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1 **A 6-minute protocol, combining mental imagery practices and breathing exercises,**  
2 **promotes hand-grip strength in firefighters: a series of “N-of-1” trials**

3

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11 **Abstract**

12 BACKGROUND: To carry out their victim rescue and fire-fighting missions, firefighters perform high  
13 levels of physical exertion and among them strenuous muscular activity. A specific mental  
14 preparation protocol that could induce better strength performance throughout their 24-hour  
15 schedule is a major issue for firefighters.

16 OBJECTIVE: This case report aims to examine whether a 6-minute Intervention combining mental  
17 imagery practices and breathing exercises, specifically designed to be used while travelling between  
18 the fire station and the mission site, would be able to promote maximum strength performance.

19 METHODS: A series of three Single Case Experimental Designs (SCED) was conducted in single blind  
20 design to investigate the effects of repeated challenge-withdrawals between the Intervention and  
21 the Baseline on the maximum voluntary isometric contraction (MVIC) strength of the hand-grip.

22 RESULTS: Data analyses revealed that 62.5% to 100% of the hand-grip strength values during the  
23 Intervention periods were greater than or equal to the maximum data point recorded in the Baseline  
24 periods. The effect sizes of these highlighted increases of the hand-grip strength performance  
25 revealed by the percentage of non-overlapping data (PND) were 75% i.e., moderately effective on  
26 average.

27 CONCLUSIONS: Such a “psyching-up” practice before an upcoming muscular activity can promote  
28 muscular strength in firefighters. These results have led French firefighter departments to integrate  
29 the teaching of these practices into the initial instruction of firefighters, and remains to be confirmed  
30 by a randomised control trial.

31

32 **Keywords:** firefighter; mental imagery; breathing exercises; hand grip force; SCED; N-of-1 trial;  
33 mental preparation

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## 38 **1. Introduction**

39 Firefighters regularly perform victim rescue and fire-fighting activities which may be carried out in  
40 hostile situations and/or environments [1, 2]. To carry out their missions, firefighters perform regular  
41 strenuous muscular activity especially in the upper limbs and hand-grip [3] (for example: lift, carry  
42 and use heavy protective devices and tools, climb ladders and ropes, grab, lift and transport  
43 unconscious victims) in dangerous and unpredictable environments (high temperatures, smoke, fire,  
44 restricted areas) in chaotic conditions (cries, noise, low visibility, void) [3]. An elevated level of  
45 fitness, muscular endurance and muscular strength have already been correlated with improved  
46 professional performance during firefighting activities [4, 5] and with a decreased risk of injury [6]. As  
47 such, the capacity of firefighters to be able, almost continuously night and day when on call, to  
48 produce an optimum muscular strength performance appears to be important. During their 24 hours  
49 on call, several factors induce fatigue and decrease the firefighters' ability to produce their maximum  
50 muscular strength performance. For example, the repetition of interventions involving physical  
51 activities with a high level of psychological and physiological stress throughout a 24-hour on call [7],  
52 the time of the day [8], the repeated heavy object handling [7], the psychological workload [9] or  
53 certain emotional interactions [10] are all known to be able to decrease muscular strength  
54 performance.

55 Without changing the work schedule to have an acceptable interference in firefighters' duty, two  
56 kinds of countermeasure would appear to limit the harmful effects of fatigue encountered  
57 throughout a 24-hour on call period and to promote muscular strength: the first way is to put in  
58 place efficient intervention protocols to promote recovery during intermittent break periods  
59 between two missions. Previous studies, including from our group, have already shown the interest  
60 of such a recovery protocol for firefighters [12, 13]. The second way is to develop intervention  
61 protocols to energize firefighters and promote their upcoming muscular strength performance by  
62 stimulating their neurophysiological system, whatever their current state.

63 The first objective of this study was thus to create an efficient intervention protocol designed to  
64 promote upcoming muscular strength performance and investigate its impact on firefighters  
65 throughout a 24-hour period. To do this, several methods are well-known to enhance muscular  
66 strength performance due to neural factors. For example, transcranial direct current stimulation [14],  
67 [15] or pre-event massage [16] have been reported to improve upcoming muscular strength  
68 performance but have not been retained here because of their impracticability in the professional  
69 context of firefighters in France. Muscular warm-up improves any upcoming muscular strength  
70 performance and is already used as a gold standard preparation for sports training by French  
71 firefighters [17]. However, muscle warm-up is made of real muscular contractions which, if they are

