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RESEARCH ARTICLE

Reaction Time to Visual Stimulus in Firefighters and Healthy Trained Subjects: A Preliminary Comparative Study

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Abstract:

Background:

In order to stay safe, and to successfully complete their work, firefighters have to constantly assess and process large numbers of sensory stimuli and adapt to the inherent risks present in the working environment.

Objective:

The purposes of the present preliminary study were to analyse the speed of Reaction Time responses (RT) of Italian Firefighters and to compare their cognitive responses with non-firefighting subjects.

Methods:

Anthropometric (weight, height and BMI) and RT (time-to-completion –TTC-, mean of reaction time –MRT-, and errors made -E-) evaluations were administered at 16 volunteers (Age: 40.3 ± 6.7 yrs; BMI: 23.8 ± 2.3 kg/m²) divided in Firefighters (FG) and Control (CG) groups. RT test consisted of 3 trials (T1 = 1s of stimulus duration and 1s interval between stimulus and the other; T2 = 0.5s of stimulus duration and 1s interval between stimulus and the other; T3 = 0.5s of stimulus duration and 0.5s interval between stimulus and the other). Mann Whitney U test between groups was applied to assess differences ($p \leq 0.05$) in TTC, MRT, and E while Friedmann test and Dunn-Sidak post hoc were used to evaluate significant differences in the 3 trials in each variable of each group.

Results:

No significant differences based on anthropometric parameters were observed between groups. Despite no significant differences emerged for TTC and MRT between groups, we observed significant differences in E between groups (CG = 4; FG = 12) and in the 3rd condition in each variable of each group.

Conclusion:

Workout programs that integrate reaction time training with job performance should be created to increase job performance.

Keywords: Fitlight trainer, Stimulus, Cognitive responses, Errors, Decision making, Training.

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1. INTRODUCTION

Firefighters are employed in a civil occupation in which they are exposed to variable and unpredictable working conditions (*e.g.*: night shift schedules, sudden and unpredictable work patterns, strenuous physical work) and environmental stressors (*e.g.*: extreme temperatures, smoke) where they are required to safely assess hazards in a dynamic operating environments. Emergency tasks are further complicated by high-intensity activity over an unpredictable work durations [1 - 6]. These environmental, physical and emotional stressors encountered by firefighters are likely the key determinants of job-related injuries and fatal events at work [7 - 10]. A recent study of Britton *et al.* [11] reported that during the 5-year period, the slips/trips/falls (34%) and equipment/ tools/machinery (31%) were the most common mechanisms with the lower extremity, the most common body part involved (35%).

In order to stay safe, and to successfully complete their work, firefighters must constantly assess and process large numbers of sensory stimuli (*i.e.*, people in need, fire conditions and behaviour, environmental events, movements of colleagues) and adapt quickly to the inherent hazards present in the dynamic working environment, often in a dynamic manner. To quickly establish and adapt to these risks, firefighters must react quickly in their dynamic working environment [12]. Reaction time (RT) is a measure of processing speed and reflects response efficiency in information processing tasks and is considered a lower-level cognitive function that supports basic information processing [13]. Previous studies [14, 15] showed that RT can be defined by three distinct processes: **1**) perception time (time for the application and perception of the stimulus and giving the necessary reaction to it); **2**) decision time (time for giving an appropriate response to the stimulus); **3**) motor time (time for compliance to the order received). In contrast, higher-level cognitive functions are often called executive functions and are important in tasks that demand concentration, coordination, change and control of instinct [16]. Both lower and higher level cognitive functions are needed to safely evaluate the dynamic risks present in an emergency.

Currently, little information is available regarding the cognitive functions (*e.g.*, attention and response time) in fire and rescue service workers. Therefore, the main goals of the present preliminary study were to analyse the RT responses of Italian Firefighters and to compare their cognitive responses with non-firefighting healthy trained subjects.

