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Safety, stress and work zone complexity: A field study on police officers performing on-foot traffic control

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ABSTRACT

Workers such as police officers are exposed to many hazardous situations while performing traffic duties, which renders them vulnerable to work accidents. Such a dangerous work context can lead to high stress levels. This is conducive to performance impairment and, consequently, to high-risk situations in which safety, for both workers and road users, may be jeopardized. It then seems important to better understand the stress experienced by traffic workers to ultimately improve road safety. Hence, the current study aims at investigating whether work context could be associated with the stress levels of police officers doing traffic duties on foot. Nineteen police officers in Quebec City and Montreal, Canada, performed traffic duties on several sites (including constructions ones) while their physiological state was measured by a wearable sensor harness. Change in subjective stress was measured every 15 min. Characteristics of the environment were also noted for every working site, which permitted to perform hierarchical cluster classifications to assess each site's complexity. Results show that stress levels were significantly lower for less complex sites. Interestingly, traffic and safety measures—identified through automated computer vision—differ depending on the site complexity and were generally associated with measures of stress. Taken together, these results suggest that the context in which pedestrian workers perform traffic duties, that is the environment and the higher-risk events to which they are exposed, can lead to higher levels of stress. Implications for road safety are discussed in light of these results.

1. Introduction

Individuals working afoot, that is pedestrian workers, often need to carry out tasks on the side of or directly on the road. Such a work context is highly prevalent among work accidents (Pignatelli et al., 2003). For instance, an analysis of 240 accidents between 1993 and 1997 involving workers from the New York State Department of Transportation showed that 15% of all the serious traffic injuries and >40% of the fatalities involved pedestrian workers (Bryden and Andrew, 1999). A systematic review of epidemiological studies whose objective was to investigate risk factors for work-related road traffic crashes and injuries has reached the conclusion that these types of accidents represent a significant public health problem (Robb et al., 2008). Workers such as flaggers or traffic-control police officers whose job may require managing car, cyclist and pedestrian traffic on construction sites or during road closures (for various events like concerts) are vulnerable in such a dangerous work context. Although several prevention programs and tools have been developed to mitigate the risks of performing such traffic duties (Fan et al., 2014; Graham and Burch, 2006), accidents still occur. For example, between 2000 and 2010, almost half of all the pedestrians hit by surrounding traffic in Wisconsin were flaggers working on construction sites (Yu et al., 2013).

Factors associated with road safety are usually put in three categories: the infrastructure, the vehicles and the road users. Road user behavior is considered the most important category and can also be affected by their own actions or state. Studies employing qualitative interviews have permitted to identify the causes that traffic workers associated most to hazardous situations. These causes included: distraction, excessive speed or non-compliance of road users, a short distance between the construction site and the road, a lack of visibility, but also fatigue and inattention among traffic workers (Davezies and Charbotel, 2005; Debnath et al., 2014; Haworth et al., 2000). Mitchell et al. (2004) also reported that fatigue is a prominent factor that increases the risk of road accidents among workers. Fatigue is also known to increase stress (Taylor and Dorn, 2006).

As put by Kolbell (1995), stress can be defined as "a particular response of an organism to an identified demand stimulus" and can be

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produced when one experiences a demand that "exceeds his or her real or perceived abilities to successfully cope with the demand, resulting in disturbance to his or her physiological and psychological equilibrium" (p. 31). Regarding road workers whose job is to manage traffic, stress can be exacerbated when facing specific situations known to be related to road accidents (Debnath et al., 2014) or because of the plethora of information that constantly needs to be attended while performing traffic duties (Warm et al., 2008). Police officers sometimes perform traffic duties. Even if their job may require intervening in dangerous, violent or extreme situations, police officers may still experience stress while managing traffic, especially in the context of road work or of traffic congestion (Kumar and Mohan, 2009; Deb et al., 2008). This may however mitigate the precision of their task and, consequently, their safety and that of the road users. Stress and high job demands have indeed been related to performance disruption under many situations (Colligan and Higgins, 2006). Several studies have shown that stress and high workload demands can hinder performance in other high-risk domains in which the safety of people is at stakes, such as in air traffic control (Hodgetts et al., 2015), piloting (Dehais et al., 2014) or command and control (Grier, 2015).

Even if traffic workers are also exposed to highly demanding and complex situations and may experience stress, very few studies have assessed what could cause stress. Recently, Marois et al. (2018) investigated whether the stress reported by police officers performing traffic duties could be predicted by a variety of different variables. In that study, the authors used real-time self-perceived stress measures of police officers performing traffic duties while measuring some situational factors and the workers' physiological activity. Results showed that self-perceived stress could be predicted with decision-tree ensembles, the situational and physiological models achieving predictive accuracy of 79.13% and 77.47%, respectively. Although the results of that study uncovered significant relationships between self-reported stress, work context elements and physiological activity while performing traffic duties, it remains unsure whether stress systematically varies across a range of contextual prototypical situations or situation categories. Clarifying what characteristics of the work environment are associated with stress could help develop prevention tools to avoid hazardous situations that may be caused by stress-induced performance disruption. This may allow determining that a given work context is conducive to higher stress and lower safety, then helping to elaborate safety systems or to establish relevant practices to render the work zones safer.

Building upon Marois et al.'s work and data (Marois et al., 2018), the current study aims at clarifying whether the context (site complexity and traffic conflict situations) in which traffic duties are performed could be associated with stress among traffic workers. This study relies on the classification of working site complexity and the extraction of traffic and safety indicators from video data collected at different sites. These latter measures represent actual risky situations that happened while traffic was being controlled, which could ultimately have impacted police officers' stress levels. More specifically, the present study seeks to: 1) Assess whether physiological and self-reported stress of the police officers could differ depending on the working site complexity in which they performed traffic duties; and 2) determine whether surrogate measures of safety, representative of traffic conflict situations, could differ according to the working site complexity, and whether these measures could be related to the police officers' physiological and self-reported stress.

