생활과학석사 학위논문

Development and Evaluation of Firefighting Garment with Both Cooling and Drinking

여름철 소방관의 서열 부담 경감을 위한 냉각음수복 개발 및 평가

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이 논문을 석사 학위논문으로 제출함

2018 년 12 월

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Abstract

Fire fighter personal protective equipment (FPPE) consisted of helmet, hood, self-contained breathing apparatus (SCBA), gloves and boots. It always worn during fire fighting, and firefighters is exposed to high temperature work environment, affecting dehydration and heat illness. This study investigated the effectiveness of wearing cooling garment under FPPE for alleviating heat strain and firefighting task evaluation during firefighting activities in summer.

The study consists of two parts: The first part covers the separate and combined effects of skin cooling and cold fluid ingestion on the alleviation of heat strain when wearing protective firefighting clothing at an air temperature of 30°C with 50%RH. We developed a vest with a dual function of cooling and providing water supply (1.2% body mass). Protocol consisted of a 10 min rest on a chair followed by 30 min 5.5 km hr^{-1} exercise on a treadmill and a 20 min recovery in a sitting position on the chair. Eight males participated in the following four conditions: control [CON], drinking only [DO], cooling only [CO], and both cooling and drinking [CD]. The results showed that rectal (T_{re}), mean skin temperature (T_{sk}) and heart rate (HR) during recovery were lower for CD than for CON ($P < 0.05$), while no significant differences between the four conditions were found during exercise. CO significantly reduced mean T_{sk} and HR and improved thermal sensation, whereas DO was effective for relieving thirst and lowering HR in recovery. CD condition showed significant difference T_{sk} (1.5 ± 0.2°C) than CON.

The second part covers the efficiency of mobility of the newly-developed Nomex cooling shirt worn under firefighting personal protective equipment (FPPE) during simulated firefighting tasks. Sixteen firefighters participated in the following four experimental conditions: FPPE (Control), cooling vest A + FPPE (Vest A), cooling vest B + FPPE (Vest B), and Nomex cooling shirt + FPPE (Nomex cooling shirt). As a result, there were no significant differences in completion time, heart rate, total sweat rate, and blood lactate acid among the four conditions. Clothing microclimate temperature on the chest was lower for Nomex cooling shirt (31.2 ± 1.1oC) than Control (33.6 ± 0.8oC) or Vest A (33.5 ± 0.9oC) ($P < 0.001$). Clothing microclimate humidity and sweat sensation showed no differences among the four conditions. Firefighters felt less hot and less uncomfortable with Nomex cooling shirt and Vest B, compared to Vest A and Control (all $P < 0.05$). There were no significant differences in mass perception among Vest A, B and Nomex cooling shirt, while Nomex cooling shirt was perceived as less stiff than Vest A and B.

In summary, we developed a novel vest with a double function of skin cooling and cold water drinking for firefighters and also developed a cooling garment in shirt form made of Nomex fabric based on fire fighters' feed backs in the present study. The first experiment proved that through wearing the novel vest, the combined effect of skin cooling and fluid ingestion was synergistically manifested in T_{re}, T_{sk} and subjective perception in recovery. The second part, conducted on the improved garment design from vest form to shirt form, proved that wearing the Nomex cooling shirt under FPPE did not interrupt fire firefighters' mobility and show the lowest heart rate.

Keyword : Cooling vest; skin cooling; hydration; firefighters; heat strain; simulated firefighting tasks

Student Number : 2017-20127

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List of Abbreviations

BMI	Body mass index
FPPE	Fire fighter Personal Protective Equipment
HR	Heart rate (bpm)
I_T	Clothing Insulation (clo)
PSI	Physiological strain index
RH	Relative humidity (%)
RPE	ratings of perceived exertion
SCBA	Self-contained breathing apparatus
SD	Standard deviation
T_{ear}	Ear canal temperature (^oC)
T_{re}	Rectal temperature (^oC)
T_{sk}	Skin temperature (^oC)
$\bar{T}_{sk}$	Mean skin temperature (^oC)
USG	Urin specific gravity