2. MATERIALS AND METHODS

2.1. Participants

Sixteen healthy male volunteers (Age: 40.3 ± 6.7 years; Weight: 84.9 ± 8.9 kg; Height: 178 ± 6 cm; BMI: 23.8 ± 2.3 kg/m²) were recruited and divided into 2 groups, each formed by 8 subjects: Firefighters (FG) and Control (CG).

A sports medicine accredited doctor examined each subject before the beginning of the study based on the following inclusion criteria: regular physical fitness activities (for at least 2 years), aged between 30 and 55 years and without clinical problems as testified by medical certificate. Exclusion criteria were: current medication intake, movement limitations or injury, history of upper limb injuries and smoking habit. All participants completed the AAHPERD exercise/medical history questionnaire prior to assessment in order to ascertain activity level, educational background, dietary habits, tobacco smoking and alcohol consumption, medication and history of physical activity.

None of the participants underwent any strenuous activity and training outside their normal training schedule 48 hrs prior to presenting for testing.

2.2. Procedures

The local Institutional Review Board approved the study designed to analyse the RT of Italian Firefighters and to compare their results with healthy trained volunteers.

Anthropometric (*i.e.*, body weight, height and Body Mass Index) and RT evaluations were administered during a single experimental session (one day) at approximately the same time of the day (10.00 am; ± 1 hr). RT tasks were assessed in the same sequence separated by 3 min of rest. All assessments were carried out in a gym with controlled ambient conditions (temperature: 22-24°C; humidity: 50-60%), and without noise or other distractions.

Subjects were instructed to avoid food and drink (*i.e.* coffee) in the hour before testing and to avoid strenuous exercise 48 hours before each trial. All participants were adequately informed about the study and gave their written informed consent. Researchers were present to explain and resolve any doubt regarding the research project.

2.3. Measurements

2.3.1. Anthropometrics measurement

Weight (cm) and height (kg) were measured with participants wearing light clothes and barefoot using an electronic scale (± 0.1 kg) and a fixed stadiometer (± 0.1 cm) (Seca 702, Seca GmbH & Co. KG, Hamburg, Germany). The Body Mass Index (BMI) assesses the weight relative to height and it was calculated dividing the body mass by height in square meters (kg/m^2).

2.3.2. Reaction Time Test

Accuracy and RT to visual stimulus were assessed using the Fitlight Trainer[®] (FitLight Sports Corp, Ontario, Canada), a wireless reaction system comprised of eight LED lights controlled by a tablet computer. The lights have an inbuilt sensor which reacts to proximity or touch and deactivates the light. In order to take the test, participants were asked to respond, tapping the light, as quickly as possible to the red light that appeared on the disc in a random order (Fig. 1).

