)	0.116	0.237	0.080	0.721	<0.001	0.995	0.059	0.058
Reaction time, time × correct (value)	>−0.001	<0.001	<0.001	<0.001				
Reaction time, time × correct (change)	0.001	0.145	−0.021	<0.001	<0.001	0.941	<0.001	0.125

Value vs. value and change vs. change comparisons display concurrent relationships. Value vs. change comparisons represent predictive relationships. Statistically significant associations are highlighted in bold and gray.

TABLE 4 Associations between reaction time and all other parameters.

Reaction time	3–day value		Weekly value		3–day change		Weekly change	
Parameter	Coeff.	p	Coeff.	p	Coeff.	p	Coeff.	p
Not enough sleep (value)	−0.378	0.763	−1.357	0.368				
Not enough sleep (change)	1.316	0.308	−0.742	0.726	0.304	0.005	−0.397	0.702
Play too much (value)	−1.640	0.159	−1.821	0.101				
Play too much (change)	−0.161	0.925	−5.686	0.037	0.927	0.559	2.661	0.041
Felt fit (value)	**−5.911**	**<0.001**	−3.850	0.034				
Felt fit (change)	−1.016	0.602	−0.927	0.799	−2.269	0.228	−1.735	0.433
Recovered well (value)	**−6.197**	**<0.001**	**−8.400**	**<0.001**				
Recovered well (change)	−0.984	0.555	8.045	0.015	−4.003	0.025	0.643	0.713
Pain 0–10 rating (value)	−0.077	0.952	**4.699**	**0.001**				
Pain 0–10 rating (change)	0.496	0.814	3.898	0.354	2.195	0.278	2.303	0.23
Performance quality rating (value)	−3.85	0.034	**−7.149**	**<0.001**				
Performance quality rating (change)	1.736	0.364	−1.493	0.315	−3.932	0.027	0.972	0.548
Playing load (value)	**−0.002**	**0.001**	**−0.002**	**<0.001**				
Playing load (change)	−0.001	0.235	−0.002	0.006	−0.002	0.085	−0.001	0.056
Playing time (value)	**−0.030**	**0.001**	**−0.029**	**<0.001**				
Playing time (change)	−0.017	0.151	−0.029	0.004	−0.025	0.096	−0.007	0.183
Rating of perceived exertion (RPE) (value)	−3.264	0.009	**−5.333**	**<0.001**				
Rating of perceived exertion (RPE) (change)	0.601	0.664	−3.665	0.108	−1.670	0.241	**−3.289**	**<0.001**
Reaction time, number correct (value)	**−5.89**	**0.001**	**−17.308**	**<0.001**				
Reaction time, number correct (change)	6.111	0.015	9.948	0.011	−3.015	0.272	1.291	0.636

Value vs. value and change vs. change comparisons display concurrent relationships. Value vs. change comparisons represent predictive relationships. Statistically significant associations are highlighted in bold and gray.
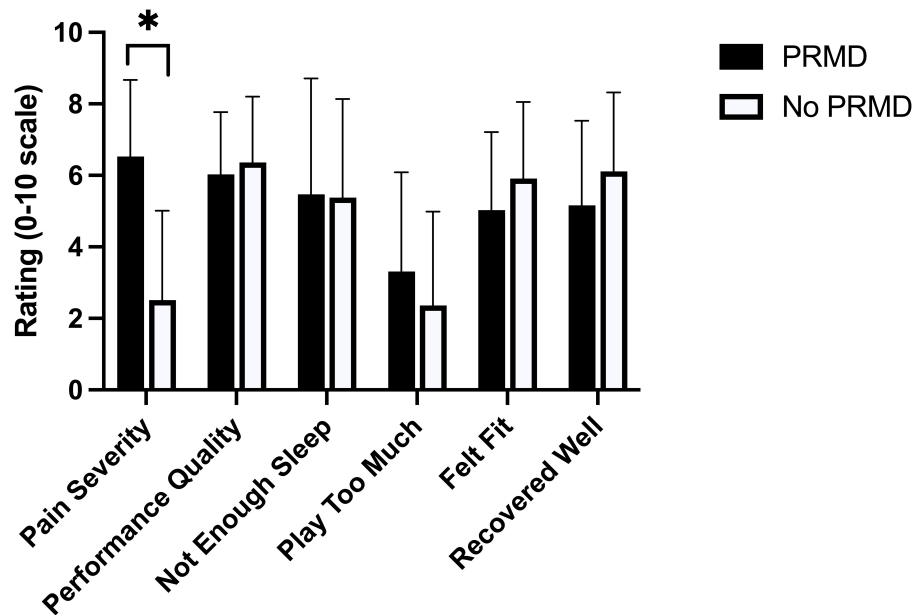
FIGURE 3
Self-report performance and physical/psychological stress outcomes with (PRMD) and without (No PRMD) concurrent reports of symptoms affecting playing (PRMD). Data presented as mean ± standard deviation. *significant difference after Bonferroni-Holm correction for multiple comparisons; $p < 0.001$.

exertion, injury, and performance (McCrary et al., 2016a). A small sample of reports of PRMDs in the present study precludes conclusive comments regarding the links between playing load and injury/PRMD incidence.

