Introduction

Emergency physicians are particularly vulnerable to sleep deprivation. The primary role of emergency departments (EDs) is to provide acute care for patients, 24-hours a day and 365 days a year. However, the role of EDs has expanded over time and they now act as a 24/7 portal for inpatient admission and as a primary safety net to relieve the load from other departments (Schuur & Venkatseh, 2012). Multiple reports point out a steady increase in emergency room visits (NASEM, 2007; Moore et al., 2017) as well as a shortage of emergency workers (Hunnicutt, 2015; Reiter et al., 2016). Overcrowding in EDs has become a significant public health problem worldwide (Derlet et al., 2001; Stead et al., 2009; Cha et al., 2009; Thijssen et al., 2012) and emergency physicians are required to work more to keep pace with this increasing demand for care. In response, in 2003 the European Commission authorised an additional weekly working time of 12 hours for emergency physicians, raising the permissible weekly working time to 72 hours per week. Additionally, emergency physicians are now allowed to work up to 24 hours in a row, to ensure care continuity. In this context, it is not surprising that situations where sleep-deprived physicians are working has been reported. Handel et al. (2006) showed that 38% of 602 emergency physicians who completed the Epworth Sleepiness Scale were suffering from excessive daytime sleepiness. More recently, another study involving 37 emergency physicians showed that 30 of them reported poor sleep quality and that the number of night shifts per month was the most important determinant of physicians' sleep quality (Tur et al., 2015).

Research has demonstrated that sleep deprivation is associated with psychomotor and cognitive impairments among physicians (Gander et al., 2008; Sanches et al., 2015; Saadat et al., 2017). However, these studies involve the completion of experimental tasks that have little in common with physicians' everyday work. In fact, studies involving emergency physicians actually providing care have yielded contradictory results. Kramer (2010) showed that naturalistic studies failed to demonstrate that sleep deprivation results in harmful medical errors in clinical situations. Multiple studies also demonstrated that mortality and morbidity rates were unaffected by the 2003 changes to duty hours (de Virigilio et al., 2006; Salim et al., 2007; Morrison et al., 2009). In a more recent meta-analysis, Gates et al. (2018) concluded that fatigue and sleep deprivation are associated with detrimental physician health and well-being outcomes, but that there is insufficient evidence regarding the potential associations with clinical performance and patient safety.

Aside from methodological weaknesses and heterogeneity across studies, it has also been suggested that the inconsistency of these results may reside in the ability of some physicians to compensate fatigue-related impairments (Czeisler, 2009; Sade, 2015; Gates et al., 2018). Dawson and McCulloch (2005) first introduced the notion of fatigue proofing strategies (FPS) to refer to any compensatory strategies aiming to reduce the likelihood a sleep-deprived operator will make an error. In contrast, fatigue reduction strategies (FRS) refer to any strategies aiming to reduce the likelihood that a sleep-deprived operator is working. According to Dawson et al. (2012), most formal controls addressing fatigue-related risk rely on reduction strategies through regulating hours of service and do not encompass the notion of fatigue proofing. Consequently, fatigue proofing strategies typically develop as informal work practices in contexts where it is not possible or desirable to further reduce work hours. Therefore, Dawson and McCulloch's framework is particularly relevant to the ED and informal FPS may be used by emergency physicians to sustain acceptable performance despite fatigue-related impairments.

Hockey (1997) first proposed a cognitive-energetic model to account for the variability of human performance under fatigue or other conditions affecting performance. According to Hockey, performance may be protected in response to high work demands by the recruitment of further resources. Although the initial response is adaptive in the short run, it is likely to attract subsequent compensatory costs if carried out under prolonged high workload conditions (Harris, 1998). The long-term effect of compensatory effort is a draining of emotional resources eventually resulting in a burnout (Bakker & Demerouti, 2006). Burnout is not merely fatigue but a specific work-related syndrome comprised of three dimensions often described as sequential stages (Schaufeli & Taris, 2005; Leone et al., 2007). High job demands cause a depletion of the operator's emotional resources in an attempt to cope (emotional exhaustion), which then precipitates negative attitudes towards patients or colleagues (depersonalization), and ultimately leads to feelings of inadequacy and failure (personal accomplishment). In this context, the benefits of FPS in terms of sustainable performance need to be analysed in relation to the associated psychological costs for the physician. Following Hockey's model, it is arguable that the recurrent use of FPS may place a strain on emergency physicians' resources and gradually lead to burnout. FRS, on the other hand, aim to reduce the burden of fatigue and thus, from a psychological standpoint, are more likely to have reparative qualities.

Although many investigations have looked at the detrimental effect of sleep deprivation (SD) on physician performance (Gates et al., 2018), as yet no studies have systematically evaluated the potential moderating role of informal FPS. The ability of some physicians to compensate for fatigue-related impairments may explain the inconsistency of the association between SD and clinical performance demonstrated in naturalistic studies (Czeisler, 2009; Sade, 2015). Moreover, little attention has been devoted to the potential longer-term effects of FPS on physicians' health. Using a mixed-method approach, we aimed to harvest FRS and FPS at the local level and to assess their efficiency in terms of fatigue, work performance and associated risks of burnout. Based on Dawson & McCulloch's framework (2005), we postulate that (1) the use of FRS is negatively associated with fatigue-related impairments, and (2) the use of FPS mediates the relationship between fatigue-related impairments and work performance. In keeping with the cognitive-energetic model (Hockey, 1997), we postulate that (3) the use of FRS is negatively associated with burnout; and (4) the use of FPS is positively associated with burnout.

