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ORIGINAL ARTICLE

STRESS OF RESCUE TEAM MEMBERS WORKING IN CONFINED SPACES DURING A DISASTER: EFFECTIVENESS OF INDIVIDUAL WIRELESS COMMUNICATION DEVICES

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Abstract This study evaluated stress experienced by rescue team members during a simulated search and rescue operation in a confined space and determine if wireless communication reduces stress. A total of 57 rescue team members of X prefecture participated. The stress visualization indices were ptyalin (i.e., salivary amylase), salivary cortisol, autonomic nervous system response, visual analog scale, and a short version of the profile of mood states.

The subjects were randomized to perform a simulated search in a confined space without or with communication, and the stress indices were compared between the two groups.

Stress was observed in the form of changes in ptyalin level, visual analog scale scores, and autonomic nervous system responses. Statistical analysis showed that the "with communication" group exhibited significantly lower stress than the "without communication" group. Thus, wireless communication is recommended to reduce the stress experienced by rescue team members working in confined spaces.

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Key words: Confined space rescue; Rescue crews; Stress response; Individual wireless communication.

Introduction

Natural disasters occur frequently in Japan. The importance of early victim detection, rescue, and treatment is highlighted by incidents such as the Great Hanshin-Awaji earthquake (1995), Niigata Chuetsu earthquake (2004), and JR Fukuchiyama Line train derailment rollover accident (2005)[1,2]. The urban search and rescue of victims trapped in collapsed buildings or vehicles includes confined space rescue (CSR) and confined space medicine[3-7]. CSR is primarily performed by firefighting rescue team members, whereas confined space medicine is primarily performed by disaster medical assistance teams or dispatch medical care teams during a disaster.

Both CSR and confined space medicine personnel receive continuous training but face serious challenges in their work. Victims have difficulty escaping from collapsed buildings or vehicles in the event of natural disasters. The survival rate is associated with the swiftness of medical care. Rescue team members experience considerable physical and psychological stress during the early stage of a disaster. They commonly receive instructions from a platoon leader and are active while communicating with other members without individual communication devices.

However, high-particulate situations may require the use of earplugs, which impede communication. Furthermore, the attachment of

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air cylinders to rescue team members' backs and breathing masks to faces limits their field of vision and range of physical activity. Rescue team members occasionally act individually to rescue victims in confined spaces and likely suffer more stress under these conditions.

Objectives

This study aimed to simulate CSR during a disaster, evaluate stress in rescue team members, and determine if wireless communication helps reduce individual stress.

Methods

Subjects

The subjects were 57 male rescue team members who were ≤50 years old and worked at the firefighting headquarters of X prefecture. The age and sex restrictions were implemented owing to the difficulty of rescue operations; moreover, ptyalin (i.e., salivary amylase) and salivary cortisol secretion capacity differ between sexes[8,9].

Standard CSR equipment

From interviews of 10 rescue team members, the standard CSR equipment consisted of a helmet, headlight, goggles, rescue uniform, safety boots, gloves, mask, elbow protectors, and knee protectors. A self-contained compressed air breathing apparatus, ear plugs, and harnesses are added as needed.

To communicate with other members, subjects pulled on a rope as a signal but rarely used individual communication devices such as wireless radios. Subjects had to secure a route to the confined space in a situation where external communication (with other members, platoon leaders, and conduct headquarters, etc.) was obstructed.

