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Fatigue, Sleepiness and Workload in Train Traffic Controllers

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ABSTRACT

The levels of fatigue, sleepiness and mental effort in workers could compromise transport system's security. The objective of this observational field study was to analyze the variation of fatigue, sleepiness and mental effort by shift (morning, afternoon, night), difficulty of work station, age group and consecutive days of work in train traffic controllers. Fatigue was measured by simple reaction time (SRT) and Samn-Perelli perceived fatigue scale; sleepiness by Karolinska Sleepiness Scale (KSS); mental effort with the Rating Scale of Mental Effort (RSME). 93 measurement series were made. The night watch registered the higher values of SRT, fatigue perception scale, KSS and RSME. Workers with 45 years or under rate the work in more difficult work stations with higher values of mental effort. Perceived fatigue and KSS increase with work days' accumulation. The perceived fatigue, sleepiness and mental effort were maintained at medium/low levels, not appearing to be concerning factors.

Keywords: Fatigue, Train traffic controllers, Shift work

INTRODUCTION

There is an increasing requirement in defense, public safety, transports and system control to improve the way the human knowledge and capabilities are used, as fewer individuals are needed to do the same task, concentrating the work in command centers with automated systems (Hollnagel, 2003). The very fast and innovative development in transportation technology, with the consequent increasing in surveillance tasks demands high attention in human factors in the area of transports and in the control centers (Schadow, J. Wwiegand, N. & Bruder, C. 2021).

The automation changed the controller's paradigm, from an element in permanent activity with the system to the supervisor acting when non-regular situations arise (Cheng & Tsai, 2011). Hence, the study of human performance is crucial in automated systems surveillance (Warm, Parasuraman, & Matthews, 2008).

The controller's work demands extensive data processing and constant use of working memory, in addition to complex visual tasks. Unusual situations, incidents and system's faults, which require fast and adequate answers, could be very demanding from cognitive, communication and emotional perspective. Due to this demands and responsibilities, stress and fatigue are common (Donald, 2001). In addition, the controllers work by shifts, an extra effort from the lag between biological and imposed rythms, leading to sleep disorders, sleepiness, fatigue, variable attention levels and decrease of sensibility to the stimuli and performance (Arendt, 2010; Bambra, Whitehead, Sowden, Akers, & Petticrew, 2008). In other hand, prolonged monotony and low-stimulus situations are common in controller's work, factors that also cause sleepiness and fatigue (Williamson, Lombardi, Folkard, Stutts, Courtney, & Jennie, 2011).

The effect of fatigue upon controllers with critical functions in all transportation industries has been a constant concern (Cabon, 2011), because fatigue is one of the major contributors to accidents in the area of transports (Roets, B., & Christiaens, J. 2019). However, there are still comprehension flaws about the interaction between the human controller, the technical system and the work organization (Hockey & Carrigan, 2003).

The work of Dorrian, Baulk, & Dawson's (2011) about the three major professions related to railroad (drivers, controllers and manutention technicians) alerts for the necessity of studying fatigue in train traffic controllers, due the scarcity of studies focused on this population. It revealed that, in average, fatigue, sleepiness and mental effort values do not appear to be problematic. However, it also states that the study of exceptional circumstances should be taken in account, given the shifts' quantity and variability. But a more recent empirical analysis (Roets, B. & Christiaens, J. 2019) shows that there may be factors related to the shift, and the day of the week that can increase the risk in the control centers.

The current study takes place at a command center of rail network, focusing in the analysis of train traffic controllers' work. It aims to add more information to this underexplored area with an integrated characterization of the differences between the three shifts (morning, afternoon, night) and during each shift, relatively to fatigue, perceived fatigue, sleepiness and mental effort levels.

To study most exceptional circumstances, the influence of work station's demands, rush-hour periods, controllers' age and consecutive days of working in the variation of fatigue, perceived fatigue, sleepiness and mental effort is also an objective.