72 repeated systematically before each mission throughout a 24-hour period, will lead to muscle  
73 fatigue. In itself, that would be the opposite of the effect sought here. On the contrary, and using no  
74 real movements, several “psyching-up” techniques have been reported to increase physical and  
75 mental activation and reported as beneficial tools for strength improvement among athletes [18] and  
76 non-athletes [19, 20]. Currently, motor imagery consists of mental simulation of an action or a  
77 muscular contraction but without any concomitant actual movement [21]. From a neuronal  
78 viewpoint, motor imagery is well known to activate some of the same brain areas as actual motor  
79 execution [22] and to induce greater activation of the corticospinal pathway when compared with  
80 rest [23, 24]. From a behavioural viewpoint, mental imagery can elicit, among other actions, a  
81 greater level of muscle activation [25], can delay the onset of neuromuscular fatigue [26], and can  
82 increase muscular strength performance [27].

83 Moreover, emotional visualisations [28] have also been reported to enhance the cortical excitability  
84 and induce enhancement of muscular strength performance. Dealing with perceived emotional  
85 contexts, high emotional arousals to avoid unpleasant contexts and to approach pleasant ones [29],  
86 or to approach unpleasant contexts in order to carry out a positive action [30] are also reported to  
87 enhance the cortical excitability of the primary motor cortex, increase neuromuscular performance  
88 [31], while the muscular strength production concomitantly increased.

89 Another method retained to promote muscular strength performance by dynamization of the  
90 Autonomic Nervous System (ANS) is the use of breathing exercises [32], which may be defined as  
91 breathing activities consciously controlled by the central nervous system (CNS) and not solely in an  
92 automatic and unconscious manner as during everyday life. Depending on the duration and mode of  
93 the inspiration and expiration phases, breathing exercises could either slow down or energize the  
94 ANS and the body [33]. In this way, enhancing the sympathetic activation prior to an intense physical  
95 exercise may induce cardiac preparation and increase muscular performance [34, 35].

96 However, even if each of the three components (i.e. motor imagery, emotional imagery, and  
97 breathing exercises) thus seems able to optimise the maximum muscular strength capacity due to  
98 neural mechanisms, it was essential to pay attention to two specific parameters in the present  
99 professional context: first, for efficiency reasons, there is the need to create a tool that can be easily  
100 implemented by firefighters when travelling between their fire station and the mission site.  
101 Consequently, the duration of practice time that was chosen was of 6 minutes in agreement with the  
102 firefighters and their operational constraints. To our knowledge, no study on the possible impact of  
103 these three methods, or a combination of the three, on muscular strength performance with such  
104 short execution times has yet been carried out. Secondly, considerable inter-individual heterogeneity  
105 exists and not all subjects systematically respond or respond equally to each of these three

106 components [33, 36]. That is why an innovative and efficient intervention protocol (the Intervention)  
107 was specifically designed combining mental imagery practices comprising motor and emotional  
108 imagery, breathing exercises, and a short 6-minute duration execution.

109 The main aim of the present study was thus to investigate, using a series of “N-of-1” study design,  
110 the effects of this experimental 6-minute Intervention on the maximum voluntary isometric  
111 contraction (MVIC) strength of the hand-grip. We hypothesized that in each Intervention period, the  
112 hand-grip MVIC strength could be systematically stronger than the MVIC strength recorded during  
113 the Baseline period.