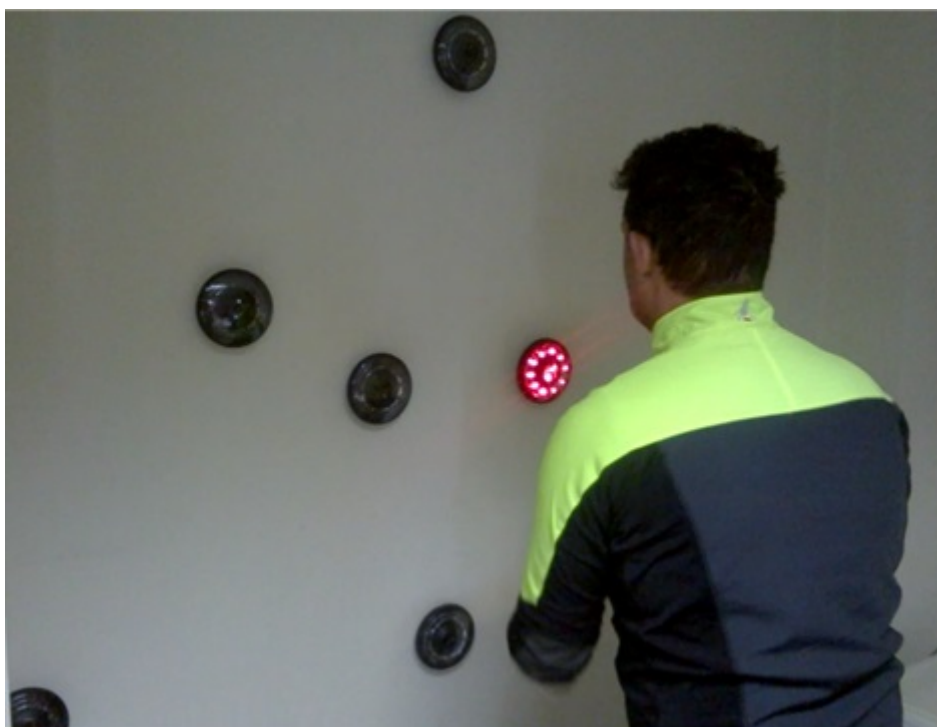


Fig. (1). Fitlight Trainer[®] and position of subjects.

Light positioning was present in Fig. (2) and eight lights were used as stimulus. Each subject was positioned at a distance of 30 cm from the wall, centered to the pattern, joined feet, standing upright with arms along the hips. After the presentation of each stimulus, the subject returned to the same position (with arms along the body) waiting for the next signal.

The test took 3 min and consisted of 3 trials (T1-T2-T3), administered in a set sequence and characterized by a frequency variation (*i.e.* the time between a visual stimulus and the following stimulus), and the duration of the single stimulus. In particular, the three trials, administered in a set sequence and sequentially, are defined as follows:

- T1 = 1 second of stimulus duration and 1 second interval between stimulus and the other.
- T2 = 0.5 seconds of stimulus duration and 1 second interval between stimulus and the other.
- T3 = 0.5 seconds of stimulus duration and 0.5 second interval between stimulus and the other.

Performance on the test was evaluated by total Time-To-Completion (TTC), Mean of Reaction Time (MRT), and errors made (subject was not quick to touch the disc activated; E).