The characterization of these variable levels within the referred conditions is relevant to assess the potential to compromise controllers' health and performance, and, consequently, the traffic control system's safety.

METHODS

Ninety three measurement series were taken through the three shifts, in a group of sixty train traffic controllers, i.e., some were evaluated in more than one shift. Average age was 45.12 ± 0.697 years, 45 of median. Thirty one

Table 1. Number of measurement series distributed by shifts and control station difficulty.

		Less Difficult	More Difficult	Total
	Morning	16	16	32
Shift	Afternoon	17	13	30
	Night	16	15	31
Total		49	44	93

individuals had 45 or more years and 29 controllers less than 45. The distribution between control station difficulty level and shifts categories was balanced, as seen on table 1.

Concerning, **observations**, in order to guide the study, were made ten days of free observation in the control stations, through the three shifts. The controllers' activities were monitored; simultaneously, questions were made about the tasks and activities, system operation and work organization.

Several **measurements** were used. SRT – Simple Reaction Time. The variation of simple reaction time to visual stimulus was selected as objective indicator to evaluate fatigue. As higher the reaction times gets, more fatigue the subject has (Kroemer & Grandjean, 1997). The test to measure the SRT was programed in Superlab, Stimulus Presentation Software, from Cedrus Corporation. The 32 visual stimuli, a black square at the center of a white background, were presented in random intervals of 1500, 2000 and 2500 milliseconds, to avoid anticipated answers. The tests were performed in a 12 inches laptop, pressing the "space" key to respond to the square appearance.

SPFS – Samn-Perelli Fatigue Scale. Seven point Samn-Perelli Fatigue Scale, developed by Samn & Perelli (1982), was used to measure perceived fatigue. Number 1, the lower degree of fatigue, matches "Fully alert, wide awake", the number 7, the highest degree, corresponds to "Completely exhausted, unable to function effectively". This scale was selected because of its easy translation for Portuguese, simplicity and fast fill out. It had been also used by Dorrian, Baulk, & Dawson (2011) with train traffic controllers. KSS – Karolinska Sleepiness Scale. To measure sleepiness was selected the Karolinska Sleepiness Scale, developed by Akerstedt and Gilbert in 1990 (Kaida, et al., 2006). It is useful for measure changes due to environmental factors, circadian rhythm variations and drugs (Shahid, Shen, & Shapiro, 2010). KSS ranges from point 1 ("very alert") to point 9 ("very sleepy, fighting sleep"). Kecklund and Akerstedt (1993) reported that KSS increase through extended periods without sleep and it's strongly correlated with the moment of the day. Kaida, et al. (2006) concluded a strong correlation between EEG, some behavioral variables and KSS. RSME - Rating Scale of Mental Effort. The scale, developed by Zijlstra (Waard, 1996), was selected for this study to measure the amount of mental effort spent during a period of operation in the control stations. This scale is composed by a 150 mm vertical line, ranging from "Absolutely no effort" to higher than "Extreme effort".

Concerning **procedures**, fifteen days of measure tacked place, five for each shift. A group of control stations was selected. The measures were made to

Table 2. Mean (SD) hours for each measurement moment.

	Moments	1^{st}	2^{nd}	3^{rd}
Shift	Morning	8:08h (26min)	10:38 (24min)	14:05 (1:07h)
	Afternoon	15:28h (24min)	18:27 (43min)	21:37 (1:50h)
	Night	23:22h (32min)	4:04 (23min)	7:06 (17min)

the assigned controller at the selected shift, instead of following up a group of controllers. The selection and categorization by difficulty was made with de board of the command center and according to the observations too. The measurement series were taken at three specific moments during the shift. The first series took place when the controllers arrived, except for the RSME, applied 30 minutes after the beginning. The second series occurred at the middle of the afternoon and night shifts, and after the rush-hour, about 10:30 am, at the morning shift. The third series was made before the controllers leave, at the end of the shift. In Table 2 can be seen the average hours when the measurement series took place. The Rating Scale of Mental Effort was the first to be filled, to take a more precise measure, temporally the closest to the tasks. After this, the KSS and SPFS with the SRT test in between.