To achieve these aims, we analyzed real-time measures of physiological and self-reported stress of police officers carrying out traffic duties and garnered environmental characteristics to assess each working site's complexity (Marois et al., 2018). Video-based analyses are also performed to extract traffic variables (counts) and surrogate measures of safety for all road user interactions (e.g., road users' speed and interactions' time-to-collision) passing through the working sites. The paper is organized as follows. First, a conceptual framework, theoreticized to underlie the relationships of the variables of interest, is presented. It is followed by the method and results sections. The discussion and conclusion sections then propose an integration of the results while contextualizing them with relevant literature, and implications of the present study for our conceptual framework, as well as for future work on the matter, are also presented.

2. Conceptual framework to observe the safety of road workers in traffic

Fig. 1 illustrates the proposed relationships (either positive or negative) between work environment, stress, traffic control performance and the safety of road users and traffic workers. Variables that are specifically measured in the present study (working site complexity, traffic conflict situations, physiological activation and psychological state) are related to the work environment and stress (text boxes with white background in Fig. 1) whereas traffic control performance and road users' and traffic workers' safety have not been assessed (grey background in Fig. 1). Working environments are characterized by the working site complexity and the occurrence and severity of traffic conflicts through surrogate measures of road safety while stress is characterized by the physiological activity and psychological state. Working site complexity is hypothesized here to be positively correlated with the number and severity of road conflict situations, leading more complex working sites to be associated with more road conflicts. The positive relationship between work environment and stress is also hypothesized to conduct to higher measures of stress in more complex work environments. Physiological activation and psychological state being strongly and positively correlated, higher work environment complexity and number of traffic conflict situations should result in higher measures of physiological and self-reported stress.

3. Material and methods

3.1. Participants

Eight Police officers from Montreal (5 women) and 11 from Quebec City (1 woman), Canada, volunteered to take part in the study. They were recruited through the project steering committee officials in charge of health and safety at work for both city precincts. In all cases, participants were monitored while performing traffic duties in a work zone for 1 to 8 work shifts ($M = 3.3$, $SD = 1.8$) that lasted between 60 and 285 min ($M = 150$, $SD = 45$). Fifty-four sessions were recorded, comprising a total of 614 periods of 15 min. Trained students (one team of two students per city) were meeting the officers before their shift to help them with the equipment. Their first meeting also included a presentation of the project, the data collection process, and the consent documents to be signed.

3.2. Data collection and pre-processing

3.2.1. Stress measures

Self-reported stress was first assessed at the beginning of each work shift using a 10-point Likert scale (where 1 = low, 10 = high). While working, participants were asked every 15 min to indicate whether their level of stress had decreased, increased or remained stable. Physiological measures were garnered and pre-processed by the built-in system provided by a Zephyr BioModule BH3 (Zephyr Technology) chest strap worn by each participant. This BioModule measured movement, cardiac and respiratory activity. Three physiological metrics computed by the system were used for this study (Marois et al., 2018): 1) heart rate (HR) was calculated by using the total number of heartbeats on the total recording time of the smoothed and artifact-filtered normal to normal (NN) signal; 2) heart rate variation (HRV) was calculated by performing a rolling 300 heartbeat-standard deviation of the NN (SDNN) signal (Camm et al., 1996); and 3) respiratory rate (RR) was calculated by