Ethical considerations

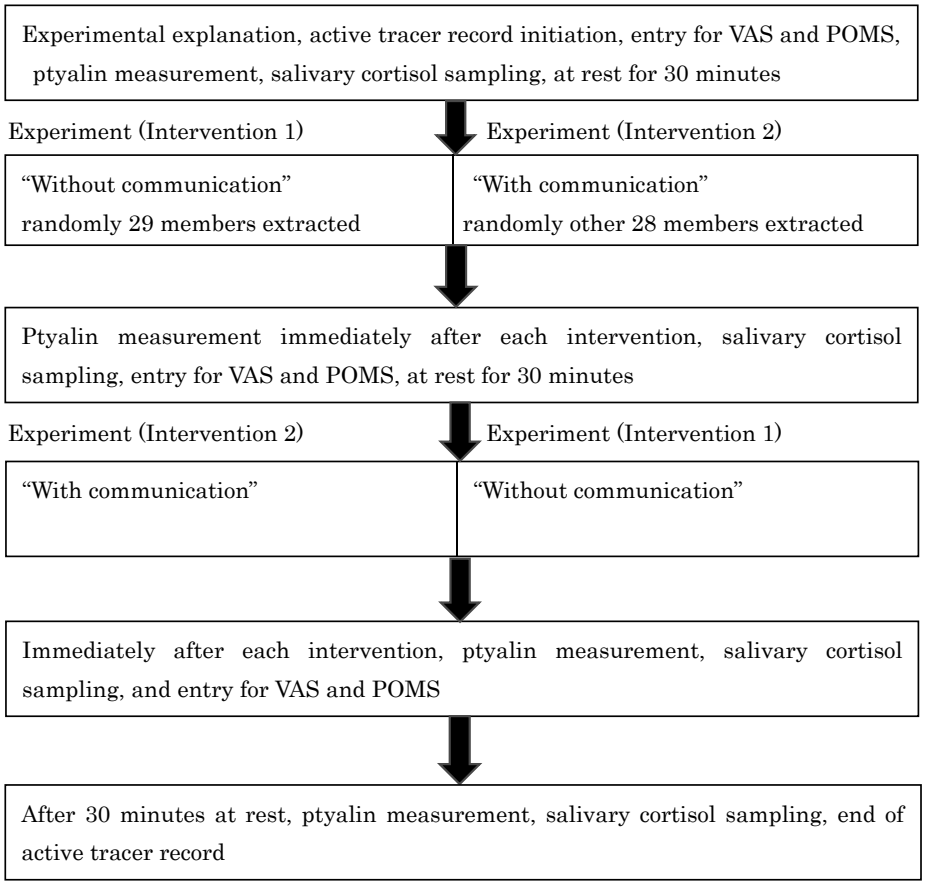
This study was approved by the Ethical Review Board of the Graduate School of Medicine of H University. We explained the experiment to the subjects orally and with a document. We clarified that individuals would not be identified in the publication of the results, objectives, or method of the study. Consent was obtained, wherein participants were free to discontinue their participation at any time. The subjects were informed regarding the storage and conservation of the results.

Experiment summary

(1) Simulated search and rescue operations were performed twice with 30 minute resting interval each by the same subjects in the same day who were randomized to the "without communication" or "with communication" (i.e., with wireless radio devices) group (cross-over comparison test). The twenty nine out of 57 members performed "without" first, then "with communication" and the rest of them (28) members did "with" first, then "without communication".

(2) Experiments were conducted in a 2-storey partially collapsed house simulation at the Urban Search and Rescue Training Ridge of Y Junior College. The interior was divided into 9 connected spaces. The confined space measured 5 × 13 × 1.2 m and consisted of a steel reinforced concrete construction that contained approximately 10 tons of concrete debris, furniture, and 6 speakers. The space was designed to require rescue team members to assume a low posture during operations. Furthermore, the interior was dark.

(3) Subjects were equipped with a helmet, headlight, gloves, elbow protectors, knee protectors, and a self-contained compressed air breathing apparatus immediately prior to entering the confined space. The facial accessory of the breathing apparatus was excluded, because the frame pressurized the



＊Each subject involved in this intervention 1 and 2 in the same day.
(This is " cross-over tests")

Figure 1 Flowchart of experiment (n=57)

salivary (i.e., parotid) glands of subjects, which would have skewed results.

(4) Each data was obtained according to the experimental flowchart shown in Figure 1.

(5) Scenario

On March 11th, a major earthquake occurred in A City at 12:05, causing the collapse of multiple buildings.