Differences among shifts were assessed using Kruskal Wallis test. The multiple comparison test was used to confirm which shift detaches. To testing differences between two evaluation moments within the shift was used Wilcoxon test.

Differences amid the two categories of age, difficulty and consecutive days of work were tested with T- test, applying the central tendency theorem.

Mann Whitney test was used to access differences between age groups by difficulty categories. The correlation between measures was assessed by Spearman's rank correlation coefficient.

RESULTS PRESENTATION AND DISCUSSION

Concerning **shifts**, observing the absolute values of SRT (Table 3), no effect of shift type on fatigue was recorded. This is according with Takeyama, et al. (2005). But, if the analyses is made by the average variation first to third moment of analysis, an effect is noted - the night shift records the highest variation (4.57 $\pm$ 7.62ms), compared to morning (2.21 $\pm$ 5.88ms) and afternoon (1.16 $\pm$ 4.39ms) shifts ($\chi 2 = 10.350$; df $= 2$; $p = 0.006$). The night shift records the higher values of perceived fatigue and sleepiness, too, when compared to the other two shifts (Table 3). Ahsberg, Kecklund, Akerstedt, & Gamberale's (2000) study report this same result only for the sleepiness values. The lower/median values of mental effort can explain why there isn't an effect of shift type. Despite this, the controllers report slightly higher values at night shift. Analysing the values variation during each shift, in every measure there is an increase, i.e., in every shift there is an indication of central nervous system activity decrease.

At the night shift there are increasing and meaningly higher variations of SRT ($z = -3.390$; $p = 0.001$), perceived fatigue ($z = -4.308$; $p < 0.001$),

Table 3. Means (SD) for each evaluation moment by shift: SRT (also has the mean variation between the 3rd and 1st moments), perceived fatigue, sleepiness and mental effort.

	Moments	Morning	n	Afternoon	n	Night	n	*p*
SRT (ms)	1st	350(50)	32	346(59)	28	361(72)	31	0.473
	2nd	374(50)	27	365(57)	30	388(79)	30	0.199
	3rd	372(57)	30	377(105)	30	407(90)	31	0.059
	Δ(3rd-1st)	2.21(5.88)	30	1.16(4.39)	28	4.57(7.62)	31	0.006*
	p(3rd-1st)**	0.005		0.124		0.001		
Perceived fatigue	1st	2.62(1.21)	32	2.81(0.79)	27	3.26(0.93)	31	0.039
	2nd	2.87(1.01)	30	2.93(0.74)	30	3.90(0.96)	30	<0.001*
	3rd	3.33(0.92)	27	3.20(0.71)	30	4,22(0.92)	31	<0.001*
	p(3rd-1st)**	0.003		0.046		<0.001		
Sleepiness	1st	3.53(1.98)	32	3.25(1.62)	28	3.58(1.86)	31	0.778
	2nd	3.53(1.89)	30	3.23(1.10)	30	5.20(2.12)	30	<0.001*
	3rd	3.93(1.69)	27	3.70(1.39)	30	5.80(2.04)	30	<0.001*
	p(3rd-1st)**	0.254		0.096		<0.001		
Mental Effort	1st	32.91(24.05)	32	33.25(25.36)	28	30.90(25.37)	31	0.945
	2nd	45.90(24.58)	30	44.80(24.46)	30	49.43(25.49)	30	0.885
	3rd	45.11(20.43)	27	50.47(24.44)	30	56,45(26.78)	31	0.267
	p(3rd-1st)**	0.003		0.001		<0.001		

* differences between shifts

** difference between 1st and 3rd moments

sleepiness ($z = -4.315$; $p < 0.001$) and mental effort ($z = -4.433$; $p < 0.001$). These results confirm the demands of shift work, especially at night, described by Donald (2001), with the higher gap between the biological and imposed rhythms occurring at the night shift (Arendt, 2010). The under/overload theory, proposed by Kroemer & Grandjean (1997), could explain this values too. At night, at one hand, are found the most demanding tasks in some control stations, like control maintenance works, which require permanent concentration during the shift, at the other hand, there are many stations with lack of tasks for almost the entire shift.