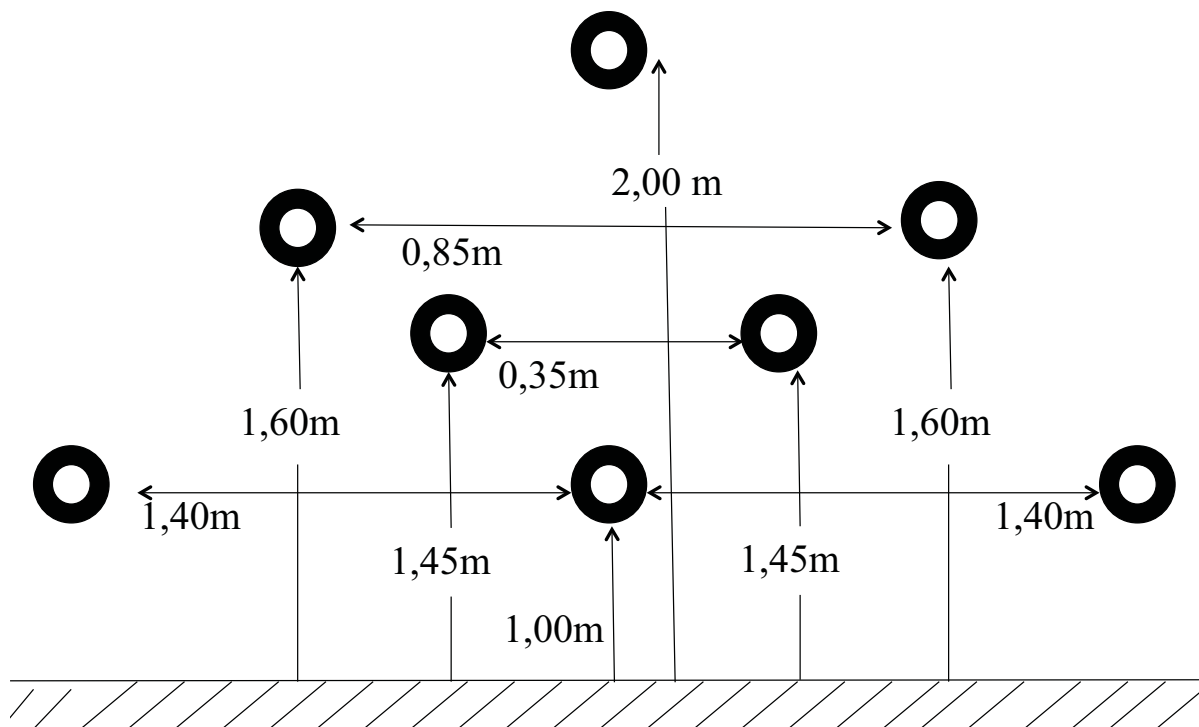


Fig. (2). Fitlight Trainer® positioning.

2.4. Statistical Analysis

Data analysis was completed using IBM SPSS (ver.23) software for Windows. Data are reported as means and standard deviations, and significance was set at $p \leq 0.05$.

Normal distribution of data was assessed by the Shapiro-Wilk test. Considering that Shapiro-Wilk test rejected the null hypothesis ($p \leq 0.05$), and concluded with 95% confidence that the data was not normally distributed, Mann Whitney U test between groups was applied to asses differences in TTC, MRT, and E. The Friedmann test and Dunn-Sidak post hoc test were used to evaluate significant differences in the 3 conditions (T1,T2 and T3) in each variable (TTC, MRT, and E) of each group (CG and FG).

3. RESULTS

No significant differences based on the anthropometric (age, weight, height and BMI) parameters were observed between groups Table 1.

Table 1. Mean ± Standard Deviation (SD) of anthropometrics characteristic of the participants.

-	Firefighters			Control Group		
-	Mean ± SD			Mean ± SD		
Age (Years)	42	±	8	38	±	5
Height (m)	1.77	±	0.05	1.78	±	0.07
Weight (kg)	86.8	±	9.5	86.8	±	8.5
BMI (kg/m ²)	27.4	±	2.5	27.5	±	2.6
-	-	-	-	-	-	-
* $p < 0.05$	-	-	-	-	-	-

Performance values (Means ± SD) of TTC, MRT, and E values between groups are shown in Table 2). Only E showed statistical differences ($p < 0.05$) between groups with higher values in FG (+177%) compared to CG.

Significant differences emerged on the 3rd condition (T1,T2 and T3) in each variable (TTC, MRT, and E) of each group (FG and CG) Table 3). Despite TTC and MRT values decreased from T1 to T3 in both groups, E value decreased in T2 (FG= -76%; CG= -33%) but increased in T3 (FG= 3137%; CG= -876%) compared to T1.

Table 2. Mean ± Standard Deviation (SD) of Time-To-Completion (TTC), Mean of Reaction Time (MRT), and errors made (E).

-	Firefighters			Control		
-	Mean ± SD			Mean ± SD		
Trial 1	-			-		
TTC (ms)	50.05	±	2.61	50.15	±	1.27
MRT (ms)	0.58	±	0.07	0.59	±	0.03
E (UA)	1.63	±	2.20	0.75	±	1.49
Trial 2	-			-		
>TTC (ms)	34.62	±	1.89	34.42	±	2.38
MRT (ms)	0.56	±	0.06	0.54	±	0.05
E(UA)	0.38	±	0.74	0.50	±	0.76
Trial 3	-			-		
TTC (ms)	32.26	±	0.85	32.11	±	1.00
MRT (ms)	0.46	±	0.02	0.45	±	0.03
E (UA)	12.13	±	5.67*	4.38	±	3.11
-	-	-	-	-	-	-
* $p < 0.05$	-	-	-	-	-	-

Table 3. Statistical differences on the 3 condition (T1,T2 and T3) in Time-To-Completion (TTC), Mean of Reaction Time (TRM), and errors made (E) of each group.