114

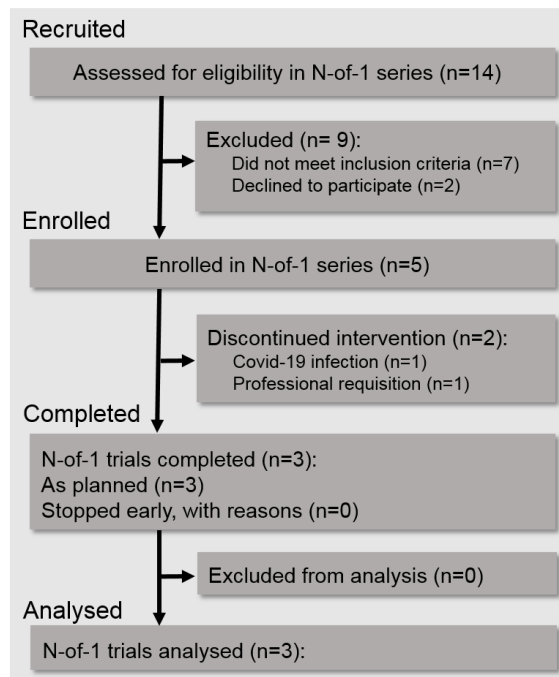
## 115 **2. Material and Methods**

### 116 2.1 Participants

117 Participants were required to have a physical check up by the local firefighter's healthcare institution,  
118 and participants received medical clearance to perform firefighting activities. Eligibility criteria were:  
119 1) aged between 22 years and 40 years old with at least three years' experience as a professional  
120 firefighter and be medically fit to work; 2) not having any musculoskeletal disorders or recent  
121 musculoskeletal injuries; 3) not suffering from post-traumatic stress disorder; 4) not having a history  
122 of neurological disorders; 5) not following acute or chronic drug treatment; 6) having a normal or  
123 corrected-to-normal hearing; 7) not undergoing sports training during the 4 days of data  
124 measurements; 8) having a minimum of 10 consecutive days off without professional work. The  
125 experimental design required 6 days. To ensure that possible fatigue related to firefighting activities  
126 did not interfere with the results of the study, we implemented a 2 days' rest period before the start  
127 of the experiment. In the same way, to ensure that possible fatigue related to the experimental  
128 protocol did not interfere with the firefighting activities of the participants, we implemented another  
129 2 days' rest period after the experiment and before that these firefighters go back to work. Exclusion  
130 criteria were: 1) consuming neuro-stimulants or energy drinks 24 hours before and during the  
131 experiment.

132 Fourteen French professional firefighters were prospected to take part in the experiment. Nine of  
133 them were excluded before being enrolled in the study because they were not eligible for at least  
134 one of the inclusion criteria (more precisely: having a recent musculoskeletal injury in the upper limb,  
135 n=4; following acute or chronic drug treatment, n=2; suffering from post-traumatic stress disorder,  
136 n=1), or because they did not wish to give their consent (n=2). Five professional firefighters were  
137 enrolled in this study but two of them had to stop the experiment: the first due to COVID 19 infection  
138 and the second for professional requisition. Finally, three right-handed French professional  
139 firefighters volunteered to take part in the study completed the experiment. The flow of participants  
140 as recommended by the CONSORT guidance for reporting series of "N-of-1" trials [34] is reported in  
141 figure 1. The descriptive characteristics of these three participants were specified in table 1.

142 All participants gave written informed consent to participate in the experiment. All procedures were  
143 approved by the Ethics Committee of the Federal University of Toulouse Midi-Pyrénées (No.: 2020-  
144 04-21-213) and complied with the Declaration of Helsinki as of 2008.



145

146 **Figure 1: Flow diagram of participant recruitment.** Representation of the flow of participants as recommended by  
 147 the CONSORT guidance for reporting series of “N-of-1” trials (36).

148

Participant	Age (years)	Height (cm)	Weight (kg)	BMI (kg.m <sup>2</sup> )
Firefighter no. 1	25	178	70	22.1
Firefighter no. 2	34	180	80	24.7
Firefighter no. 3	31	181	83	25.3

149 **Table 1:** Descriptive characteristics of the participants (n=3). Abbreviations: BMI, body mass index.

150

151 **2.2 Rationale and experimental design of the series of “N-of-1” trials**

152 The recruitment for group trials and retention (6 days in this study) may be difficult without causing  
 153 some alteration of the organisation of protection of the population in France. The availability of such  
 154 professionals to participate in a study are limited, and recruiting large numbers of professional  
 155 firefighters at the same time is very difficult because of obvious operational constraints inherent in  
 156 the profession. Moreover, it remained some reasonable doubts about the efficacy of the  
 157 experimental intervention in such timeframes and with these professionals (because of their  
 158 particular professional activities, firefighters cannot be considered identical to other members of the  
 159 general population [3]). That is why, according to Shamseer and colleagues [37] “when recruitment  
 160 for group trials is not always feasible and retention may be difficult”, we chose to design a series of  
 161 “N-of-1” studies according to the CONSORT extension for “N-of-1” trials guidelines [37, 38].  
 162 Introduced as early as 1960 by Sidman [39], single-case study designs are now well-known to allow  
 163 drawing strong causal inferences [40, 41, 42]. Such experimental design has been used in many  
 164 recent behavioural and clinical research [43]. It is indeed listed as “level 1” evidence by the Oxford



165 Centre for Evidence-Based Medicine 2011 levels of evidence [44]. That is why, according to the  
 166 Consolidated Standards Of Reporting Trials Statement guidelines [37], this study is thus a series of N-  
 167 of-1 trials designed to evaluate the same intervention across three individuals, namely a repeated  
 168 challenge-withdrawal trial for each individual. Here the intervention combined mental imagery  
 169 practices (motor and emotional imagery) and breathing exercises. In this so-called “ABAB” trial (in  
 170 the present study, “A” is the Baseline whereas “B” is the Intervention), the period, namely the time  
 171 during which a single treatment (A or B) is administered, was 24 hours. The sequence for each  
 172 participant comprised two blocks of two periods with a 48-hour washout period between each block.  
 173 The timeline of the experimental design is given in figure 2. The washout duration was chosen to  
 174 match the firefighters' rest period after a 48-hour period on call, and should allow recovery from  
 175 night-time activities.