The morning shift records less demarked values than the night shift, but maintain an increase in SRT ($z = -2.818$; $p = 0.005$), perceived fatigue ($z = -2.941$; $p = 0.003$); and mental effort ($z = -2.959$; $p = 0.003$). This result could be explained due to the workers' early wake up, going against the circadian cycle and, eventually, sleeping less time with less quality. Gander (2011) identified this fatigue genesis in her work with air traffic controllers. In this unfavorable internal state, they initiate the shift with a demanding rush-hour period management, without a "harm-up" period.

The afternoon shift it's the less expressive of the three. An effect was recorded just in perceived fatigue ($z = -1.998$; $p = 0.046$) and mental effort ($z = -3.395$; $p = 0.001$). The inicialy long and low demanding period, ending with a lengthy, but less demanding rush-hour, may explain these results.

All shifts recorded an increasing in perceived fatigue and mental effort; just in the night shift the sleepiness increases. The maximum average values

Table 4. Comparison between the two categories of control stations' difficulty (less/more difficult) by measure's mean (SD).

	Difficulty	N	Mean	p*
SRT	less	49	364(62) ms	0.212
	more	44	381(70) ms	
Perceived fatigue	less	49	3.26(0.94)	0.806
	more	44	3.21(0.86)	
Sleepiness	less	49	4.01(1.81)	0.860
	more	44	3.95(1.62)	
Mental effort	less	49	38.26(23.00)	0.015
	more	44	49.35(19.69)	

*differences between less difficult and more difficult control stations

of perceived fatigue, sleepiness and mental effort stay at medium to low levels. Perceived fatigue at the night shift stay close to point 4 of Samn-Perelli scale ("A little tired, less than fresh"). Sleepiness, at the same shift, approaches to point 6, at Karolinska Sleepiness Scale, and mental effort stay around ("Rather much effort") mark, between 50 and 60 points. In other words, the average values are around or below medium levels even at the more demanding periods, not becoming concerning factors. Dorrian, Baulk, & Dawson (2011) obtained the same result with the Samn-Perelli Fatigue Scale and made the same conclusion. The results related to inter and intra shift analyses were summarized at table 3.

An effect of **control station difficulty** was registered in mental effort. The controllers reported higher mental effort in the control stations categorized as more difficult. The previous difficulty categorization of control stations proved adequate. However, no other value corroborate this assumption. Table 4 depicts the comparison between more and less difficult control stations.

An effect of **rush-hour** period on SRT, perceived fatigue and mental effort was noted, all the values increase in this demanding period. It can be said that, in fact, the morning rush-hour is a more demanding period, with higher rates of fatigue and mental effort, than the rest of the shift, wherein just sleepiness and perceived fatigue increases (Table 5).

The afternoon shift also has a rush-hour period, but it matches with the shift's end, so, it can't be said exactly that the results are due to tiredness or to a demanding period.

No effect of **age group** was recorded. The SRT, perception of fatigue, sleepiness and mental effort do not changed with age.

Concerning age group by control station difficulty, no effect of age group it's seen in the two categories of control station difficulty. Despite this, controllers with more than 45 years old record slightly inferior values in the more difficult control stations (Table 6). This difference suggests that the older controllers may have developed strategies to deal with more demanding tasks.

Table 5. Comparison between two periods (1st-2nd evaluation moments/rush hour and 2nd to 3rd evaluation moments) at morning shift, by measure.