Method

Participants

This study was conducted over a 10 month period in 2016/17 in the ED of the Liège University Hospital Center, a tertiary-care center with an ED volume of 92,775 patients in 2015. All participants were informed about the study and asked to participate on a voluntary basis. Twenty-eight out of 32 emergency physicians agreed to participate in the study. In accordance with the Declaration of Helsinki, all participants gave their written informed consent prior to their inclusion in the study. Physicians were free to withdraw from the study at any time. The study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège and by the Ethics Committee of the Medical Center of the University of Liège**.**

Materials

Fatigue management strategies. We designed the Fatigue Management Survey (FMS) assessing the frequency of use of fatigue management strategies (Berastegui et al., 2018). Strategies were previously extracted from focus group discussions with emergency physicians from the same facility as the current study. The survey assesses the frequency of use of 33 fatigue management strategies on a six-point Likert scale (see Procedure for further details on the development of the FMS). Physicians were asked to indicate how often they used each strategy when they felt tired (from "never" to "very often"). In order to measure relatively stable habits, physicians were asked to relate to a reference period of six months.

Fatigue-related impairments. The Psychomotor Vigilance Task is a reaction time task which is widely used to discriminate between sleep deprived subjects and alert subjects (Lee et al., 2010; Basner et al., 2011). Lapses in attention as measured by the PVT indicate fatigue-related impairments that are caused by either sleep loss or time-on-task (Warm et al., 2008). We measured fatigue-related impairments using an Android-based touchscreen version of the Psychomotor Vigilance Task (Kay et al., 2013). The application was installed on a Huawei Y560 Android smartphone. Participants were presented with stimuli that occur at random intervals with an inter-stimulus interval (ISI) of between two and ten seconds. We used a five minute version instead of the standard 10 minute PVT for reasons of time constraints. Research shown that the five minute PVT is a reasonable substitute in applied settings where use of the standard 10 minute PVT is not feasible or desirable (Lamond et al., 2005; Roach et al., 2006). Reaction times were used to compute the fastest tenth percentile (i.e., optimal performance) for each trial. The fastest tenth percentile is known to be particularly sensitive in terms of detecting the very early effects of growing need for sleep (Graw et al., 2004).

Work performance. We measured work performance using a four-item retrospective scale (WPS) asking physicians to indicate how they performed during the shift according to four areas of expertise. These areas were adapted from the self-assessment component of the Physician Achievement Review (PAR) by the College of Physicians and Surgeons of Alberta (Hall et al., 1999). The original tool is a 360-degree performance review gathering data from patients, medical colleagues, co-workers and self-assessment to evaluate the working performance of general physicians. We eliminated items which were not relevant to emergency medicine from the self-assessment subscale and obtained a set of 25 items. Items were regrouped into four performance areas: Clinical Competency, Patient Interaction, Care Coordination and Professional Self-Management. “Clinical Competency” refers to the ability to assess, diagnose, select and execute appropriate treatments for the patient. “Patient Interaction” refers to the ability to communicate with patients and families in a manner that conveys respect and compassion. “Care Coordination” refers to the ability to communicate effectively the steps needed for continuing care to patients or colleagues. “Professional Self-Management” refers to the ability to maintain quality medical records, to manage health care resources, professional development and stress. Physicians reported how well they performed on each of these dimensions on a five point Likert Scale ranging from ”very poorly” to “very good”. We combined the performance scale and PVT-Touch into a practical and functional Android-based application installed on a Huawei Y560 smartphone.

Occupational burnout. We measured occupational burnout using the Medical Personnel variation of the Maslach Burnout Inventory Human Services Survey (Maslach, 1986). The MBI is the most frequently used instrument worldwide to evaluate burnout, due to the well-established support for its reliability and validity (Maslach et al., 1996). The questionnaire is composed of 22 items assessing the three dimensions of occupational burnout: emotional exhaustion (EE), depersonalization (DP) and personal accomplishment (PA). The EE subscale contains nine items describing feelings of being emotionally exhausted because of work. The PA subscale contains eight items describing feelings around competence and successful achievement at work. The DP subscale contains five items and describes detached and impersonal treatment of patients. Participants are asked to record their feelings on a seven point scale, ranging from never having those feelings to having those feelings every day. Burnout syndrome is characterized by the conjunction of high scores on EE (>30) and DP (>12) subscales, and a low score on the PA subscale (<33).

Procedure

1. **Strategy identification phase**

As mentioned above, we previously conducted a focus group study to identify strategies used by emergency physicians to manage fatigue-related risk (Berastegui et al., 2018). We conducted four focus group sessions with a total of 25 emergency physicians from the same facility as the current study. Qualitative data were collected using a semi-structured discussion guide in two parts. Participants were first asked to describe how on-the-job fatigue affected their efficiency at work. A mind map was progressively drawn based upon participants' perceived effects of fatigue. Participants were then asked to describe any strategies they personally used to cope with these effects. We used inductive qualitative content analysis to reveal content themes for fatigue management strategies. Strategies aiming to reduce the subjective experience of fatigue were categorised as Fatigue Reduction Strategies (FRS), and strategies aiming to alleviate the impact of fatigue on performance were labelled as Fatigue Proofing Strategies (FPS). Emergency physicians reported 12 FRS and 21 FPS. Each reported strategy was converted in a positively worded behavioral item and physicians were asked to indicate how often they use each strategy on a six point Likert scale ranging from "never" to "very often"**.**