Block 1: 48 hours		48 hours	Block 2: 48 hours	
Period 1 24-hours	Period 2 24-hours	W A S H O U T	Period 1 24-hours	Period 2 24-hours
Randomized order: A Baseline 'A' & an Intervention 'B' period			Randomized order: A Baseline 'A' & an Intervention 'B' period	

176  
 177 **Figure 2: Timeline of the experimental design.** Representation of the two 48-hour blocks made up of two 24-hour  
 178 periods, the two experimental 48-hour blocks being separated by a 48-hour washout phase.

179  
 180 In order to overcome any possible order and/or fatigue effects in the sequence, the order of the two  
 181 repeated pairs was pseudo-randomised for each participant (i.e., the outgoing combinations were  
 182 automatically removed for the draw order for the next participant). Participating firefighter no. 1  
 183 followed an “AB BA” sequence, firefighter no. 2 a “BA BA” sequence and firefighter no. 3 an “AB AB”  
 184 sequence.

185 2.3 Progression of a period

186 Each period began at 4pm. In each 24-hour period, a signal was emitted every 3 hours from a beeper  
 187 worn on the participant’s belt for a total of 8 measurements in a 24-hour period and a total of 32  
 188 measurements per participant in each whole SCED. At this signal, the participant had to go as fast as  
 189 possible to a locker room to don his firefighting outfit. The participant then sat in a seat with  
 190 armrests and put on headphones. The experimenter started a 6-minute soundtrack which was  
 191 broadcast via the participant’s headphones. The broadcast was either the control soundtrack to  
 192 establish the Baseline, or the Intervention soundtrack (Intervention contents are summarized step by  
 193 step in table 2). At the end of the 6 minutes, the participant went to an adjacent room to perform the  
 194 maximum hand grip force measurement. The entire protocol was conducted in single-blind on the

195 experimental side. The experimenter carrying out the measurements and analyses did not know the  
 196 sequence (Baseline or Intervention) until the blinding was lifted at the end of data analysis.

197 2.4 The Baseline and the Intervention

- 198 • **“A” The Baseline period:** during the 6-minute soundtrack, the participant heard the ambient  
 199 sounds and noises recorded from inside a firefighter rescue vehicle driving from the fire  
 200 station towards a mission site (noise of the engine, sound of other vehicles, crossing  
 201 intersections and overtaking vehicles with the siren, radio link, horn). Participants were  
 202 instructed to carefully listen to the soundtrack and imagine feeling himself inside the  
 203 emergency vehicle travelling to the mission site.
- 204 • **“B” The Intervention period:** during the 6-minute soundtrack, the participants listened to the  
 205 same baseline sound with an additional vocal track added over the background Baseline and  
 206 clearly heard by the participant. The participant was instructed to follow a protocol combining  
 207 mental imagery and breathing exercises. He was guided step-by-step through the exercises to  
 208 be performed. This interventional protocol is summarized minute-by-minute in table 2.

Timeline (min) of the Intervention period	Instructions and tasks
0:00-1:00	Perform in motor imagery: 6 concentric contractions of the hand grips at moderate intensity. Each imagined contraction had a 5-second duration and was followed by 5 seconds of imagined muscular relaxation. During the muscular relaxation, participants were instructed to mentally visualise oxygen-rich blood coming into the muscles of their hands.
1:00-2:00	Was a repeat of the previous step.
2:00-2:30	Perform a 30 seconds' full lung apnea and concurrently perform an imagined maximum isometric hand grip contraction. The participants received encouragement and kinesthetic guidance.
2:30-3:00	Fully exhale, then perform alternately the fullest possible inspiration over 2 heartbeats followed by the fullest possible expiration over 1 heartbeat and repeat until the next step.
3:00-3:30	Perform a 30 seconds' full lung apnea and concurrently to imagine gripping a rope with all his might. The rope was harnessed to a victim hanging above a void.
3:30-4:00	Was a repeat of the 2:30-3:00 step.
4:00-4:30	Perform a 30 seconds' full lung apnea and concurrently to imagine himself suspended by the arms from the last rung of the hook ladder above the greatest void ever seen, and to climb up the first four rungs only using his arms and hands.
4:30-5:00	Was a repeat of the 2:30-3:00 step.
5:00-5:30	Perform a 30 seconds' full lung apnea and concurrently to imagine grabbing a fire hose as firmly as possible in order to lower a teammate using an S-rappel solely by muscular strength.
5:30-6:00	Was a repeat of the 2:30-3:00 step.