(i) Without communication

Emergency instructions from the platoon leader:

"The location is the C building of B University in the west. It is likely that a 3-storey building has collapsed, and one rescue is required. Other details are unknown. Because the entrance route is small, search and rescue must be performed individually by member D, take action!".

(ii) With communication

Emergency instructions from the platoon leader: "The location is the C building of B University in the west. It is likely that a 3-storey building has collapsed, and one rescue is required. Other details are unknown. Because the entrance route is small, search and rescue must be performed individually by member D. In addition, the radio call sign of member D is "rescue101" and will communicate at any time. Take action!".

(iii) A thunderstorm and the sound of collapsing debris were played from a speaker in the confined space.

(iv) A baby doll was the simulated victim contained a small speaker that emitted

infant cries. It was placed under debris in different places in each replicate.

(v) In cases "with communication", internal situation reports were required, and the subject was offered additional information by the platoon leader as *described below*:

From the leader of platoon (L) outside:

L: "Report the current situation in the confined space and give us additional information."

L: "A rescuer required is a 5 year old boy."

L: "According to the information from his mother, he seems to have been left near the center of building."

L: "The building seems to be stable now."

From a rescue member(R) inside:

R: "I am now searching him towards the center of neighborhood of present building . "

R: "I just confirmed the crying of a child. "

L: "Go ahead to the direction of the crying."

R:" The rescuer was found. "

R: " I'll save him and then escape with him out of the building. "

L: " Roger! "

Data collection method

(1) Ptyalin measurement

When subjected to stress, the sympathetic nervous system is stimulated, and the secretion of salivary amylase increases within minutes[10,11]. Saliva sampling test strips and ptyalin monitoring (Nipro, Cocoro Meter) were administered to the 57 subjects as follows:

① at rest for 15 minutes or more before intervention,

② immediately after the first intervention (without and with communications),

③ 30 minutes after the first intervention,

④ immediately after the second intervention (without and with communications),

⑤ 30 minutes after the second intervention.

(2) Salivary cortisol

Stress increases salivary cortisol secretion[12,13]. Saliva was obtained with cotton, which was swabbed under the tongue in the same way as described (1) above. Samples were immediately cryopreserved and measured later.

(3) Autonomic nervous system response

Autonomic nervous system response is a stress index obtained by analyzing cardiac frequency response to the autonomic nervous system[14-17]. An active tracer (AC-301) was used to record cardiac activity from 30 minutes before to 30 minutes after each intervention. Measured parameters included heart rate, LF (category integral calculus value of the heart low-frequency component [m/s^2] that conveys sympathetic and parasympathetic nerve functions), HF (category integral calculus value of the heart high-frequency component [m/s^2] that conveys parasympathetic nerve functions), and LF/HF (representing cardiac sympathetic nerve functions), whose higher values indicate greater cardiac sympathetic nerve functions. Acceleration was expressed in m/s^2.

(4) Visual analog scale (VAS)

The VAS subjectively scores subjects' stress[18,19]. In this study, 0 indicates no stress at all, and 10 is the highest level of stress. The degree of physical and psychological stresses experienced immediately after each intervention by subjects was recorded as the length of bar [cm] (Figure 2).

(5) Short version of the Profile of Mood States (POMS).

The POMS objectively evaluates subjects' mood[20]. The shortened version comprises 6 items: Tension-Anxiety (T-A), Depression-Dejection (D), Anger-Hostility (A-H), Vigor (V), Fatigue (F), and Confusion (C). The fifty seven subjects completed the POMS questionnaire immediately after each intervention.