2. **Time window determination phase**

Prior to data collection, we conducted a pre-study to determine the most appropriate time for measuring fatigue (i.e., 6.30pm to 7.30pm for the day shift; 9.30pm to 11pm for the night shift). Our objective was to measure fatigue at its peak in order to maximize the effect size and thus increase the statistical power of the study. Additionally, typical daily workload distribution was taken into account in order to minimise disruption to the physicians' activity and reduce missing values. To this end, we assessed physicians' physical activity using a tri-axial accelerometer (GENEActiv Original). The device was attached to the physician's dominant wrist with a strap and worn for a two-week period. Twelve emergency physicians participated in this phase for a total of 20 shifts. Accelerometer data were collected for regular day shift (n=12) and 24-hour shift (n=8). We computed a gravity-subtracted sum of vector magnitudes (SVMgs) based on 60 seconds epoch and averaged data across participants. Figure 4 shows a 60-second epoch chart with accelerometer data compiled for both shifts. We isolated a time window for each shift based on accelerometer data and the circadian drive for arousal. Time windows had to meet three criteria: 1) be characterized by sedentary activity (SVMgs < 57.5), 2) succeed a significant peak of physical activity (SVMgs > 84.4), and 3) be as close as possible to the window of circadian low. We used intensity cut-points validated by Dillon and colleagues (2016) for dominant wrist on GENEActiv accelerometer.

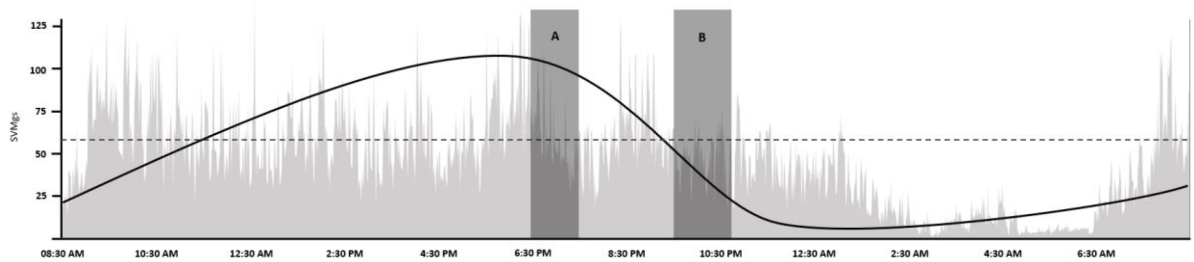

Figure 4. Physical activity as a function of time (fitted with the circadian drive for arousal).
SVM: Sum of Vector Magnitudes (30Hz frequency, 60-seconds epoch).
Bold line: circadian drive. Dashed line: sedentary activity cut-point.
A: testing time for regular day shift. B: testing time for 24-hour shift.

3. Data collection phase

At enrollment, participants answered the fatigue management survey and the Maslach Burnout Inventory, and were provided with an android smartphone preinstalled with the application. Participants were instructed to perform the PVT at previously specified time windows and to answer the performance scale at the end of shift. Additionally, physicians were asked to report the times they went to sleep and woke-up the preceding night. Sleep logs were combined with accelerometer data in order to provide a more accurate assessment of the actual sleep duration (Littner et al., 2003 ; Girschik et al., 2012). Specifically, self-reported bed and awakening times were validated using periods of activity and inactivity based on SVMgs on 60 seconds epoch. Twenty-eight emergency physicians took part in the study for a total of 182 shifts (114 day shifts and 68 24-hour shifts). A summary of the procedure is presented in Figure 5.

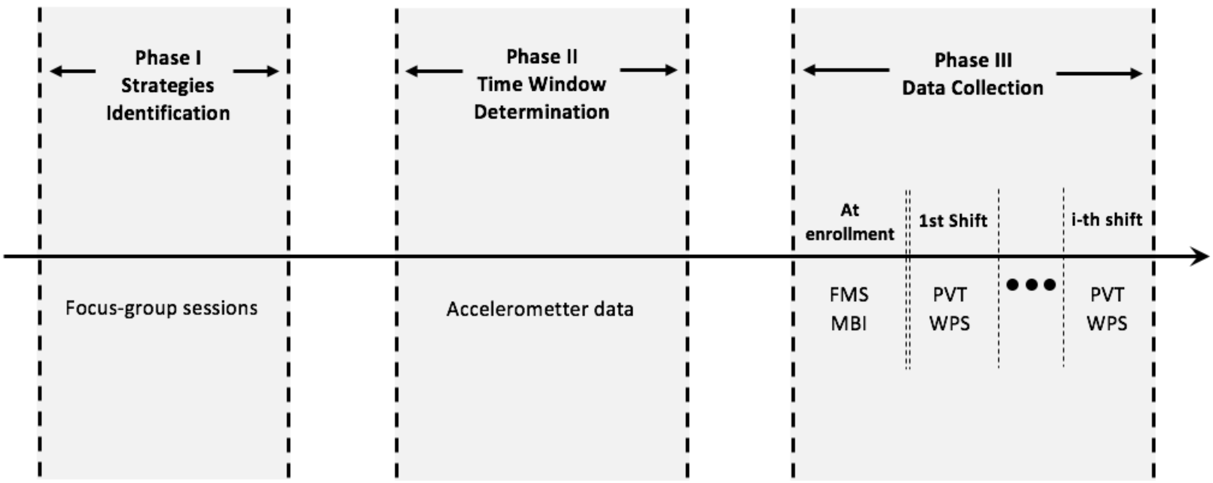

Figure 5. Timeline of measurements.
Phase 1: strategies extracted from focus group sessions and development of the FMS.
Phase 2: determination of the most appropriate time windows to capture fatigue at its peak using accelerometer device.
Phase 3: prospective longitudinal data gathering with FMS & MBI as a baseline, and PVT & WPS on each shift
FMS: Fatigue Management Survey. MBI: Maslach Burnout Inventory. PVT: Psychomotor Vigilance Task. WPS: Work Performance Scale.