-	-	-	Trial 1	Trial 2	Trial 3
Firefighters	TTC	Trial 1	-	0.01	0.01
		Trial 2	0.01	-	0.04
		Trial 3	0.01	0.04	-
	MRT	Trial 1	-	N.S.	0.01
		Trial 2	N.S.	-	0.01
		Trial 3	0.01	0.01	-
	E	Trial 1	-	N.S.	0.01
		Trial 2	N.S.	-	0.01
		Trial 3	0.01	0.01	-
Control	TTC	Trial 1	-	0.01	0.01
		Trial 2	0.01	-	0.03
		Trial 3	0.01	0.03	-
	MRT	Trial 1	-	0.01	0.01
		Trial 2	0.01	-	0.01
		Trial 3	0.01	0.01	-
	E	Trial 1	-	N.S.	0.02
		Trial 2	N.S.	-	0.02
		Trial 3	0.02	0.02	-
$p < 0.05$	-	-	-	-	-

N.S. = not significant

4. DISCUSSION

Firefighting involves a very complex set of tasks performed in a potentially hostile environment that can affect health and safety of workers. Considering that to evaluate responses in a live-fire scenario is complicated; the present study sought to analyse the cognitive responses to a visual stimulus of Italian Firefighters in an easy manner. To our knowledge, this is the first attempt done in scientific literature. The main findings of the present study are that FG made significantly more errors than CG where the reaction to stimulus required (0.5 s of stimulus duration and 0.5 s interval between stimuli), and it was high (*Trial 3*) highlighting at lower levels of cognitive function.

Previous studies [17, 18] described RT as **1) Simple RT** (one stimulus and one response), **2) Recognition RT**

(stimulus that should be responded to and others that should not get a response), and 3) Choice RT (multiple stimulus and multiple responses). Solanki *et al.* [19] highlighted that RT is a valid indicator of rate of processing of sensory stimuli by the central nervous system and its execution in the form of motor response.

In this study, RT performance was measured using the Fitlight Trainer[®], a commercially available wireless reaction system comprised of LED lights used as targets for users to activate or deactivate, that is fast and simple to use in different place (field and/or indoor) on every surface (floor and/or wall). It is used in many different sports to train basic physical skills, such as speed and agility in addition to RT. No modifications were made to the system. The setup of the lights and the programming of the light sequences were original.

In sport science literature, the RT values of volleyball [20], basketball [21], and soccer [22] were significantly greater when athletes were compared to control subjects.

Both the FG and CG group demonstrated differences in the 3 condition (T1, T2 and T3) of Time-To-Completion (TTC), Mean of Reaction Time (MRT), and Errors made (E), and significant differences in visual RT between them. However, in our study, it was surprising that the CG showed significantly fewer errors (n=4) than the FG (n=12) in high-intensity task (T3). It is likely that, despite a relative advantage conferred as a result of training, that performance in the open-field environments of sport is potentially altered by training, rather than by ability alone. Thus, given the lack of significant differences in RT between firefighters and the general population, we hypothesize that this “static” and “non-functional” test (in front of the wall) was not likely to significantly reflect the “dynamic” and highly variable working conditions where firefighters generally operate (*i.e.* temperature, smoke, noise, visibility, time urgency and the knowledge that civilians are in imminent danger) thus negating any potential advantage previously observed in this population. During the emergency, activity firefighters regularly assess multiple stimuli and it is likely that the present study did not sufficiently reflect the normal working conditions. Regardless of this, the ability to maintain attention, to store important details (*e.g.* escape routes from a structure), and to rapidly and effectively make critical decisions are an important cognitive component for firefighters as reduction in RT could result in injury and ineffective and unsafe task performance if the firefighter is unable to respond to a rapidly degrading environment. We recommend that a more thorough investigation of more ecologically valid firefighting RT tasks be undertaken in the future to validate our hypothesis.