Data analysis

(1) Ptyalin

Each parameter was measured by five

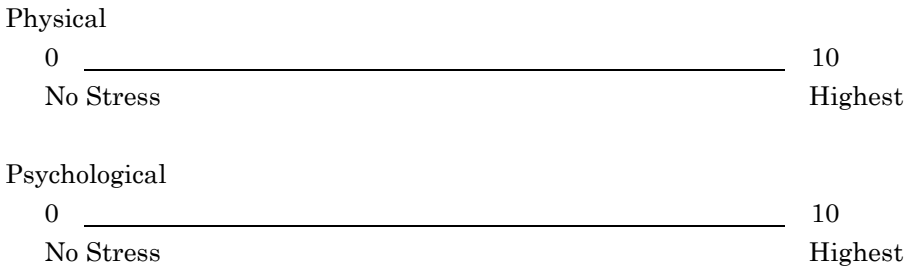


Figure 2 VAS: Visual Analog Scale

samples each from 57 subjects, and 2-factor ANOVA was performed using ANOVA4 on Web to compare means. The level of significance was set at $p < 0.05$.

Sampling was performed as below:

① at rest for 15 minutes or more before intervention,

② immediately after the first intervention (without and with communications),

③ 30minutes after the first intervention,

④ immediately after the second intervention,

⑤ 30 minutes after the second intervention.

(2) Salivary cortisol

Samples were obtained in the same way (1) described above and then analyzed by ELISA and a Bio-Rad Absorption Meter. Means were compared by 2-factor ANOVA using ANOVA4 on Web. The level of significance was set at $p < 0.05$.

(3) Autonomic nervous system response

Data obtained from 57 subjects were analyzed by an active tracer (AC-301) in MemCalc (Tawara). The one minute means were measured each after

①15 minute rest or more before the first intervention,

②2 minute CSR without communication, and

③2 minute CSR with communication, respectively.

Means were compared by one-way ANOVA (iteration measurement) in SPSS version 19.0. The level of significance was set at $p < 0.05$.

(4) VAS

① Immediately after intervention without communication,

② Immediately after intervention with communication,

Based on the results obtained from the experiments described above by 57 subjects, the degree of subject physical and psychological stresses was digitized, and means of both groups were compared by paired *t*-test in SPSS version 19.0. The level of significance was set at $p < 0.05$.

(5) POMS

Changes in mood of subjects were recorded by the same experiments (4) described above were analyzed by paired *t*-test in SPSS version 19.0. The level of significance was set at $p < 0.05$.

Results

1) Characteristics of Subjects

The mean age ± SD in 57 male subjects was 26.1 ± 3.6 years. The mean number of years of firefighting duty was 4.9 ± 3.3 years. The mean number of search and rescue experiences was 24.8 ± 91.9. Mean height and weight were 172.7 ± 4.3 cm and 69.2 ± 10.6 kg, respectively (Table 1).

2) Ptyalin

The mean ptyalin levels in simulations without communication were 146.4 ± 114.4, 202.7 ± 122.6, and 112.5 ± 97.3 KU/L at rest for 15 minutes or more before intervention, immediately after intervention, and 30 minutes after intervention, respectively; those in simulations with

Table 1 The Subject's Characteristics (n =57)

Age (Year)	Years of Service(Year)	Search and Rescue Practice Experience(Count)	Height(cm)	Weight(kg)
26.1 ± 3.6	4.9 ± 3.3	24.8 ± 91.9	172.7 ± 4.3	69.2 ± 10.6

＊Each subject involved in this intervention 1 and 2 in the same day.