Associations between increased feelings of physical fitness and feelings of recovering well physically and reduced pain severity are consistent with prior studies demonstrating links between increased physical fitness and reduced pain severity (Chan et al., 2014; Andersen et al., 2017). Study participants also indicated that low levels of pain (mean 2.5/10) did not interfere with playing; this result is, once again, consistent with prior research asserting that low-level pain symptoms are common in musicians and do not necessarily impact playing (White et al., 2003). Significantly increased pain intensity (mean 6.5/10) was associated with reports of PRMDs, indicating that one benefit of increased physical fitness in musicians may be reported analgesic effects which may globally reduce pain severity to manageable levels without pathological injury (Pacheco-Barrios et al., 2020). Further research into relationships between fitness, pain and PRMDs in musicians is required to confirm this hypothesis.

The absence of consistent associations of reaction time, an indicator of psychomotor fatigue in athletes (Rietjens

et al., 2005; Dupuy et al., 2014), with playing load or physical/psychological stress outcomes in the present study has multiple explanations. This result could be explained by differential fatigue processes in musicians vs. athletes (McCrary et al., 2022), which could mean that reaction time and/or the specific recognition reaction time task used in the present study are ill-suited for identifying fatigue in musicians. Low numbers of consecutive data entries in this study limited statistical power, providing an additional possible explanation and precluding further comment regarding the appropriateness of the reaction time task. Additional study is needed to determine whether reaction time tasks can be valid indicators of fatigue states in musicians.

Limitations

Analyses of associations between study outcomes, as well as assessment of the content validity and prospective utility of the pilot fatigue monitoring tool, are ultimately limited, however, by challenges with uptake in professional and student musicians. Despite a recruitment push across multiple large international music universities and conservatoires and multiple incentives for participation, only 96 participants were enrolled in

22 months and the average participant engaged with the fatigue management tool for just 1 week. While internal app pre-testing confirmed good functionality, the unvalidated pilot app may not have been conceptually appealing and/or presented enticingly enough for musicians with many competing priorities. Recruitment difficulties were also likely exacerbated by the conduct of the study during various stages of COVID lockdowns and remote university/conservatoire learning from 2020-21 to multiple authors noted substantial impacts of the pandemic on the engagement of their students. Further, our app relied on participation prompted by email reminders, with analyses of data explicitly not provided to study participants to avoid influencing practice and performance behaviors. Fatigue monitoring data in sport are typically collected and analyzed by staff on an ongoing basis (Halson, 2014), which likely increases long-term engagement. Further research using ongoing staff data collection/analysis methods in musicians is needed to determine its impact on both engagement and observed results. Additionally, appropriately powered future research studies should seek to establish the equivalence of German and English language versions.

Alternately and/or additionally, recruitment difficulties could underscore the importance of ongoing international work to enhance musicians' health literacy (Baadjou et al., 2019). Low health literacy in musicians is hypothesized to present a critical barrier to engagement of musicians in health-promoting practices. Mandatory health education seminars and coursework are integrated into the curricula of an increasing number of conservatoires and university music programs, including the majority of collaborating institutions in this study. However, such integrated health education may not yet translate into general enthusiasm for new approaches to health promotion and enhancement such as the novel app presented in this study. Further research into motivations influencing the uptake of novel approaches to health promotion in musicians is needed to provide further insights and enhance recruitment practices in future studies.

Conclusion

In conclusion, this study demonstrates the prospective value of regular individual self-report playing load, stress, and performance data collection in musicians. However, limited uptake of the online fatigue management app piloted in this study indicates that new approaches to the collection of these data are needed to realize their potential impact.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

This study was reviewed and approved by the Central Ethics Committee at Leibniz University Hannover and the Conservatoires UK Ethics Committee. All participants provided their written informed consent prior to participation.

Author contributions

JM designed, funded, coordinated the study and all data analyses, and drafted the final manuscript. SA, PS, SS, LM, ER, and SB-G assisted with participant recruitment and data collection and provided critical revisions to the final manuscript. EA assisted with study design, participant recruitment and data collection, and provided critical revisions to the final manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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