4. Statistical procedures

All statistical analyses were conducted using SPSS 22.0 software (IBM Corporation, Armonk, New York, US). We conducted linear mixed-effects regression models with maximum likelihood estimation to test 1) whether FRS was significantly associated with reaction time, and 2) the potential moderating role of FPS in the relationship between reaction time and work performance. Subjects were specified as a random intercept to control for their associated infraclass correlation (Pinheiro & Bates, 2000). In contrast to a traditional regression analysis, mixed-effects models make it possible to control for the variance associated with random factors without data aggregation (Baayen et al., 2008; Judd et al., 2012). For the sake of brevity, we present only the F tests from the mixed-effects procedure results (type III Wald F tests with Satterthwaite degrees of freedom approximation). Finally, 3) we conducted separate multiple regression analyses with maximum likelihood estimation to test whether FRS and FPS frequency significantly predicted the three dimensions of burnout.

Results

1. Participant characteristics

Participants were 28 (17 men and 11 women) emergency physicians working at the Emergency Department (ED) of the Liège University Hospital Center. Participants' median age was 34 (M = 36.89, SD = 10.73) with a median working experience in the ED of six years (M = 7.36, SD = 6.58).

2. Frequency of use of fatigue management strategies

Table 1 shows the mean frequency of use of each fatigue management strategy included in the FMS. Frequently-used FRS included rest time management, food or energy drink intake, physical exercise and social interactions. To a lesser extent, physicians reported listening to or thinking about music, getting a breath of fresh air, showering or freshening up. Napping was the least frequently used strategy. Three of the four most frequently-used FPS relate to communication with patients and colleagues. Physicians reported completing the patient record as and when it comes rather than letting things pile up. Frequently-used FPS also include focusing, self-motivation, double-checking, rehearsal and the increased use of cognitive aids, manuals or databases. To a lesser extent, physicians reported seeking instrumental support, varying tasks and relying on checklists. Least-frequently used FPS included seeking moral support, deferring tasks and cross-checking.

Table 1. Mean Likert scores for FRS and FPS frequency of use (1 ["never"] to 6 ["very often"]), n = 28.

Fatigue reduction strategies	Mean	SD
I anticipate and regroup tasks as much as possible in order to maximize rest time	4.86	1.23
I have an energy drink (coffee, tea, coke, etc.)	4.50	2.06
I take advantage of lull periods to have a non-work related talk with my colleagues	4.05	1.36
I take advantage of lull periods to take the time to eat slowly	4.00	1.30
I try to keep moving as much as possible to stay awake	3.95	1.28

I have a quick snack	3.90	1.65
I take advantage of lull periods to be physically active (running, walking, etc.)	2.60	1.72
I sing or I think about songs	2.57	1.83
I take advantage of lull periods to take some fresh air and/or to smoke a cigarette	2.50	1.82
I listen to music while doing paperwork to stay awake	1.90	1.45
I take a brief shower or I dampen my face with cold water	1.79	1.23
I have a nap whenever it is possible	1.70	0.98
Fatigue proofing strategies		
I tend to interact with patient in way that creates a climate of closeness	4.95	0.94
I complete the patient record as and when it comes rather than letting things pile up	4.85	1.39
I engage conversation with the patient on a humorous note	4.75	1.33
I communicate more with my colleagues	4.53	0.92
I strongly focus to avoid any inattention mistakes	4.50	1.57
I talk to myself or others about what I've done to make sure I didn't forget anything	4.50	1.15
I double check drug prescriptions and dosage regimen	4.42	1.02
I do some self-motivation, I tell myself to hold on and that the shift is about to end	4.33	0.82
I focus on one task at a time	4.33	1.05
I use algorithms or other cognitive aids more often	4.10	1.45
I rely more on manuals or databases than my memory	4.05	1.23
I seek instrumental support from my supervisor or colleagues	4.00	1.34
I try to vary tasks as much as possible to avoid boredom	3.55	1.50
I let nurses know I'm tired so they pay more attention to what I'm doing	3.37	1.34
I rely more on experimented nurses for specific tasks they are qualified for	3.35	1.35
I write down things I've left to do so I don't forget them	3.00	1.59
I seek moral support from my colleagues	2.95	1.36
I defer secondary goals to colleagues while I take care of the primary goal	2.93	1.22
I ask a colleague to double-check what I've done	2.70	1.45
I take a brief moment to relieve the tension before interacting with a patient	2.65	1.42
I defer complex but non-urgent tasks to my colleagues working the following shift	2.50	1.50

3. Sleep duration

Sleep logs and accelerometer data for the night prior to testing were combined in order to compute sleep duration (Figure 6). Participants slept for an average of 7.39 (SD = 1.16) hours the night preceding the testing. In order to ascertain the sensitivity of the five minute PVT for measuring fatigue, we performed a linear mixed-effects regression of sleep duration and time since awakening on PVT reaction time (Table 2). It was found that the time since awakening significantly predicted reaction time (F = 41.65, $p < 0.01$) as did sleep duration (F = 8.48, $p < 0.01$). A 10-hour increase in time-since awakening is associated with an increase of 26.40 milliseconds in mean RT, while a 3-hour decrease in sleep duration is associated with an increase of 45.21 milliseconds.