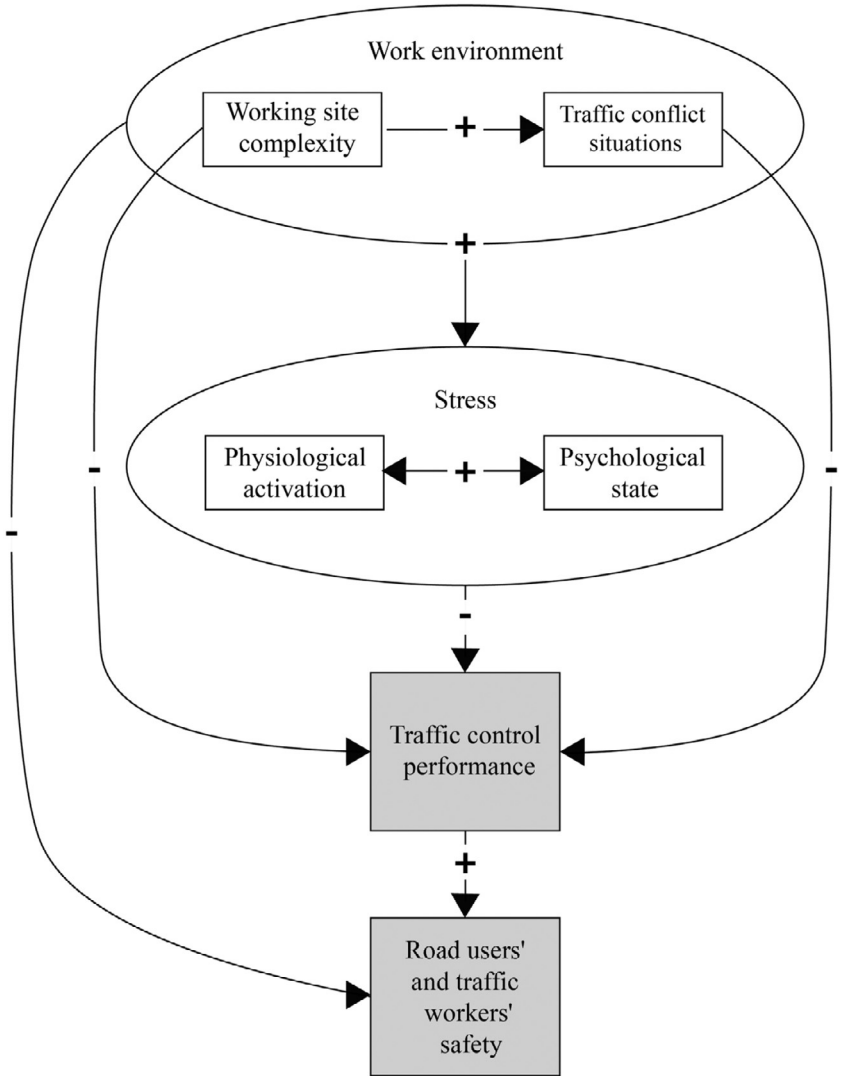


Fig. 1. Conceptual framework of the current study. The relationships depicted between the variables that were measured (white background) or not (grey background) can either be positive (+) or negative (−).

using the total number of torso expansion-contraction cycles on the total recording time. Data for which the system indicated a validity index of 80% or less were removed afterward.

3.2.2. *Working sites characteristics and classification*

Several characteristics of the working sites were noted each time a police officer was on duty. The presence of the police officer at those specific sites was mostly due to construction (29 of the 37 sites were labeled as such), the rest of them being sites where special events or festivals were blocking the road. Data were gathered on iPad using the Survey123 app (ArcGIS, Environmental Systems Research Institute) either for each 15-min period (traffic conditions: cars, pedestrians and cyclists) or once a day (site characteristics). Information on site was collected at the street segment level and then aggregated at the intersection level. To create the site typology, four category variables were generated based on observed characteristics (see Table 1). The first two of them are the total number of street segments and the type of segments at the working site, both with four categories. The two other indicators are capturing the complexity of the task and the complexity of the site. While the former is based on the presence of specific infrastructure, the latter considers the number of different workers on site (Table 1). The indicators were calculated by summing up the presence of selected variable at each site, divided by the maximum value possible (12 for the task and 20 for the site), to create indicators varying from 0 (very low complexity) to 1 (very high complexity).

Table 1
Variables used in the cluster analysis and their attributes.

Variable	Attributes
Number of street segments at the working site (categories 1 to 4)	1.Two segments: not an intersection 2. Three segments: T-type intersection 3. Four segments: typical intersection 4. More than 4 segments: complex intersection
Type of street segments at the working site (categories 1 to 4)	1. In the middle of a single segment 2. On the shoulder or near entry/exit 3. At an intersection with at least one local street 4. At an intersection with all major streets
Task complexity at the working site (value between 0 and 1)	1. Number of two-way street segments 2. Number of cycling lanes 3. Number of pedestrian crossings
Working site complexity (value between 0 and 1)	1. Number of segments affected by construction/event 2. Number of workers (related to the construction/event) 3. Number of flaggers 4. Number of police officers (excluding the one under observation)

Table 2
Description of working sites clusters.

Description	Cluster				Total
	Cluster 1	Cluster 2	Cluster 3	Cluster 4	
Number of sites					
In Montreal	9	3	1	1	14
In Quebec	4	8	8	3	23
Complexity of the task (*M*)	0.53	0.55	0.38	0.54	0.50
Complexity of the site (*M*)	0.51	0.40	0.35	0.25	0.41
Number of segments per site					
Not an intersection	0	0	2	0	2
3 segments	0	0	7	4	11
4 segments	9	11	0	0	20
More than 4 segments	4	0	0	0	4
Type of segments at the working site					
In the middle of a single segment	0	0	2	0	2
On the shoulder or near entry/exit	0	0	7	0	7
At least one local street	0	11	0	1	12
All major streets	13	0	0	3	16

The final four variables were used to perform a hierarchical cluster analysis using the between-groups Euclidean square distance aggregation under the Ward method (SPSS Statistics, IBM). Four clusters were identified, and Table 2 presents the descriptive statistics for each variable in each cluster. Cluster 1 encompasses the most complex sites where police officers must deal with higher traffic since these sites are all major roads. Cluster 2 is also complex (all 4-segment sites) but all sites had at least a local road and the site complexity is lower than cluster 1. Cluster 3 is the least complex with most segments not being at an intersection and therefore having low values for both complexity indices. Finally, cluster 4 has two distinct characteristics: it only comprises 3-legged intersections (T-intersections) and it has the lowest site complexity, meaning very few workers were on site.

3.2.3. *Video-recording, traffic variables and surrogate measures of road safety*

Traffic video data were garnered to obtain traffic variables and surrogate measures of road safety (Ismail et al., 2009; Saunier et al., 2011). Cameras were installed on telescopic poles on each of the working sites on which traffic duties were performed to collect these measures. This video-based analysis of surrogate measures was chosen given that more traditional measures of road safety (e.g., road accident data) are too scarce and lack details (Zangenehpour et al., 2015).

The software used to extract the surrogate measures of safety is available in the open-source Traffic Intelligence project (Saunier, 2016). Based on the computer vision library OpenCV (Brahmbhatt), this software provided a feature-based tracker, trajectory management and coordinate projection functionality for each road user, and the analysis of all road user interactions, defined by the co-existence of two road users for at least half a second in the area of interest where the subject was working (St-Aubin et al., 2015a). For each period of 15 min, 12 traffic variables and measures of safety regarding speed, distance, post encroachment time (PET)—that is the time between the moment one road user leaves a spatial zone and the moment another one crosses the same zone (Allen et al., 1978)—and time to collision (TTC)—namely the time remaining before two objects collide if no evasive actions are undertaken (Hayward, 1971)—were extracted (see Table 3). All measures are based on variables that are continuous over time at the road user or interaction level, except for PET. Therefore, these variables need to be aggregated at the road user or interaction level first, then for each 15-min period. Percentiles are generally favored as they are more robust to noise and errors in automated video data analysis, and the 15th percentile of TTC was in particular identified as the best TTC statistic by St-Aubin et al. (St-Aubin et al., 2015b). Aggregation per 15-min time interval is done in two ways, through a percentile of the distribution per user or interaction, but also by counting the number of events where the user or interaction-level statistic reaches some critical level, e.g. the number of users with their 85th percentile speeds over 50 km/h or the number of interactions with their 15th percentile TTC below 1.5 s. Higher speed-related measures and lower proximity measures (time-based measures like PET and TTC and distance measures) are related to lower safety.