	(1st - 2nd) rush-hour	*p*	(2nd - 3rd)	*p*
SRT		0.030		0.677
Perceived fatigue		0.038		0.007
Sleepiness		0.892		0.026
Mental effort		<0.001		0.442

Table 6. Comparison between age groups by the two categories of control station difficulty, through measure's means (SD).

	Less Difficult Control Stations			More Difficult Control Stations		
	≤45	>45	*p**	≤45	>45	*p**
SRT	356(31)	372(82)	0.857	401(87)	364(46)	0.085
Perceived fatigue	3.13(0.73)	3.39(1.12)	0.355	3.47(0.94)	3.00(0.75)	0.156
Sleepiness	3.93(1.55)	4.09(2.09)	0.968	4.13(1.78)	3.79(1.52)	0.585
Mental effort	36.04(23.40)	40.58(22.84)	0.589	54.23(16.88)	45.29(21.24)	0.077

*Differences between age groups

Table 7. Comparison between consecutive days of work categories (<3 – n = 46; ≥3 – n = 47) by measure's means (SD).

			p
SRT	<3	371 (64)ms	0.952
	≥3	372 (68)ms	
Perceived fatigue	<3	2.98 (0.87)	0.006
	≥3	3.48(0.87)	
Sleepiness	<3	3.59 (1.55)	0.031
	≥3	4.36 (1.79)	
Mental effort	<3	42.31(20.09)	0.606
	≥3	44.6879(24.05	

An effect of **consecutive days of work** was found on perceived fatigue and sleepiness. The controllers with 3 or more consecutive days of work reported more fatigue and sleepiness (Table 7).

Concerning **correlation between measures,** Samn-Perelli Fatigue Scale established high correlation with Karolinska Sleepiness Scale ($\rho = 0.839$; $p < 0.001$). This result may be justified by the similarity of the scales, both Likert's, with resembling descriptors. Ahsberg, Kecklund, Akerstedt, & Gamberale (2000) had observed this same correlation. SRT has low correlation with the SPFS ($\rho = 0.280$; $p = 0.007$) and the KSS ($\rho = 0.388$; p <

0.001), indicating the perceived scales' utility as references to more objective methods. RSME has low correlation with the SPFS ($\rho = 0.209$; $p = 0.044$).

CONCLUSION

One limitation should be appointed to this study, concerning the inexistence, to date, of reference values for SRT in any kind of population, which could establish a parameter to compare the level of fatigue. So, it was difficult to understand if a difference in SRT can be, in fact, considered fatigue. It was also not possible a full comparison of this work with other studies, because they used different population or different tests to measure fatigue. Just having the Samn-Perelli Fatigue Scale as reference, did not allowed to understand the absolute value of fatigue.

The results of this study with train traffic controllers feature the night shift with more evidence of fatigue, sleepiness and mental effort. There is suggestion of CNS activity's decreases in every shift, more demarked at night. This assumption is according to the literature.

Other hints were revealed: the control stations perceived as more demanding were, in fact, the most difficult. The morning rush-hour may be a more demanding period of work. The controllers with more than 45 years old may be less tired in more demanding posts, due to experience. After 3 or more days, there was perception of more fatigue and sleepiness.

The controllers' work does not appear to be problematic, referring the medium to low levels of fatigue, sleepiness and mental effort, according to Dorrian, Baulk, & Dawson (2011). However, it is necessary to maintain surveillance and deepen the study of some situations with potential to affect controllers' health and performance, namely the night shift, rush-hours and the work through several consecutive days.

Therefore, the great contribution of this study was to establish bases for future studies, which could explore the combined effect of demanding control stations, controllers' psychophysical state, critical situations and non-regular events on controllers' performance and system safety. In this factors combination lies the potential to negatively affect the normal function and safety of the railroad network system.

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REFERENCES

Ahsberg, E., Kecklund, G., Akerstedt, T., & Gamberale, F. (2000). Shifwork and different dimensions of fatigue. International Journal of Industrial Ergonomics, 26(4), 457–465.