209 **Table 2: The Intervention contents step by step.** The contents of the 4:00-4:30 and 5:00-5:30 steps are emergency  
210 rescue procedures in degraded conditions known to each participating firefighter.  
211  
212

213 2.5 The outcome measurement: hand-grip MVIC recordings

214 The outcome investigated was the maximum voluntary isometric contraction of the hand grip using a  
215 Hydraulic Hand Dynamometer (200lbs/90kg 5030J1, Jamar, Sammons Preston Rolyan,  
216 Nottinghamshire, United Kingdom). Since posture and handle position of the dynamometer can  
217 modulate the measured maximum grip strength, however, there is no consensus concerning  
218 measurement protocols for hand grip strength [45]. Therefore, this study assessed grip strength by  
219 the American Society of Hand Therapists protocol [46, 47, 48]: the participants in a seated position  
220 with the elbow flexed at 90° resting on a height-adjustable armrest. Their shoulders were adducted  
221 and their forearms in a neutral position. The wrist and the dynamometer were in the prolongation of  
222 the forearms and strictly over the void, i.e. not resting on the armrest. As recommended by Bechtol  
223 [49], a dynamometer with adjustable handle spacing with a verified and current calibration [50] was  
224 used to measure hand grip MVIC. Each maximum hand grip force measurement was done with the  
225 right hand less than 3 minutes after the end of the Baseline or Intervention period.

226 2.6 Analysis

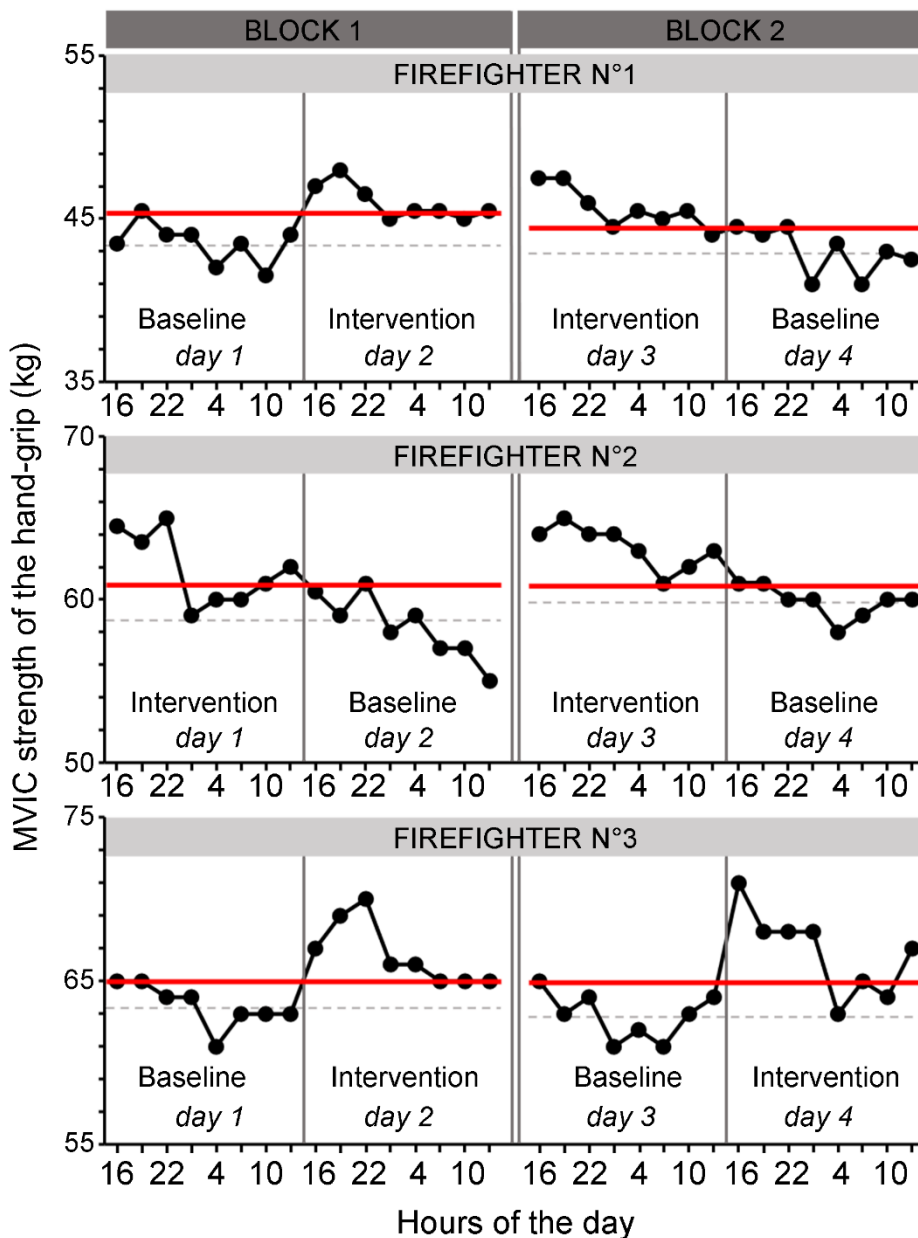
227 In this series of “N-of-1” trials, in order to investigate the impact of a combination of breathing  
228 exercises and mental imagery on the maximum strength of the hand grip for each participant, we  
229 used the percentage of non-overlapping data (PND) method [50]. This method is specifically designed  
230 and validated for quantitative synthesis of SCEDs or series of “N-of-1” [43, 52, 53]. In this method,  
231 the percentage of data points during the Intervention period which is greater than or equal to the  
232 maximum performance data during the Baseline period is calculated as the index of effectiveness of  
233 the Intervention. The effect-size is defined by the value of the PND between the Baseline and the  
234 Intervention periods within each single-case block, and defined as follows: highly effective  $\geq 90\%$ ,  
235 moderately effective [70-90]%, minimally effective [50-70]%, ineffective  $< 50\%$  [54].