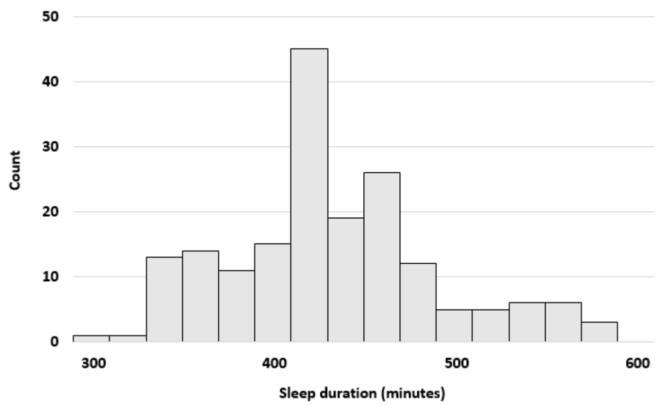

Figure 6. Histogram of sleep duration in minutes

Table 2. Mixed-effect model with Mean RT as dependent variable and participant as a random intercept

	Estimate	SE	t	95% CI
(constant)	450.54	6.27		
Fixed effects				
Time Since Awakening	**2.64**	**0.41**	**6.45**	**1.83 – 3.45**
Sleep Duration	**-15.07**	**2.45**	**-2.91**	**-15.29 – -3.00**
Random effects				
Subject	698.33	240.75		
Residual	1059.51	86.77		

Note. Reaction times (RT) measured in milliseconds. Time since awakening and sleep duration measured in hours. SE = standard error. Significant effects are indicated by boldface.

4. Effect of fatigue reduction strategies on reaction time

The first model tested whether FRS frequency significantly predicted the fastest 10% reaction time (Figure 7). Indeed, we found a significant negative effect of FRS on the fastest 10% reaction time, $F(1, 22) = 8.02$, $p = 0.01$. High FRS frequency of use was associated with a fast reaction time on the Psychomotor Vigilance Task.

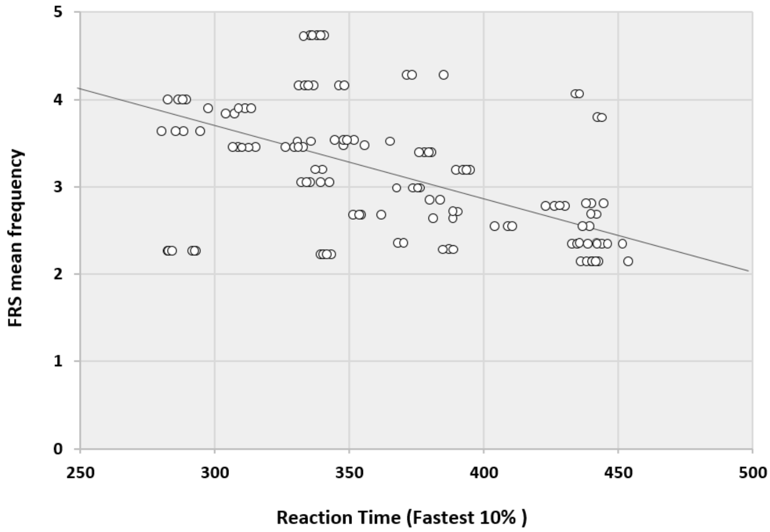

Figure 7. Scatterplot showing associations between the fastest 10% reaction time and frequency of use of Fatigue Reduction Strategies

5. Role of fatigue proofing strategies in the relationship between reaction time and self-reported work performance

We used additional mixed-effects models to investigate whether FPS frequency mitigates the relationship between the fastest 10% reaction time and self-reported work performance. After centering FPS frequency and the fastest 10% reaction time and computing the interaction (Aiken & West, 1991), the two predictors and the interaction term were entered into separate models for each of the four self-reported work performance dimensions (Table 3). All models indicated an acceptable level of multicollinearity between predictors (VIF < 3). The fastest 10% reaction time was found to have a significant positive effect on patient interaction, $F(1, 25) = 27.61$, $p < 0.001$, and FPS significantly moderated that relationship, $F(1, 94) = 4.91$, $p = 0.029$. There was a significant positive effect of FPS on self-management, $F(1, 23) = 5.99$, $p = 0.023$, and a significant interaction, $F(1, 101) = 5.92$, $p = 0.017$. FPS was found to have a positive effect on clinical competence, $F(1, 21) = 21.20$, $p < 0.001$, but the interaction with fastest 10% reaction time is non-significant, $F(1, 69) = 3.25$, $p = 0.076$. The care coordination model shows no significant main effects or interaction. Figure 8 shows slopes for self-reported work performance at various value of FPS.

Table 3. Mixed-effect models with clinical competence, patient interaction, care coordination and self-management as dependent variables and participant as a random intercept.