Robinson *et al.* [23] have noted that the impairment of cognitive function can increase the risk of injury and death. To further reinforce this position, Morley *et al.* [24] tested whether cognitive function changed after treadmill exercise in thermal protective clothing. The results showed that neurocognitive test scores did not change immediately after exercise but a memory test was reduced 60 and 120 min after exercise with the mean of the 10 slowest reaction times increased in the 120 min after exercise. The authors suggest a need for additional rest and recovery after stress activity.

Various studies [3, 12, 24 - 27] have previously reported similar impairments in cognitive function after performing simulated firefighting without exposure to smoke, and reported impairments in cognitive function. Robinson *et al.* [23] discovered that simulated firefighting emergency can exacerbate cognitive impairments, which justify maladaptive responses observed during fire suppression. Kivimäki and Lusa [28], assessed the relationship between stress reaction and cognitive function during a simulated smoke-diving task in a poorly lit, unfamiliar site. The results showed that as the stress response increased during simulated smoke-diving, cognitive function concurrently declined. However, in contrast to these studies, previous research using experienced firefighters indicated some positive changes in visual attention following work in the heat despite no meaningful changes in processing speed or working memory [29]. It is likely that despite elevated core temperatures and fatigue levels, the relative experience of the firefighters studied by Walker *et al.* [29] may have provided a protective mechanism against cognitive decline in the heat.

Understandably, our study was subjected to a number of limitations. First, the tests with Fitlights Trainer[®] do not represent the real firefighting situation (people in need, environmental events, movements of colleagues). Second, the population was not very large. Third, it was not verified whether changing the order of the various trial test modifies results. Fourth, this study did not evaluate job performance in relation to fatigue. Regardless of these limitations, it is not possible to make a criterion validation by comparison of the test with respect to an established test, because there is no “gold standard” for the evaluation of reaction time in firefighters. Future research including a larger sample size and simulated firefighter activities is recommended to ascertain the effect of cognitive training protocol on job performance.

Based on our findings, neurocognitive training in firefighters is likely a worthwhile training protocol, given the apparent lack of links between RT and firefighter training in simple tasks. Regardless, further investigation of the causal links between training and higher order cognitive should be undertaken into the future. Considering that firefighters

should have a high level of decision-making capabilities, these results may also represent the basis for strength and conditioning trainers to develop appropriate conditioning programmes aimed at improving the cognitive responses of a firefighter. In fact, the relationship among injuries, environments, physiological strain and the cognitive function impairment suggests to develop methods for keeping firefighters' cognitive function below critical levels during work. Furthermore, a periodic evaluation of cognitive function could be necessary to ensure capable and immediate responses by personnel who perform important public safety occupation.

CONCLUSION

Firefighters are often required to perform demanding cognitive and physical tasks simultaneously. High levels of cognitive capabilities are generally important for all firefighters activities that require complex and rapid decision-making. For this reason, the administration of this type of training should be constantly and adequately proposed in Firefighters to increase their job performance. Currently, it is unclear whether cognitive training programs are a part of the regular training of firefighters. Furthermore, it is likely that where cognitive training is undertaken, most of all do not take into account operational requirements, and thus may not optimally instill the combined skills that are required to perform their jobs efficiently and effectively. We believe that the work presented in this study provides a solid base to reach the goal of developing exercises that will improve occupational job performance and the day-to-day readiness of firefighters. To address this issue, we should start research and to develop a program that seeks to create and validate specific exercises, and workout programs that integrate cognitive training with job performance.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The local institutional review board approval this study.

HUMAN AND ANIMAL RIGHTS

No animals/humans were used for studies that are base of this research.

CONSENT FOR PUBLICATION

Written informed consent were obtained from all participants.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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