Arendt, J. (2010). Shift work: coping with the biological clock. Occupational Medicine, 60, 10–12.

Bambra, C. L., Whitehead, M. M., Sowden, A. J., Akers, J., & Petticrew, M. P. (2008). Shifting Schedules-The Health Effects of Reorganizing Shift Work. American Journal of Preventive Medicine, 34(5), 427–434.

Cabon, P. (2011). Fatigue in air traffic control. Hindsight: Human and organizations factoors in operations, 13, 55–59. (Recovered in 28 February 2022 in: https://skybrary.aero/bookshelf/hindsight-13-fatigue-air-traffic-control)

Cheng, Y.-H., & Tsai, Y.-C. (2011). Railway-controller-perceived competence in incidents and accidents. Ergonomics, 54(12), 1130–1146.

Donald, C. (2001). Vigilance. In J. Noyes, & M. Bransby, People in Control - Human factors in control room design (35-38). London: The Institution of Engineering and Technology.

Dorrian, J., Baulk, S. D., & Dawson, D. (2011). Work hours, workload, sleep and fatigue in Australian Rail Industry employees. Applied Ergonomics, 42(2), 202–209.

Gander, P. (2011). Fatigue management in air traffic control: the New Zealand approach. Transportation Research Part F, 4(1), 49–62.

Hockey, B., & Carrigan, N. (2003). Human Factors in railway systems: implications for safety. Leeds, UK: Human Factor Laboratory, School of Psychology, University of Leeds.

Hollnagel, E. (2003). Handbook of Cognitive Task Design. Lawrence Erlbaum Associates, ublishers: London.

Kaida, K., Takahashi, M., Akkerstedt, T., Nakata, A., Otsuka, Y., Haratani, T., et al. (2006). Validation of the Karolinska sleepiness scale against performance and EEG variables. Clinical Neurophysiology, 117(7), 1574–1581.

Kecklund, G., & Akerstedt, T. (1993). Sleepiness in long distance truck driving: an ambulatory EEG study of night driving. Ergonomics, 36(9), 1007–1017.

Kroemer, K. H., & Grandjean, E. (1997). Fitting the task to the human (5^a ed.). Taylor & Francis.

Roets, B. & Christiaens, J. (2019) Shift work, fatigue, and human error: An empirical analysis of railway traffic control, Journal of Transportation Safety & Security, 11(2), 207–224.

Samn, S. W., & Perelli, L. P. (1982). Estimating aircrew fatigue: a technique with application to airlift operations. Brooks Air Force Base, Texas: USAF School of Aerospace Medicine.

Schadow, J., Wiegand, N., & Bruder, C. (2021, September). Human Factors in Urban Transport: Control Room Resource Management Training (CRRM). In Proceedings of the Human Factors and Ergonomics Society Annual Meeting. 65(1), 1466–1469. Sage CA: Los Angeles, CA: SAGE Publications.

Shahid, A., Shen, J., & Shapiro, C. M. (2010). Measurements of sleepiness and fatigue. Journal of Psychosomatic Research, 69(1), 81–89.

Takeyama, H., Itani, T., Tachi, N., Sakamura, O., Murata, K., Inque, T., et al. (2005). Effects of shift schedules on fatigue and physiological functions among firefighters during night duty. Ergonomics, 1–11.

Waard, D. d. (1996). The Measurement of Drivers' Mental Workload. Haren, Holanda: The Traffic Research Centre VSC.

Warm, J. S., Parasuraman, R., & Matthews, G. (2008). Vigilance Requires Hard Mental Work and Is Stressful. Human Factors, 50(3), 433–441.

Williamson, A., Lombardi, D. A., Folkard, S., Stutts, J., Courtney, T. K., & J. L. (2011). The link between fatigue and safety. Accident Analysis and Prevention, 498–515.