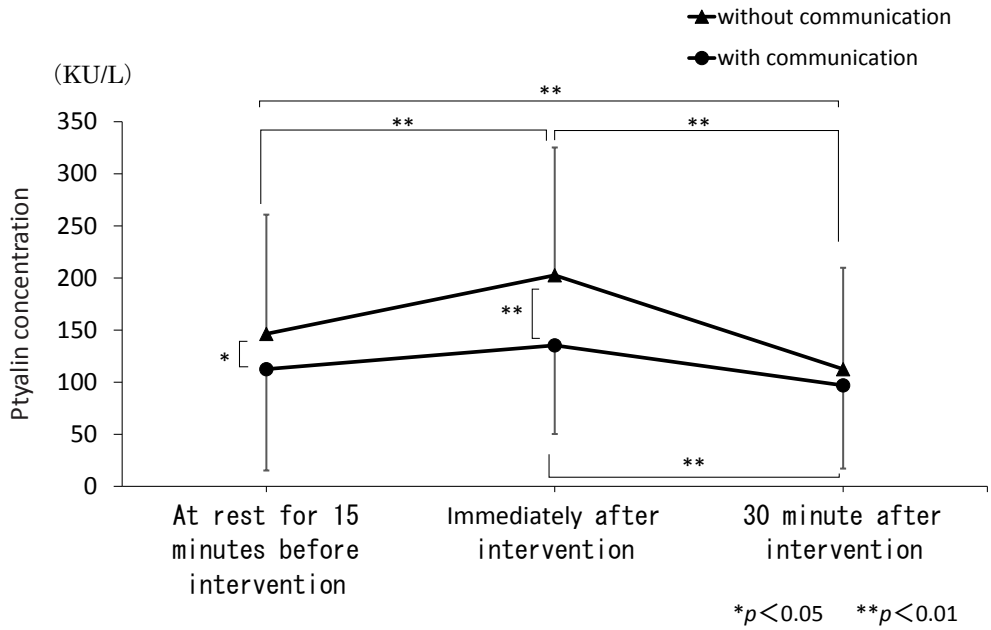


Figure 3 Ptyalin (n=57)

communication were 112.5 ± 97.3, 135.4 ± 85.1, and 97.0 ± 79.9 KU/L, respectively. Two-factor ANOVA indicated a significant interaction (F = 3.7, p = 0.03) before intervention (F = 6.8, p = 0.01) and immediately after intervention (F = 26.7, p = 0.001) for both the without communication (F = 24.5, p = 0.001) and with communication (F = 4.4, p = 0.01) groups. Multiple comparison (i.e., the Ryan method) showed significant differences before and immediately after the intervention (p = 0.001), before and 30 minutes after intervention (p = 0.01), and immediately after and 30 minutes after intervention (p = 0.001) in the without communication group. With communication, a significant difference was found only between immediately after and 30 minutes (p = 0.003) (Figure 3).

3) Salivary cortisol

The mean salivary cortisol level at rest for 15 minutes or more in simulations without communication was 0.36 ± 0.42μg/dL and 0.35 ± 0.42, and 0.42 ± 0.59μg/dL immediately after and 30 minutes after intervention, respectively; those in simulations with communication were 0.42 ± 0.59, 0.35 ± 0.47, and 0.36 ± 0.52μg/dL, respectively. There was no significant difference immediately after and 30 minutes after intervention in either group (Figure 4).

4) Autonomic nervous system response

Mean heart rate was 74.4 ± 11.1, 119.0 ± 16.7, and 112.5 ± 18.8 bpm at rest for 15 minutes or more before the intervention, after 2 minutes of CSR without communication and with communication, respectively. One-way ANOVA (i.e., subjects) showed heart rate was

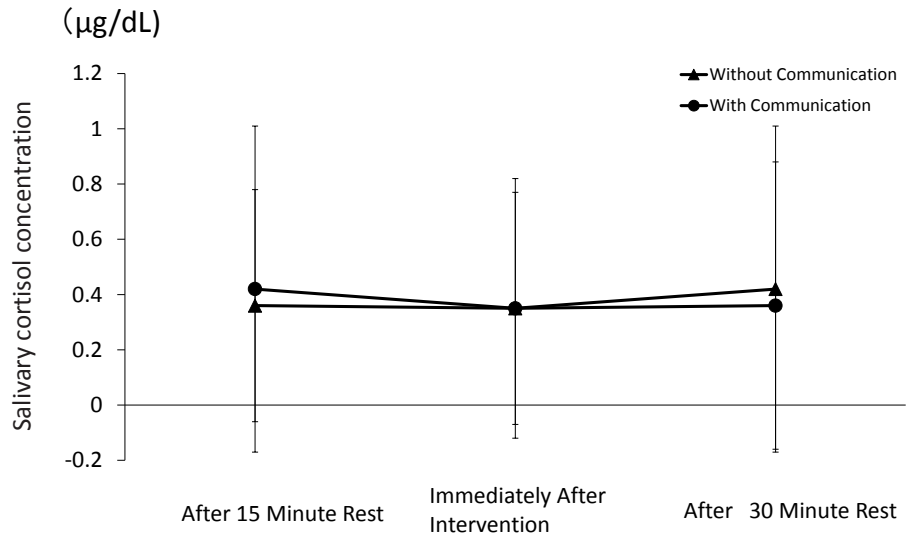


Figure 4 Salivary Cortisol (n=57)