236

237

238 **3. Results**

239 All results of the hand-grip MVIC strength recorded either just after a passive listening session  
 240 simulating a 6-minute emergency vehicle journey (the Baseline), or just after the same listening  
 241 superposed with the 6-minute experimental Intervention were presented and contrasted for each of  
 242 the three participating firefighters.



243  
 244 **Figure 3: Hand-grip MVIC strength.** Scatter chart with lines carrying over the values of the hand-grip MVIC  
 245 strength in kilograms (y-axis) depending on the experimental period (Baseline or Intervention), the day and the  
 246 time of day (x-axis), in Block 1 (to the left of the double vertical grey full line) and in Block 2 (to the right of the  
 247 double vertical grey full line). The double vertical grey full line represents the 48-hour washout period. From the  
 248 top to the bottom, each line corresponds to a participating firefighter. In each block and for each participating  
 249 firefighter, the horizontal solid red lines represent the highest value in the Baseline period taken into account for  
 250 the PND analyses, and the horizontal dashed grey lines show the mean value in the Baseline period.  
 251

Participant	Block	Baseline period		Intervention period		PND	Effect size
		Mean $\pm$ SD	Max	Mean $\pm$ SD	Max		
Firefighter no. 1	1	43.5 $\pm$ 1.3	45.5	46.0 $\pm$ 1.0	48.0	75.0 %	moderate
	2	43.0 $\pm$ 1.4	44.5	45.8 $\pm$ 1.1	47.5	87.5 %	moderate
Firefighter no. 2	1	58.3 $\pm$ 1.9	61.0	61.8 $\pm$ 2.2	64.5	62.5 %	minimal
	2	59.9 $\pm$ 1.0	61.0	63.2 $\pm$ 1.2	64.0	87.5 %	moderate
Firefighter no. 3	1	63.5 $\pm$ 1.5	65.0	66.6 $\pm$ 1.9	70.0	100 %	high
	2	62.9 $\pm$ 1.5	65.0	66.8 $\pm$ 1.2	70.5	75.0 %	moderate

252 **Table 3:** main results of the hand grip MVIC strength performance for each participant and within each block.  
253 Abbreviations: SD, standard deviation; Max, maximum value; PND, percentage of non-overlapping data.

254

### 255 3.1 Firefighter no. 1

256 For firefighter no. 1, the order of the sequence conditions was “AB BA”. In the Baseline sequences,  
257 the (mean  $\pm$  standard deviation) hand grip MVIC was 43.5  $\pm$  1.3 kg on average in Block 1 and 43.0  $\pm$   
258 1.4 kg in Block 2. In the Intervention sequences, the hand grip MVIC was 46.0 ( $\pm$ 1.0) on average in  
259 Block 1 and 45.8 ( $\pm$ 1.1) on average in Block 2. PND analyses showed an average effect size of 81.3%  
260 (75% in Block 1 and 87.5% in Block 2). In other words, this means that in Blocks 1 and 2, 75% and  
261 87.5% respectively of the data points recorded in the Intervention period were greater than or equal  
262 to the maximum data point recorded in the Baseline period (see Table 3 and Figure 3, top graph).