The conditions that were generated by the Traffic Intelligence software (Saunier, 2016) were visually inspected for validation and unrealistic measures (e.g., very high speed) were identified to correct the video-analysis parameters. Epochs in which the video feed comprised too much noise (e.g., if the camera moved systematically) were removed from the analysis. Periods for which the video feed comprised >5 min of missing data were excluded of the analysis. This allowed obtaining 296 valid periods of 15 min (corresponding to 74 h of processed video data) for which the 12 traffic and safety measures presented above were available. Although no systematic validation was performed, it is noteworthy that this algorithm was successfully used and previously applied to compute similar surrogate measures of safety in other studies (Zangenehpour et al., 2015; Saunier and Sayed, 2006).

3.3. *Analysis*

Two different types of analysis were performed to answer our research questions: working site types were compared according to stress measures and traffic and safety measures; and both stress measures (physiological and self-perceived) were related to traffic conflicts indicators. Analyses were always performed at the 15-min period unit because we aimed at analyzing the relationship between stress and other dynamic safety and roadway conditions for each self-reported measure. This allowed us to avoid using averaging techniques that would have led to a variability loss for each measure. Due to missing data, between 296 and 398 15-min periods were employed for both types of analysis.

Table 3
Surrogate measures of safety extracted from the video-based analysis.

Measure[a]	Description
1. *N* Interact	Number of interactions between road users over the 15-min period
2. PET15 (s)	15th percentile of PET over the 15-min period
3. Distance15 (m)	15th percentile of road user distance in an interaction (15th percentile per interaction) over the 15-min period
4. Speed diff85 (km/h)	85th percentile of road user speed differential in an interaction (85th percentile per interaction) over the 15-min period
5. TTC15 (s)	15th percentile of TTC15 (15th percentile of the TTC per interaction) over the 15-min period
6. *N* PET 1.5 s	Number of interactions characterized by a PET under 1.5 s
7. *N* Distance15 30 m	Number of interactions characterized by the 15th percentile of the road user distance under 30 m
8. *N* Speed diff85 50 km/h	Number of interactions characterized by the 85th percentile of the road user speed differential over 50 km/h
9. *N* TTC15 1.5 s	Number of interactions characterized by the 15th percentile of the TTC per interaction under 1.5 s
10. *N* Road users	Total number of road users over the 15-min period
11. Speed85 (km/h)	85th percentile of the road user speeds (85th percentile per road user) over the 15-min period
12. *N* Speed85 50 km/h	Total number of road users with their 85th percentile of speed over 50 km/h

[a] Measures 1 to 9 are at the interaction level whereas measures 10 to 12 are at the road user level.

3.3.1. Working site complexity analysis

To test for differences in stress among the work site subgroups, a one-way Multivariate Analysis of variance (MANOVA) with the factor clusters (clusters 1 to 4) was run on the self-perceived stress and on the measures of HR, HRV and RR activity available for each 15-min period. These three physiological measures were specifically chosen given the previous demonstration of stress prediction by using these physiological data (Marois et al., 2018) and the MANOVA analysis was privileged as both physiological and subjective types of stress measures were expected to represent a common latent stress construct (Kolbell, 1995) (see also Fig. 1). Despite the heterogeneity of variance-covariance matrix (Box's $M = 242.46$, $p < .001$), the MANOVA was still performed as group sizes were all over 30 (Allen and Bennett, 2007).

Measures of traffic and safety were also compared across all four working sites clusters to investigate whether the complexity of a site could be associated with traffic and safety indicators. Such analysis was also conducted by performing a one-way MANOVA comprising each of the 12 traffic and safety measures collected each 15 min as dependent variables, representative of a common safety latent construct (cf. Fig. 1). Again, the MANOVA was performed despite the heterogeneity of variance-covariance matrix (Box's $M = 2420.47$, $p < .001$) due to the group sizes (Allen and Bennett, 2007). Univariate tests for both MANOVAs were performed using a Welch correction and estimated ω^2 was used as a measure of effect size when variance homogeneity was violated. Multiple comparisons were undertaken with a Games-Howell correction to adjust for variance heterogeneity. For both MANOVAs, no problem could arise from normality nor from the number of dependent variables due to the overall large sample size ($N > 40$) (Seo et al., 1995) and the cases-to-dependent variables ratio ($n > 12$) (Tabachnick and Fidell, 2013), respectively.

3.3.2. Measures of traffic and safety and correlation with stress

The impact on stress of traffic and safety measured through video analysis was assessed through correlational analyses, using the Pearson correlation coefficient. For each 15-min period, self-reported stress was compared with the 12 traffic and safety measures. Physiological data (namely HR, HRV and RR) were also averaged over the same 15-min periods to match the self-reported stress intervals and the traffic and safety measures.