	Clinical competence			Patient interaction			Care coordination			Self-management		
Variable	**F**	**df**	**p**	**F**	**df**	**p**	**F**	**df**	**p**	**F**	**df**	**p**
Fatigue proofing strategies	21.20	21	<.01*	3.13	23	.09	1.42	25	.25	5.99	23	.02*
Fastest 10% reaction time	1.26	20	.28	27.61	25	<.01*	0.88	26	.36	2.17	34	.15
FPS * Fastest 10% RT	3.25	69	.08	4.91	94	.03*	0.38	100	.54	5.92	101	.02*

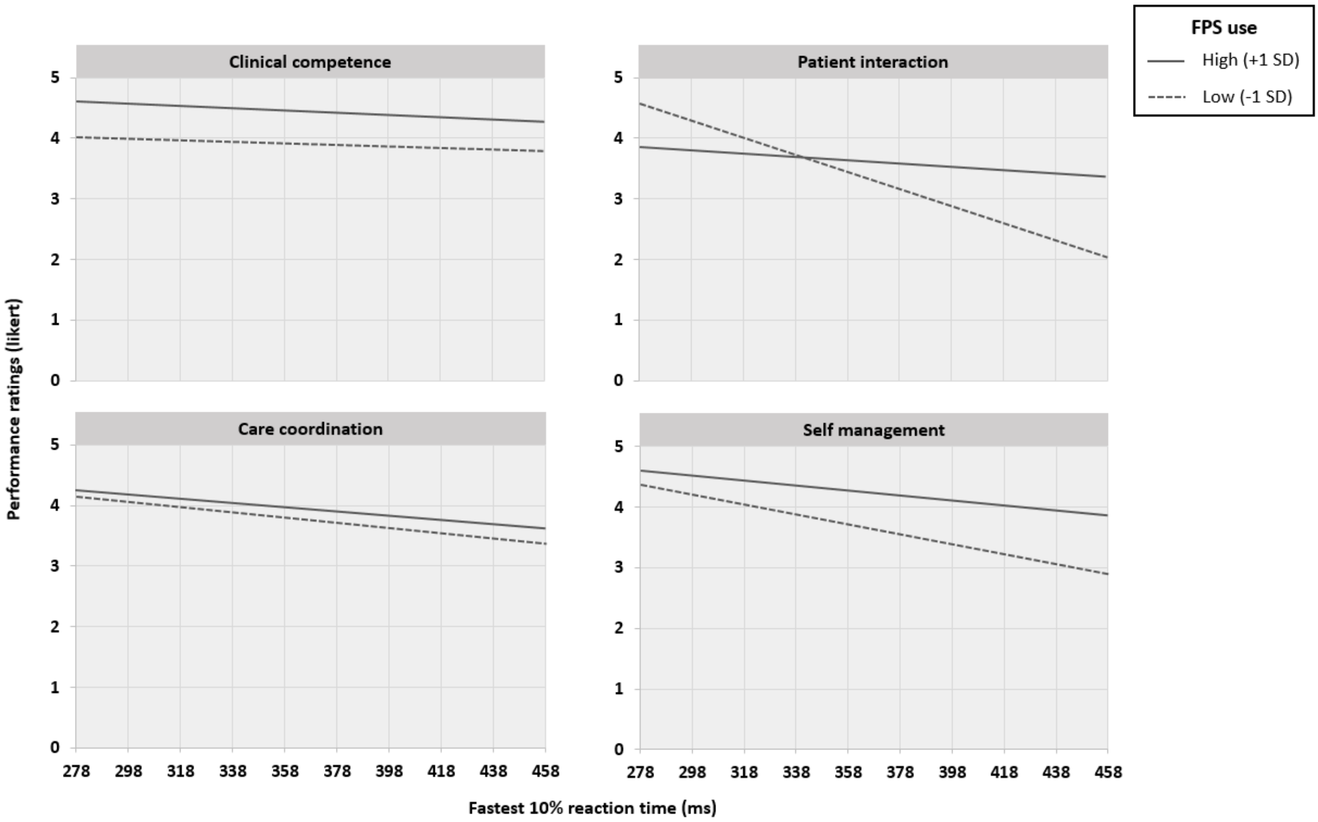

Figure 8. *Simple slopes showing the moderating effect of Fatigue Proofing Strategies on the relationship between the fastest 10% reaction time and each of the four work performance dimensions. Dashed/bold lines: subjects scoring one standard deviation below/above mean FPS frequency of use.*

6. Effect of fatigue reduction and proofing strategies on burnout

The levels on MBI subscales are illustrated in Figure 9. Based on MBI thresholds (Maslach, 1996), 7% of the physicians presented high levels of emotional exhaustion, 25% demonstrated high levels of depersonalization and none presented low levels of personal accomplishment at work. 25% of physicians demonstrated at least one of the three dimensions indicating a high bias towards burnout, while 7% presented at least two of the three dimensions. A high proportion of physicians had medium levels of emotional exhaustion and depersonalization. The relatively high scores recorded for personal accomplishment indicated that none of the physicians were suffering from burnout syndrome at the time the MBI was administered.

Separate multiple regression analyses were conducted to test whether FRS and FPS frequency significantly predicted the three dimensions of burnout (Table 4). It was found that FPS frequency significantly predicted emotional exhaustion ($\beta = 0.79$, $p < .001$). High FPS frequency of use was associated with high scores on the emotional exhaustion MBI subscale (Figure 10).