### 263 3.2 Firefighter no. 2

264 For firefighter no. 2, the order of the sequence conditions was “BA BA”. In the Baseline sequences,  
265 the hand grip MVIC was 58.3  $\pm$  1.9 kg on average in Block 1 and 59.9  $\pm$  1.0 kg in Block 2. In the  
266 Intervention sequences, the hand grip MVIC was 61.8  $\pm$  2.2 on average in Block 1 and 63.2  $\pm$  1.2 in  
267 Block 2. PND analyses showed an average effect size of 75% (62.5% in Block 1 and 87.5% in Block 2)  
268 (see Table 3 and Figure 3, middle graph).

### 269 3.3 Firefighter no. 3

270 For firefighter no. 3, the order of the sequence conditions was “AB AB”. In the Baseline sequences,  
271 the hand grip MVIC was 63.5  $\pm$  1.5 kg on average in Block 1 and 62.9  $\pm$  1.5 kg in Block 2. In the  
272 Intervention sequences, the hand grip MVIC was 66.6  $\pm$  1.9 on average in Block 1 and 66.7  $\pm$  2.2 in  
273 Block 2. PND analyses showed an average effect size of 87.5% (100% in Block 1 and 75% in Block 2)  
274 (see Table 3 and Figure 3, bottom graph).

275

#### 276 4. Discussion

277 The first objective of this project was to create an efficient “psyching-up” tool with the aim to  
278 promote muscular strength performance throughout a 24-hour on-call period in firefighters. For a  
279 good acceptance rate in firefighters’ duty, the execution of this mental intervention should not have  
280 modified the schedule of the firefighters’ work and needed to be easily implemented by firefighters  
281 when travelling between their fire station and the mission site. For this, a 6-minute Intervention was  
282 created by combining mental imagery practices (namely motor imagery and emotional imagery) and  
283 breathing exercises. Then the aim of the present study was to investigate whether this 6-minute  
284 intervention executed before an upcoming exercise of hand grip MVIC strength during a 24-hour  
285 period could induce better strength performance in firefighters over a 24-hour period. Hand grip  
286 MVIC performance was compared within three SCEDs in which multiple Baseline and Interventional  
287 data were recorded allowing investigating a hypothetical causal relationship between the data values  
288 recorded and the execution of the “psyching-up” Intervention.

##### 289 4.1 The 6-minute Intervention in a 24-hour period promotes hand-grip strength performance in 290 firefighters over a 24-hour period.

291 The results of this study demonstrated that in each of the three SCEDs, the sixteen hand-grip MVIC  
292 strength performance values recorded during the Intervention condition were strictly greater than  
293 the average of the sixteen MVIC strength performance values recorded during the Baseline condition  
294 (see Table 3 for more details). In addition, the effect sizes of these highlighted increases of the hand-  
295 grip strength performance were moderately effective on average (see Table 3). Overall, these results  
296 showed that the three firefighters included in this series of “N-of-1” studies had a positive response  
297 to the Intervention, and thus validate the initial hypothesis.

298 These results are in accordance with the neurophysiological literature concerning methods used  
299 during the intervention phases of this study, which could lead to hypothesize about the theoretical  
300 neurophysiological mechanisms underlying these results: Indeed, motor imagery [24], emotional  
301 imagery [28], and breathing exercises [33] are reported in the literature to be able, under certain  
302 conditions, to increase neuron responsiveness associated with an increased muscular strength  
303 performance for the same motor action. For example, Paravlic and colleagues [55] reported in their  
304 systematic review and meta-analysis that the favourable effect of motor imagery on the upper  
305 extremity muscles when compared with no-exercise controls was moderately beneficial on average,  
306 whatever the numerous designs and training protocols of the motor imagery which were used. In the  
307 same vein, similar results with similar effect size are also reported for modulation of the emotional  
308 context [28] and breathing exercises [32, 34]. So, to conclude, we could hypothesize that one or

309 more of these mechanisms, or interactions between them, may potentially be an underlying cause of  
310 the increase in the MVIC strength highlighted in this study.

311 4.2 When combined with emotional imagery and breathing exercises, just a few imagined muscular  
312 contractions were enough to promote the upcoming hand grip strength performance.