4. Results

4.1. Subjective and physiological stress

As reported by Marois et al. (2018), the pre-work shifts subjective stress reported by police officers was 2.06 out of 10 ($SD = 2.01$). Among the 15-min periods, stress decreased 8.14% of the time, increased 10.91% of the time and remained constant 78.83% of the time. A stress value dependent on the stress measure garnered at the beginning of the work period was also computed for each 15-min periods. This "anchored-stress" measure varied between −2 and 17 ($M = 2.31$, $SD = 2.69$). As for the physiological responses, the mean HR was 89.68 beats/min ($SD = 13.16$), the mean HRV was of 43.30 *SD*s/ms ($SD = 17.74$), and the mean RR was 23.23 breaths/min ($SD = 5.94$).

4.2. Working site complexity and stress

The anchored-stress level and the mean measures of HR, HRV and RR for every period of 15 min were compared according to the working site cluster in which traffic duties were performed (see Fig. 2 for the observed, non-estimated marginal means). There were significant differences in the stress measures based on the type of cluster, $F(12, 1179) = 5.97$, $p < .001$, Pillai's trace = 0.17, $\eta^2_p = 0.06$. Further tests uncovered a significant effect of clusters on the anchored-stress level, $F(3, 394) = 6.30$, $p < .001$, $\eta^2_p = 0.05$, the mean HR, $F(3, 394) = 3.02$, $p = .030$, $\eta^2_p = 0.02$, and mean RR, $F(3, 394) = 3.12$, $p = .026$, $\eta^2_p = 0.02$. No association of cluster was observed with the mean HRV, $F(3, 394) = 1.63$, $p = .182$, $\eta^2_p = 0.01$. Univariate Welch-corrected ANOVAs showed that, when correcting for variance heterogeneity, the anchored-stress level and measures of RR still differed depending on the type of cluster (Welch's $F(3, 220.26) = 16.30$, $p < .001$, est. $\omega^2 = 0.08$, and Welch's $F(3, 249.11) = 26.07$, $p < .001$, est. $\omega^2 = 0.12$, respectively). However, the effect of cluster on HR did not reach significance, Welch's $F(3, 183.73) = 1.98$, $p = .119$, est. $\omega^2 < 0.01$. Games-Howell-corrected decomposition of the effect of cluster within the MANOVA showed that the anchored-stress values significantly differed between clusters 1 and 3 ($p = .001$), 2 and 3 ($p < .001$), and 3 and 4 ($p < .001$). Still, clusters 1 and 2 ($p = .987$), 1 and 4 ($p = .950$), and 2 and 4 ($p = .604$), did not differ on their anchored-stress values. Further tests showed that the RR mean values were significantly lower for cluster 4 in comparison with cluster 2 ($p = .022$) and cluster 3 ($p = .043$). Nonetheless, RR did not differ between clusters 1 and 2 ($p = .146$), 1 and 3 ($p = .282$), 1 and 4 ($p = .542$), and 2 and 3 ($p = .958$).

4.3. Working site complexity and measures of traffic and safety

The 12 traffic and safety measures were compared according to the working site cluster in which traffic duties were performed to assess whether the site complexity is related to the amount of potential traffic conflict situations. Table 4 presents the descriptive statistics of each of the 12 traffic and safety measures for each of the four clusters, and displays the univariate Welch-corrected ANOVA results, as well as the clusters differing from one another. The MANOVA demonstrated a significant association of clusters with every traffic and safety measure, $F(36, 849) = 10.37$, $p < .001$, Pillai's trace = 0.92, $\eta^2_p = 0.31$. Welch-corrected ANOVAs showed that each measure of traffic and safety indeed differed according to the cluster (*p*-values < .001 for each measure). Multiple comparisons showed that, globally, working sites of higher complexity were associated with worst levels of safety (lower PET, TTC and distance, and higher speed measures). More precisely, cluster 1, that is working sites with the highest complexity, was generally characterized by a higher number of interactions between road users, shorter PET, shorter distances between the road users, larger speed differences, shorter TTC, larger numbers of interactions with low PET, TTC and distance, and more road users. However, other clusters sometimes comprised higher risk situations than cluster 1 or differed in a fashion unrelated to their complexity level (e.g., cluster 3's measures of Speed85 and *N* Speed85 50 km/h).

4.4. Measures of traffic, safety and stress

Traffic and safety measures, aggregated to 15-min periods, were related to the average measures of self-reported and physiological stress. Pearson correlation analyses showed that subjective self-reports of stress (anchored-stress levels) were negatively correlated with measures of PET15 ($r = -0.20$, $p = .003$), Distance15 ($r = -0.26$, $p < .001$), and TTC15 ($r = -0.21$, $p = .001$), and positively correlated with *N* TTC15 1.5 s ($r = 0.14$, $p = .041$). Measures of HR were negatively correlated with measures of Distance15 ($r = -0.20$, $p = .001$), Speed diff85 ($r = -0.21$, $p = .001$), Speed85 ($r = -0.18$, $p = .003$), and *N* Speed85 50 km/h ($r = -0.23$, $p < .001$), but positively correlated with TTC15 ($r = 0.19$, $p = .002$). Measures of HRV were positively correlated with measures of Distance15 ($r = 0.13$, $p = .038$), Speed diff85 ($r = 0.26$, $p < .001$), *N* Speed diff85 50 km/h ($r = 0.21$, $p = .001$), Speed85 ($r = 0.19$, $p = .003$), and *N* Speed85 50 km/h ($r = 0.26$, $p < .001$), but negatively correlated with measures of TTC15 ($r = -0.24$, $p < .001$). Lastly, measures of RR were negatively correlated with measures of PET15 ($r = -0.14$, $p = .015$), TTC15 ($r = -0.16$, $p = .007$), and positively correlated with measures of Speed diff85 ($r = 0.15$, $p = .012$), *N* Speed diff85 50 km/h ($r = 0.14$, $p = .018$), and *N* TTC15 1.5 s ($r = 0.17$, $p = 003$). All other unreported correlations did not reach significance (*p*-values > .05).