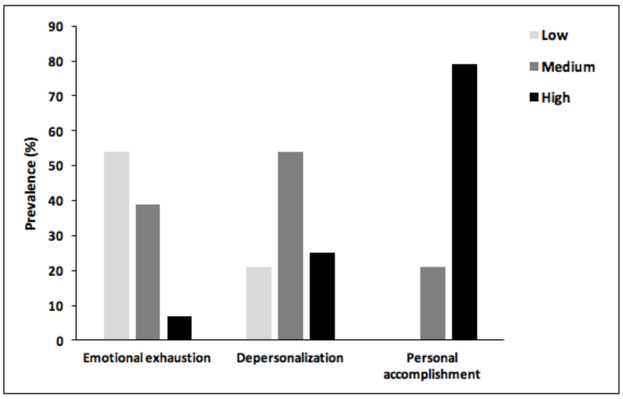

Figure 9. *Prevalence of MBI subscales according to Maslach's threshold scores*

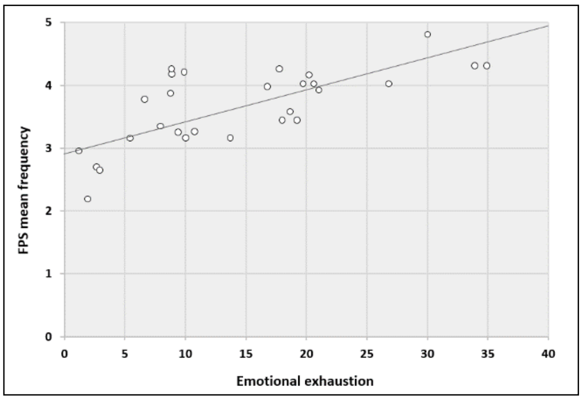

Figure 10. *Emotional exhaustion dimension as a function of FPS frequency of use*

Variable	Emotional exhaustion	Depersonalization	Personal accomplishment

	Estimate	SE	95% CI	Estimate	SE	95% CI	Estimate	SE	95% CI
(constant)	-27.82	7.54		-5.50	5.97		52.63	3.25	
FRS	-0.79	2.10	-5.12 – 3.55	2.29	1.67	-1.14 – 5.72	-1.57	0.91	-3.44 – 0.30
FPS	**11.93**	**2.25**	**7.29 – 16.56**	1.87	1.78	-1.81 – 5.54	-1.62	0.97	-3.62 – 0.38
Adjusted R^2		.57			.14			.29	

Table 4. Multiple linear regression models with emotional exhaustion, depersonalization and personal accomplishment as dependent variables.

Note. SE = standard error. Significant effects are indicated by boldface.

Discussion

In this study, we aimed to assess the impact of informal fatigue management strategies on fatigue-related impairments, self-reported work performance and well-being using burnout measurements. In accordance with Dawson & McCulloch's framework (2005), we postulated that FRS are associated with reduced levels of fatigue-related impairments, and that FPS effectively mitigate the relationship between fatigue-related impairments and work performance. Following a cognitive-energetic approach (Hockey et al., 1997), we hypothesized that FPS, unlike FRS, may result in a trade-off between performance and well-being, using burnout as a measurement. We will discuss our results in relation to the scientific literature and propose further considerations for the implementation of a Fatigue Risk Management System (FRMS) in the ED.

Studies conducted in controlled settings have repeatedly demonstrated that chronic sleep deprivation has a detrimental effect on attention (Lim & Dinges, 2008), working memory (Harrison et al., 2000), psychomotor proficiency (Khazaie et al., 2010), decision making (Schnyer et al., 2009) and behavior (Alhola & Polo-Kantola, 2007). Emergency physicians are particularly vulnerable to these impairments due to long working hours (Gander et al., 2008; Sanches et al., 2015; Saadat et al., 2017). However, researches in residency settings have been inconclusive on how these impairments translate into physicians' performance Kramer (2010). Our attempt to investigate this relationship suggests that only some aspects of physicians' performance are impacted. Of the four dimensions addressed, patient interaction was the only one associated with decreased reaction time. These results are consistent with meta-analyses which conclude that sleep deprivation alters mood to an even greater extent that it does cognitive or motor functions (Pilcher & Huffcutt, 1996; Philibert, 2005). Sleep deprivation is known to be associated with reduced empathy (Guadagni et al., 2014; Bonnet, 2003; Harrison & Horne, 2000). Empathy is an essential attribute of the patient-physician relationship, and has been shown to facilitate more accurate diagnoses and caring treatment (Schliesman, 2016). Altogether, our results are consistent with the literature showing that SD is detrimental to empathy, a critical resource involved in the patient-physician relationship.

With regard to the measures used in our study, our findings revealed a significant interaction between the fastest reaction time and FPS frequency of use for the patient interaction and self-management subscales. These results advocate for the potential moderating role of FPS to sustain acceptable work performance despite decrements in sustain attention typically associated with sleep loss. More specifically, it is arguable that physicians use proofing strategies to maintain appropriate patient-physician relationships and effective management of healthcare resources while working under adverse conditions. However, our results suggest that informal FPS may represent a significant risk for the operator over the longer term. In fact, physicians' scores on the emotional exhaustion sub-dimension of MBI were found to be positively associated with the frequency of use of FPS. Taken together, these results may indicate that FPS may cause the depletion of physicians' emotional resources. This interpretation is line with the cognitive-energetic model according to which performance may be protected in response to high work demands at the expense of compensatory costs (Hockey, 1997). However, we cannot completely rule out the possibility that the direction of causation is the opposite: it could be that emotional exhaustion triggers the use of FPS in an attempt to cope. Indeed, research on emotion regulation shows that emotional labor can be simultaneously considered as an effortful process that drains mental resources and as a process for recovering resources by contributing to the development of rewarding relationships (Brotheridge & Grandey, 2002). Further research involving longitudinal follow-up is required to ascertain the nature of causality in this relationship.