significantly higher without communication than with communication when at rest 15 minutes before intervention (F = 248.5, p = 0.000). The Tukey multiple comparison test revealed significant differences in heart rate at rest before intervention without communication (p = 0.000), at rest before intervention with communication (p = 0.000), and between "without communication" and "with communication" (p = 0.003).

Mean LF before intervention was 1,223.1 m/s^2 and 395.3 ± 517.2, and 471.6 ± 399.0 m/s^2 after 2 minutes of CSR without and with communication, respectively. One-way ANOVA showed a significance difference between LF at rest 15 minutes before the intervention without communication and with communication (F = 47.7, p = 0.000). The Tukey multiple comparison test showed a significant difference between rest before the intervention without communication (p = 0.000) and that with communication (p = 0.000).

Mean HF was 513.9 ± 531.0, 156.7 ± 312.2, and 181.2 ± 354.3 m/s^2 at rest, and after 2 minutes of CSR without and with communication, respectively. One-way ANOVA showed a significance difference between rest before the intervention without communication and that with communication (F = 28.2, p = 0.000). The Tukey multiple comparison test showed a significant difference between rest before the intervention without communication (p = 0.000) and that with communication (p = 0.000).

The mean LF/HF ratio was 4.0 ± 2.3, 5.2 ± 3.1, and 5.3 ± 2.6 at rest, and after 2 minutes of CSR without and with communication, respectively. One-way ANOVA showed a significance difference between rest before the intervention without communication and that with communication (F = 5.1, p = 0.008). The Tukey multiple comparison test showed a significant difference between rest before the intervention without communication (p = 0.03) and that with communication (p = 0.01) (Table 2).

5) VAS

Mean VAS psychological and physical stress scores during the intervention without communication were 4.99 ± 2.36 and 4.22 ± 2.26, respectively, ; those during the intervention with communication were 3.22 ± 2.16 and 3.13 ± 2.16, respectively. Both psychological stress (t = 8.1, p = 0.001) and physical stress (t = 4.4, p = 0.000) were significantly lower during the

Table 2 Analyses of the Autonomic Nervous System (n=47)

Variable	At rest for 15 Minutes before Intervention		After 2 minute activities without Communication		After 2 minute activities with Communication	*p*-value
		*				
HR bpm	74.4 ± 11.1	***	119 ± 16.7	***	112.5 ± 18.8	0.000***
		***				
LF m/s^2	1,223.1 ± 784.7	***	395.3 ± 517.2		471.6 ± 399.0	0.000***
		***				
HF m/s^2	513.9 ± 531.0	***	156.7 ± 312.2		181.2 ± 354.3	0.000***
		**				
LF/HF	4.0 ± 2.3	*	5.2 ± 3.1		5.3 ± 2.6	0.008**

* $p<0.05$ ** $p<0.01$ *** $p<0.001$

Table 3 Results of VAS (n =57)

Variable	Immediately after intervention "without communication"	Immediately after intervention "with communication"	*p*-value
Physical Stress	4.99 ± 2.36	3.22 ± 2.16	0.000***
Psychological Stress	4.22 ± 2.26	3.13 ± 2.16	0.000***
		paired *t*-test	***$p<0.001$

Table 4 Results of POMS (n =57)

Variable	Immediately after intervention "without communication"	Immediately after intervention "with communication"	*p*-value
T-A: Tension-Anxiety	4.19 ± 3.49	3.82 ± 3.64	0.364
D: Depression-Dejection	1.12 ± 1.49	1.49 ± 2.50	0.256
A-H: Anger-Hostility	0.25 ± 0.83	0.29 ± 1.49	0.761
V: Vigor	7.58 ± 5.47	7.71 ± 5.61	0.728
F: Fatigue	1.91 ± 2.54	1.14 ± 2.27	0.027*
C: Confusion	3.89 ± 1.91	3.86 ± 2.26	0.918
		paired *t* test	*$p<0.05$

intervention with communication than without communication (Table 3).