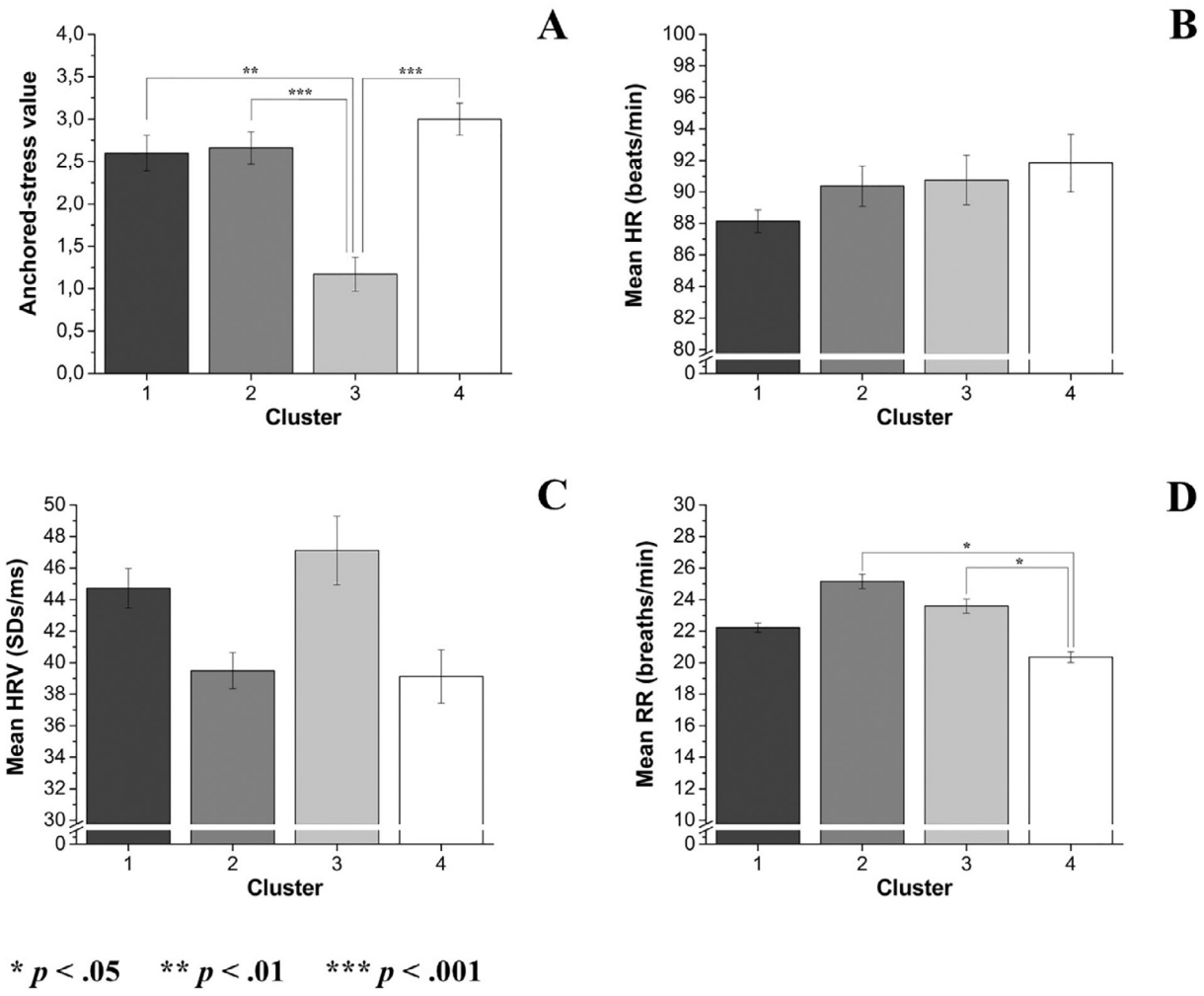


Fig. 2. Observed means of the stress variables (anchored-stress, HR, HRV and RR levels in panel A, B, C, and D, respectively) used in the MANOVA between the four clusters, and significant differences identified among them. Differences among the clusters within the MANOVA, after correction for variance heterogeneity, were only found for anchored-stress and RR. Error bars represent the standard error of the mean.

5. Discussion

This study aimed at assessing whether characteristics of the work environment, which comprises the complexity of the working site, traffic and the safety of road user interactions, could impact psychological and physiological stress of traffic workers. Results first showed that measures of stress, more particularly self-reported stress and measures of RR, differed depending on the type of working site in which traffic duties were performed. This association between stress and RR is coherent with previous findings (Hernando et al., 2016). More importantly, levels of self-

Table 4
Descriptive statistics (mean and standard deviation) and results of the Welch-corrected ANOVAs performed on each of the 12 traffic and safety measures according to the four site clusters.