Emotional exhaustion is often defined as the first stage of burnout, followed by depersonalization and a loss of personal accomplishment (Maslach et al., 1996). Our findings are a snapshot of the current situation and may be only the visible part of a latent process. Moreover, the final stages of burnout are associated with various forms of job withdrawal (Maslach & Leiter, 2016), making it even more difficult to get a clear picture of the actual situation. However, none of the participants fulfilled the three criteria for burnout diagnosis at the time the MBI was administered. Physicians' high scores on the personal accomplishment sub-dimension act as a protective factor against burnout. The non-significant relationship does not allow us to conclude that FPS are responsible for physicians' beliefs in their competence and successful achievement at work. Finally, our results show that FRS frequency was not significantly associated with any of the three sub-dimensions of burnout, but was associated with decreased reaction time. This suggests that the recurrent use of FRS has no associated costs for physicians' wellbeing in the longer-term. However, we cannot rule out the possibility that the absence of significant relationship is due to small sample size or lack of variability in the data. This study is a first attempt to examine the efficiency of informal fatigue-related risk strategies. Larger and more robust studies are needed to confirm these findings and to evaluate the generalizability of this approach.

Implications for safety

Working fewer hours a week and having healthier sleep habits remains the most efficient way to cope with fatigue-related risks. However, research showed that a reduction in duty hours must be accompanied by appropriate adjustments to the workload if it is to show significant results (12). Conversely, a policy framework based solely on reducing duty hours can be counterproductive. It has been demonstrated that the 2003 ACGME duty hours limitations were associated with reduced educational opportunities, care continuity and perceived quality of care (Desai, S.V. et al., 2013). Our method was to collect accelerometer data to identify recurrent peaks of physical activity and sedentary periods. Taking into account when these peaks occur has potential implications for workload adjustment. This approach could be used to distribute the workforce in such a way that it better matches care demands. Research has shown that ED crowding follows regular patterns and that recent levels of activity can be used to effectively forecast patient volume and adjust the workforce accordingly (Chase et al., 2012). Moreover, by analysing accelerometer data regarding the circadian process we can identify critical periods in terms of fatigue-related risk. Combining these indicators in a comprehensive forecasting tool would allow for further workforce adjustments as well as the development of timely, formal FPS. Finally, this approach is relevant in terms of increasing statistical power and minimizing missing values in small sample field studies of fatigue-related risk.

FRMS should focus on promoting fatigue reduction strategies through formal education programs. In our previous study (Berastegui et al., 2018), focus groups proved to be a powerful way of sharing experiences of fatigue-related risk management. Formal fatigue workshops in the ED could involve physicians sharing ways of managing fatigue-related risk and help managers identify scope for the implementation of more formal processes. Fatigue proofing strategies, on the other hand, should be addressed at the organizational level. It is a challenge for EDs to provide physicians with appropriate resources to keep pace with job demands. Our results highlight that a lack of job resources shifts the strain to the operator's own resources in order to maintain acceptable performance, causing a subsequent risk of burnout. FRMS should focus on developing FPS through the creation of a supportive work environment rather than relying on operators' informal proofing behaviors. Strategies reported during the focus groups showed significant potential for the implementation of more formal processes. The systematic identification of at-risk operators, task redistribution within the team, or increasing standard checks for at-risk operators are examples of such processes (for the detailed results of focus group sessions, see Berastegui et al., 2018). In the same way, FRMS should address the trade-off between work performance adjustments and burnout. Screening for the early symptoms of burnout and awareness programs on coping with these symptoms could provide additional support for emergency physicians while providing valuable indications for managers about the supportiveness of the work environment.

Limits

The empirical results reported herein should be considered in the light of some limitations. First, this is an observational study with possibility of confounding factors inherent to this kind of design. Other notable limitations include small sample size and lack of control group. More robust research is needed in order to clarify whether the main findings can be attributed to other factors rather than fatigue-related risk management strategies.

We used a self-reported measure of work performance. We briefed participants on the anonymity of the data and the fact that no individual information would be shared with colleagues or management. Despite these standard precautions, physicians may have been reluctant to report themselves as poorly competent in specific performance areas. It may be easier for physicians to admit that they lack compassion or empathy for patients rather than to recognise a fault regarding diagnosis or treatment. Literature show that physicians are reluctant to admit problems related to fatigue (O'Reilly, 2012) because of their concerns about confidentiality and about what colleagues may think about their competency (Rosenstein, 2013). Further research with more objective measures is needed to ascertain the impact of fatigue on physician performance.

Reaction times observed in the present study are larger than those typically observed for post-duty PVT in residency settings (Gander et al., 2008). We deliberately sought to maximize effect size by isolating critical time windows regarding to the two-process sleep-regulation model. One alternative explanation for this discrepancy could reside in the latency of response inherent to the consumer level, touch-screen device we used in comparison to a standard manual PVT. We used the fastest 10% reaction rather than standard 500ms lapses to account for this bias. However, we are unable to compare our results with similar studies conducted using manual PVT devices.

Sample slightly differs between phase 1 and phase 3 due to turnover and workforce rotation. We recruited newly arrived physicians in phase 3 in order to increase sample size, and statistical power of the study. As a consequence, the set of strategies identified during focus-group may not be entirely exhaustive. Finally, our results are bound up to the operational setting, and strategies used by emergency physicians are likely to vary from one organization to the other. Further research with larger sample from different facilities is encouraged in order to evaluate the prevalence and effectiveness of these strategies.

Conclusion

This study is a first step towards understanding, quantifying and assessing the impact of informal strategies on fatigue-related risk in the workplace environment. Our findings point out that some of these strategies might result in a trade-off between work performance and physician burnout. This conclusion is consistent with the literature showing that ED professionals are particularly exposed to burnout (Shanafelt et al., 2012), and that clinical performance is relatively preserved despite adverse working conditions (Kramer, 2010). However, as with every observational study, we cannot exclude with certainty potentially unknown confounders which might have influenced our results. Further research in other facilities is required to confirm these preliminary findings and to evaluate the generalizability of this approach.

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