6) POMS

POMS scores immediately after the intervention without communication were T-A, 4.19 ± 3.49; D, 1.12 ± 1.49; A-H, 0.25 ± 0.83; V, 7.58 ± 5.47; F, 1.91 ± 2.54; and C, 3.89 ± 1.91. Those immediately after the intervention with communication were T-A, 3.82 ± 3.64; D, 1.49 ± 2.50; A-H, 0.29 ± 1.49; V, 7.71 ± 5.61; F, 1.14 ± 2.27; and C, 3.86 ± 2.26. Only the F item was significantly lower with communication than without communication (t = 2.3, p = 0.027) (Table 4).

Discussion

1) Characteristics of Subjects

The subjects were generally younger. Firefighters generally enter firefighting school and

take basic classes. The educational curriculum comprised defense (i.e., fire extinguishing and prevention), emergency relations, and rescue relations. However, CSR education and training are not required. Therefore, most subjects experienced CSR for the first time by participating in this study. The mean number of search-and-rescue experiences was 24.8. Scenarios included fires, traffic accidents, and mountain rescues as well as searching for lost children and elderly people. Mean height and weight were similar to the mean height and weight (171.6 cm and 66.5 kg) of similarly aged Japanese males[21].

2) Stress of the firefighting rescue team members

(1) Ptyalin

Ptyalin levels are regulated by the circadian rhythm. The resting reference value is <30 KU/L. The highest level observed in the investigation of fatigue in ambulance crews was 52.3 ± 29.9 KU/L[9]. The ptyalin levels recorded in this study were high, indicating subjects in both simulations with and without communication experienced very high stress.

Just after the rest for 15 minutes or more before intervention with and without communication, a significant difference was found statistically. Not only the immediately after the intervention after the rest for 15 minutes or more, but also just after the rest for 15 minutes or more, a significant difference was found statistically.

However, at rest for 15 minutes or more, the second intervention might be started without a ptyalin level reaching enough to a rest level in case of without communication. It was thought that a stress level before the intervention affected the stress increase at search and rescue operation.

Therefore inspection is necessary for the method that it changes an experiment day and lengthens rest maintenance time in the next study.

(2) Salivary cortisol

Salivary cortisol levels are regulated by the circadian rhythm and ranging from 0.087 ± 0.012 to 0.452 ± 0.70 μg/dL in ambulance crews performing routine work in studies of Takatsuki et al.[22].

An increase in salivary cortisol levels was observed in simulations without communication immediately after and 30 minutes after the intervention compared to those at rest before the intervention. In simulations with communication, reduced levels of salivary cortisol were observed immediately after and 30 minutes after the intervention compared to those at rest before the intervention.

In the study for healthy adults, Fujibayashi et al.[23] determined that the salivary cortisol levels peak when waking up early in the morning (mean 0.76 ± 0.23 μg/dL), gradually decrease in the afternoon, and reach a nadir (0.07 ± 0.05 μg/dL) by 22:00 at night[24]. Both groups exhibited salivary cortisol levels within this reference range shown in preliminary research[14-17] There were no significant differences between groups. Also, the statistically significant difference was not found between both groups and was not able to judge the efficacy of the wireless communication, too.