Traffic and safety measures	Mean (and *SD*) per cluster				Welch's *F*	Est. ω^2	Games-Howell corrected significant multiple comparisons of the clusters
	Cluster 1 (n = 103)	Cluster 2 (n = 73)	Cluster 3 (n = 65)	Cluster 4 (n = 55)			
1. *N* Interact	8102.51 (6428.83)	4646.27 (2641.53)	5796.60 (3133.61)	4877.75 (1931.35)	9.28***	0.08	1-2, 1-3, 1-4
2. PET15 (s)	0.55 (0.24)	0.97 (0.35)	0.85 (0.48)	0.98 (0.21)	54.77***	0.35	1-2, 1-3, 1-4
3. Distance15 (m)	11.86 (2.16)	11.59 (2.10)	13.98 (4.10)	13.83 (2.32)	15.65***	0.13	1-3, 1-4, 2-3, 2-4
4. Speed diff85 (km/h)	47.12 (10.71)	38.09 (15.02)	57.26 (17.96)	46.05 (10.09)	15.41***	0.13	1-2, 1-3, 2-3, 2-4, 3-4
5. TTC15 (s)	2.20 (0.58)	3.08 (0.92)	2.83 (1.11)	3.56 (0.49)	82.24***	0.45	1-2, 1-3, 1-4, 2-4, 3-4
6. *N* PET 1.5 s	548.07 (471.48)	230.77 (168.31)	344.88 (202.83)	245.29 (127.54)	16.60***	0.14	1-2, 1-3, 1-4, 2-3, 3-4
7. *N* Distance15 30 m	4380.27 (2898.32)	2948.03 (1538.97)	2952.71 (1986.13)	2731.78 (959.48)	9.18***	0.08	1-2, 1-3, 1-4
8. *N* Speed diff85 50 km/h	1196.92 (1368.65)	477.92 (611.01)	1160.25 (896.60)	679.71 (524.88)	13.18***	0.11	1-2, 1-4, 2-3, 3-4
9. *N* TTC15 1.5 s	174.21 (101.52)	70.29 (64.76)	136.20 (125.74)	51.45 (21.38)	53.65***	0.35	1-2, 1-4, 2-3, 3-4
10. *N* Road users	1415.03 (524.59)	967.21 (338.71)	1126.72 (468.01)	986.98 (230.04)	19.57***	0.16	1-2, 1-3, 1-4
11. Speed85 (km/h)	38.06 (8.88)	28.58 (10.71)	48.17 (19.75)	36.09 (7.30)	21.66***	0.17	1-2, 1-3, 2-3, 2-4, 3-4
12. *N* Speed85 50 km/h	86.99 (95.79)	21.42 (38.46)	145.97 (180.56)	53.87 (36.84)	23.64***	0.19	1-2, 1-4, 2-3, 2-4, 3-4

Note. Multiple comparisons that are absent from this table did not reach significance (p-values > .05).
*** $p < .001$.

reported stress were lower for police officers whose traffic duties were performed in working sites characterized by the lowest complexity tasks (cluster 3) whereas levels of RR were lower for participants working on the sites with the lowest complexity site (cluster 4). This difference between the subjective psychological measure of stress and the more objective physiological index may originate from the fact that self-reported stress is more affected by one's conscious behaviors whereas RR may represent a broader, unconscious measure of stress. Psychological measures of stress are indeed known to represent an interaction between environmental demands and one's subjective assessment of those demands (Fried et al., 1984), which largely relies upon one's tasks. On the contrary, physiological measures are seen as more objective as they are hardly manipulated by one's expectations, opinions or even social desirability. Differences in traffic and safety measures were also found between the four clusters of complexity of the working sites. Although differences were not always consistent with expectations relative to the complexity of clusters 2, 3 and 4, cluster 1—which comprised sites of higher complexity—was associated with the lowest level of safety. Indeed, the working sites of this subgroup were generally characterized by higher traffic, more severe interactions, shorter PET and TTC, shorter distances and higher speeds. Overall, such demonstration of safety and stress differences among the site clusters with different complexity levels is consistent with expectations of the conceptual framework suggested in the present paper (see Fig. 1).

Interestingly, some of these measures were associated with the measures of stress. Indeed, safer 15-min periods, measured by higher proximity indicators and lower speed indicators, were mostly associated with lower measures of self-reported stress, HR and RR, and higher measures of HRV. Although no assessment of the relationship between stress and traffic and safety measures has been hitherto performed in the literature, these results are, again, in line with what was expected from our study framework (see Fig. 1). Indeed, lower safety globally entailed higher levels of self-perceived stress for traffic-control police officers which, as previously demonstrated, is related to higher levels of HR (van Hedger et al., 2017), RR (Hernando et al., 2016) and lower HRV (Pereira et al., 2017). This relationship between high-risk situations of the environment and measures of stress is also consistent with the previous demonstration of stress prediction based on several characteristics of the work environment in which traffic duties were performed (Marois et al., 2018). Notwithstanding these results of interest, some traffic and safety measures also varied between the other complexity clusters, without having necessarily a simple relationship with the complexity level. Indeed, some working sites deemed less complex sometimes showed periods of lower safety (see, e.g., cluster 3 for the road user-level measures of speed). Other studies are thus necessary to replicate or clarify the relationships found between stress, site complexity and measures of traffic and safety.

The fact that differences in stress, traffic and safety were found between the four sites with different complexity levels—with generally lower measures of stress for less complex sites and lower safety levels for more complex sites—is interesting as it supports the relevance of classifying working sites according to their complexity level and the validity of using the cluster analysis that was performed accordingly. Such analysis indeed permits to identify sites and the expected level of stress for police officers performing traffic duties, which can ultimately impact their ability to control traffic and their own safety (Kolbell, 1995). Besides, the inverse causal effect cannot also be ruled out, i.e. that higher levels of stress in more complex sites lead to lower performance and errors by police officers, which in turn makes traffic less safe.

This classification also enables one to predict the sites that may be characterized by more risky situations. Some clusters were related to lower levels of stress, while others were characterized by more high-risk situations which were, sometimes, associated with higher levels of stress. However, no direct demonstration of higher stress was observed for more complex sites. This could originate from the fact that traffic workers were trained police officers. It could be hypothesized that traffic duties may not necessarily represent a stressful task for police officers whose job is sometimes to intervene in hazardous, high-risk situations in which extreme stress, associated with violence and criminal activity, may be experienced. Although it has been shown that police officers do feel stress when performing traffic duties (Kumar and Mohan, 2009; Deb et al., 2008), the absence of higher levels of self-reported and physiological stress in more complex sites could still be explained by this hypothesis. Moreover, a study by Hammad et al. (2012) showed that stress can be considered useful by traffic control officers and is significantly correlated to employee performance. This relationship was however moderated by coping strategies. Police officers are known to benefit from a lot of peer support and several resources to cope with the stress experienced in the context of their work (Anshel, 2000; He et al., 2002). Still, such resources are not necessarily available for civil pedestrian traffic workers or flaggers. Thus, the relationship between stress and work zone complexity identified for less complex sites in the current study could potentially extend to more complex work environments among civil workers.