313 In the eleven different protocols reported by the review by Paravlic et al. [55], the motor imagery  
314 training durations were from one to twelve weeks, with two to five training sessions per week, from  
315 eighty to three thousand the total number of repetitions per study. Their meta-regression analysis  
316 revealed that a training period of 4 weeks with a frequency of three times per week with two to  
317 three sets of 25 repetitions per set were associated with moderately enhanced improvements in  
318 muscle strength following motor imagery practice. Although the above methodology makes it  
319 possible to highlight some recommendations for designing protocols in motor imagery for muscular  
320 strength improvement, it did not directly allow to favourably respond to the operational objectives  
321 and constraints in firefighters that was the main aim of this study. In a novel way, and for  
322 professional efficiency reasons, the new experimental Intervention designed and investigated here  
323 required to be able to be used during travelling between the fire station and the mission site, i.e.  
324 within a maximum of a 6-minute duration as required by the firefighters themselves. In this allotted  
325 duration, the intervention protocol was composed of “solely” twelve muscular concentric  
326 contractions at medium intensity, and four maximal isometric contractions maintained for thirty  
327 seconds each. To conclude, although the present results and their effect-sizes are in the same vein as  
328 those reported by Paravlic et al. [55], an important original finding of the present study remains that  
329 the muscular strength optimisation of the hand-grip was obtained with a 6-minute Intervention,  
330 coupling motor imagery with emotional imagery and breathing exercises. Unlike previous studies  
331 [54], the present intervention was carried out systematically before each upcoming performance  
332 measurement throughout 24-hour period. The results highlighted during the Baseline periods  
333 revealed also that this Intervention carried out for only 6 minutes 8 times a day, for only two days  
334 and separated by a minimum of 48 hours of rest without practice (the washout period), did not allow  
335 a persistent increase of the hand-grip strength over time. Repetition of this “psyching-up”  
336 intervention before each measurement would seem to be necessary here to promote hand-grip  
337 strength performance.

338 4.3 Limitations, recommendations and perspectives

339 The results highlighted in the present study are exploratory in nature. Given the small sample size of  
340 three participants, and despite the repetition of 32 measurements in total over 96 hours per  
341 participant, a first limitation of the present result is that it should not be generalised beyond the  
342 sample without further research. A second limitation is that the 6-minute duration of the



343 Intervention raises the issue of the optimal duration to promote an upcoming performance in  
344 firefighters to be even more efficient.

345 A third limitation concerns the performance of mental imagery tasks itself. Even though the voice  
346 commands reflect usual firefighters' activities, they look like complex commands. In the present  
347 study, a simple overall check at the very end of the experiment was carried out with a single  
348 question: "were you able to carry out all the exercises in the experimental protocol each time?" All  
349 participants answered "yes, absolutely". However, this does not consist of a self-assessment  
350 questionnaire. That is why we recommend in further study to implement any form to better verify if  
351 volunteers could effectively follow all the instructions as a self-evaluation for example.

352 A fourth limitation is that voluntary hand-grip strength is a reliable measurement, easy to set up, and  
353 easily reproducible from a scientific point of view. However, it alone does not guarantee or explain  
354 the whole operational performance of firefighters. That is why we recommend to study, in addition  
355 to the muscular strength, the impact of such a "psyching-up" tool on other outcome parameters such  
356 as muscular endurance, aerobic power, psychological stress or motor skills performance.

357 Such a "psyching-up" practice is very well received by the firefighters and the French fire service  
358 departments. Initiator and Instructor certifications in operational mental preparation for firefighters  
359 are being implemented for the very first time in France. Moreover, these results and other works of  
360 our group [12] have led French firefighter departments to integrate the teaching of these practices  
361 into the initial instruction of firefighters. That is why these promising results have to be confirmed by  
362 future research. More precisely, this primary study is leading our team to conduct a randomised  
363 control trial including some comments and testimonies from the firefighters in order to make even  
364 better the contents of the Interventions and even better evaluate their impact in firefighter  
365 operational safety and performance.

366 **5. Ethical approval**

367 All procedures were approved by the Ethics Committee of the Federal University of Toulouse Midi-  
368 Pyrénées (No.: 2020-04-21-213) as also by the Institutional Review Board of the Regional Fire and  
369 Rescue Service of Loire (Department n°42) and complied with the Declaration of Helsinki as of 2008.

370 **6. Informed consent**

371 All participants gave written informed consent to participate in this experiment. No identifying  
372 information, including participant' names, initials, or firefighters' numbers, are published in written  
373 descriptions or photographs in the present study.

374 **7. Conflict of interest**

375 The authors declare that they have no conflict of interest.

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386 **10. References**

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