(3) Autonomic nervous system response

The mean heart rate of 74.4 ± 11.1 bpm at rest 15 minutes before the intervention was within the adult reference value. The mean increased after 2 minutes of CSR without and with communication. The LF/HF ratio is an important index of sympathetic function (i.e., stress reaction). LF comprises both sympathetic and parasympathetic nerve functions, whereas HF involves only parasympathetic nerve function. As the LH/HF ratio reflects sympathetic function, higher values indicate greater sympathetic function. The LF/

HF ratio showed that sympathetic nerve function was active in both groups, indicating subjects experienced stress in search simulations[24]. All of data obtained in heart rate, LF, HF, and LF/HF showed significantly higher than those of a resting period in both interventions without and with communication. However, the evidence that individual wireless communication was effective for the stress reduction of the members of rescue team was not obtained because the difference was not observed in the both groups by the comparison between with and without communication.

(4) VAS

There was no reference value for VAS. However, as a state without stress was set at 0, both groups appear to have experienced moderate psychological and physical stress. As for the VAS score to express the subjectivity of subjects, the group with communication exhibited significantly lower VAS scores than the group without communication. Furthermore, subjects evaluated radio wireless communication positively: “it helps when troubled with making judgments when inside,” "there is the optimism even if we were alone and were active because we could communicate at any time", and "there is a limit for the signal with the natural voice and the rope by these confined space activity". Thus, the possibility that wireless communication helped the stress reduction of the member of rescue team was suggested.

(5) POMS

The mean sex- and age-specific POMS scores of 20 ~ 29-year-old males are as follows: T-A, 11.9 ± 6.0; D, 8.9 ± 9.4; A-H, 10.7 ± 8.1; V, 13.3 ± 6.0; F, 9.7 ± 6.0; and C, 8.4 ± 4.5. In the present study, A-H and F scores were moderately low, but the others were within their respective reference ranges. Therefore, major mood changes were not observed in either group before intervention and immediately after the simulation.

Of the 6 items of the POMS, only "F: fatigue" was significantly lower in the group with communication than without communication. However, it is unclear whether wireless communication helped reduce stress in this aspect.

3) Efficacy of the individual wireless communication

In the firefighting headquarters of each place, there is some setting of the individual radio instruments. However, there seems to be a difference in the setting situation by an area, and there seem to be higher in a deployment rate in the urban area,. According to unofficial hearing investigations, communication devices are more frequently used in urban areas, differing with respect to deployment situations and leadership. For instance, several subjects stated that the use of such devices may interfere with activity in a fire and thus the decision to use them was left to the judgment of the platoon leader.

Whereas, there were many impressions that wireless communication was effective in the case of CSR including "there is optimism even if we were alone and were active because we could communicate at any time" and "the radio is useful when we were troubled with a judgment inside" as having mentioned above. Individual wireless communication in a confined space, from the results such as ptyalin of this study, a response of the autonomic nervous system, VAS, and the opinion of subjects, was found to have possibilities to relieve the stress of the member of active rescue team. Also, the results of the present simulated search-and-rescue experiment suggests station and platoon leaders can more easily grasp internal situations and confirm the safety of rescue team members through wireless communication.

The stress reduction of the member of rescue team and the safe improvement lead to

acceleration of a search, a help, and the hospital practice of the victim.

Conclusions

1) In search-and-rescue operations in confined spaces, objective and subjective analyses show that rescue team members experience physical and psychological stress in confined spaces.
2) Communication with the conduct headquarters and the platoon via individual wireless radio communication devices likely reduces physical and psychological stress of the members of rescue team.
3) The individual wireless communication is beneficial in intelligence and safety management by dispatchers and platoon leaders sending rescue team members penetrating into confined spaces out.

Study limitations

The study subjects were active fire station staff and were limited by night duty or holidays on experiment days. Subjects' physical homogeneity was limited. Ptyalin and salivary cortisol levels may have been affected by smoking, eating, and drinking immediately prior to participation in the experiments. However, it is unclear whether the subjects were affected by those behaviors in the present study.

An active tracer was attached to subjects to see the response of the autonomic nervous system, but the data for ten were not able to be recorded by an accident such as a cord coming off by active mass with or more assumption, and an electrode coming off. Also, the "with communication" was able to be compared with "without communication" about VAS, and the POMS, but the data before the experiment were not obtained. Therefore, future problems are to compare before and after the experiment on the VAS and POMS.

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