Given the differences observed between the four types of complexity clusters and the relationships found between measures of stress, traffic and safety, it seems that the conceptual framework proposed in Fig. 1 could, in part, be used to ultimately predict traffic control performance and safety of the road users and traffic workers. Yet, no direct measures of traffic control performance and of road safety (in terms of crashes) were collected. Hence, studies are still needed to further investigate the impact of the variables presented in the current study on these two variables. These studies may be necessary to better understand the relationship between work stress and work performance, and its expected impact on road safety. Moreover, demonstrating such a relationship could further support the necessity of studying stress and the environment of workers performing traffic duties to decrease the occurrence of hazards and road crashes while on duty.

6. Study limitations

Although the current study proposes a promising way to prevent hazardous situations by assessing the relationships between safety, work site complexity and stress among police officers performing traffic duties, some limitations must be addressed in future studies. Higher stress levels could not be directly observed for more complex sites and, as hypothesized earlier, this may originate from the fact that stress levels were low and quite homogenous ($M = 2.06$, $SD = 2.01$). Moreover, the police officers that were monitored while controlling traffic often came back on the same work site, hence associating work environments to particular workers while only 19 different police officers were monitored. Despite the large number of 15-min periods that were used in all the analyses, the low number of participants may have decreased variability in the results, thus leading to some generalization issues in respect to other traffic-control police officers, or even other traffic management activities. However, statistical differences were still found between the four types of cluster and significant relationships were identified between both stress and safety measures. Generally, results were consistent with previous literature and with the proposed conceptual framework, which thus gives support to their potential extension to other samples and work zones and allows to provide useful insight to the study of stress, traffic control and work environments. Future studies should however favor a larger sample of traffic control personnel to confirm the absence of sample size biases.

Even though physical movements were not related to stress in Marois et al. (Marois et al., 2018), other confounders such as external temperature, age and physical fitness, which are all known to impact physiological activity (Claremont et al., 2015; Levenson et al., 1991; Tulppo et al., 1998), were not necessarily controlled. This could have mitigated chances of reaching differences in stress among the clusters as the stress levels measured during the different work periods may be more impacted by individual differences than intended. To further test this assertion, and to extend the current results to other contexts and populations, the present study could be replicated among larger samples of non-police pedestrian

flaggers, each performing traffic duties on several work sites. Confounding variables such as temperature, age and physical fitness could also be measured comprehensively and controlled for to isolate the sole impact of stress on physiological activity. This could represent a useful solution as stress may be more sensitive to environmental characteristics, such as the dangerous traffic interactions and the complexity of the sites, and that it may be distributed more equally among the different work sites, while considering stress- and physiological-related factors.

7. Conclusion

Overall, results of the present study suggest that stress level, traffic and safety measures differ according to the complexity of the working site in which traffic duties are performed. Moreover, the stress level is also associated with some of the traffic and safety measures extracted by video analysis. These findings can represent useful insights for decision-makers who are interested in increasing safety in the context of traffic management by accounting for the characteristics of the work environment and for the stress of the pedestrian personnel in their guidelines of safe working conditions and environment (Marois et al., 2018). Combining psychophysiological, computer and civil engineering approaches to assess stress among traffic controllers in different work contexts is also highly original and represents an efficient way to improve road user safety while considering both the human factors and the road and traffic environment. Using the present method to classify the complexity of a working site and observe differences in stress and safety measures has indeed provided useful insights and such an ecologically-valid and interdisciplinary method should be privileged among other research teams interested in pedestrian workers and their work environment. Although future studies could provide some improvements, e.g., by differentiating road users by category (pedestrians, cyclists and motorized vehicles), by monitoring police traffic workers in other potentially more stressful contexts (e.g., while responding to a disabled vehicle or at a car accident site), or by calibrating more robust models of stress with more periods of measurements, current findings are useful for decision-markers or workplace health and safety practitioners. For instance, by knowing which sites constitute more complex environments, which are conducive to higher levels of stress and more unsafe situations, preventive actions such as giving more breaks or scheduling more workers on a specific zone to alleviate worker's workload and stress can help avoid hazardous situations. This can lead to safety improvements for both road users and traffic workers.

Traffic control personnel could also be given opportunities to rely on more support and on stress management resources, especially if they are to perform their duties on more complex—and less safe—work zones. Simple strategies that are used by police departments to mitigate stress, such as providing personnel with pocket cards summarizing warning signs of operational stress (Chapin et al., 2008), providing a prevention program (Amaranto et al., 2003) or a resilience training (Mccraty and Atkinson, 2012), could be employed by all traffic control workers. The stress that can be experienced while managing traffic could specifically be addressed among these strategies, for both police and non-police traffic workers. Given the relationship found between measures of stress and complexity, the known association between stress and work performance (Colligan and Higgins, 2006), and the positive impacts of stress management resources and coping strategies on this relationship (Hammad et al., 2012) this could help traffic control personnel to alleviate pression originating from their work, which would entail better work performance and improve road safety. Furthermore, the present study speaks to the feasibility of employing technologies for real-time monitoring of worker stress and video analysis of risk factors. Such technologies may soon help provide early warning signals allowing dynamic adaptation to changes in risk levels.

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