1. Introduction

Firefighting is one of the most physically demanding occupations, inducing a considerably high rate of heat-related disorders. In hot environments, in particular, firefighting personal protective equipment (PPE) exacerbates heat strain by increasing metabolic rate due to its weight (~26 kg) and thermal insulation of ~2.44 clo (Barr et al. 2010, Holmer et al. 2006) as well as by inhibiting dry and evaporative heat dissipation from the skin to the air due to the encapsulating clothing layers. There are a lot of studies that investigated additional metabolic costs coming from wearing firefighting PPE in various environmental conditions. For example, Firefighting PPE results in a 115 $W \cdot m^{-2}$ increments in metabolic rate during heavy work (Dorman and Havenith 2009), a 0.8~1.2 $l \cdot min^{-1}$ increments in oxygen uptake ($\dot{V}O_2$) while walking (Skoldstrom 1987), a 15~20% increments in $\dot{V}O_2$ during high-intensity treadmill walking (5 km h^{-1} at 7.5% gradient) (Graveling et al. 1999) and a significant reduction in maximal oxygen uptake capacity ($\dot{V}O_{2max}$) ranging from 8 to 20% (Dreger et al. 2006, Lee et al. 2013, Louhevaara et al. 1995). The increase in metabolic rate and reduction in $\dot{V}O_{2max}$ due to the heavy PPE lead to a rise in core body temperature and to a reduction in tolerance time, respectively. The restriction of dry and evaporative heat dissipation from the skin aggravates the accumulation of body heat. According to a survey of 796 Japanese firefighters (Tochihara et al. 2005), approximately 50% of firefighters experienced heat disorders during firefighting. Another international survey on the next generation of PPE in Australia, Japan, Korea and US with 1,672 firefighters reported that among 13 elements, an automatic body cooling system among 13 examples was chosen as the most important element along with the location monitoring system (Lee et al. 2015).

The body cooling systems have been applied through pre-cooling, intermittent cooling for breaks, or post-exercise cooling. Cooling agents, such as ice packs, gel frozen packs, phase change material (PCM), circulated liquid or air fans have been proposed for workers, athletes and patients. There is evidence suggesting that workers wearing cooling garments under their PPE contribute to cooling effects and cooling efficacy. According to Kenny et al. (2011), wearing an ice vest under full PPE significantly improved exercise time and attenuated physiological strain during exercise. However, the cooling garments could be an additional weight burden as well as restricting body movements for firefighters because, after melting, the cooling effect is eliminated. In addition, rapidly taking off or exchanging the cooling vest after melting might not be feasible for firefighters because of their turnout gear. Also, the melted cooling packs may hinder body movement and such uncomfortable experiences can limit the next choice of cooling vests for firefighters. Most investigations on firefighters' body cooling focused on rapid cooling after work or during breaks (Barr et al. 2011, Carter et al. 1999, House et al. 1997, Selkirk et al. 2004, Zhang et al. 2009). There is almost no domestic nor international researches on whether the wearing of auxiliary clothing hinders the fire fighters' movements and most of the researches on fire fighters' movements are about development of simulated fire fighters' task protocol or cover burden on the body from wearing PPE under exercise protocol on a treadmill. Few studies investigated active cooling during work while wearing firefighting PPE (House et al. 2013). The only domestic study that developed simulated fire fighters' task protocol is Kim and Lee's and it contains three circuits of eight tasks, including transporting hose and ladder, going up and down stairs, waling in front of radiant heat source.

The limited water vapor permeability of PPE causes excessive sweat production for firefighters. Excessive sweating under heat stress without any fluid ingestion often results in dehydration. Brown et al. (2007) investigated urine specific gravity (USG) of 190 firefighters prior to participation in simulated firefighting activities and found that firefighters in a dehydrated state (USG>1.020) showed greater cardiovascular strain than firefighters in a euhydrated state (USG <1.020) (HR 151 ± 3.4 vs. 135 ± 9.3 bpm). Progressive body fluid losses during exercise in heat increase body temperature and plasma tonicity and decrease blood volume. The hyperthermic-hypertonic-hypovolemia during exercise in heat is confirmed by increased core body temperature (Sawka et al. 2001), an increase in plasma osmolality along with increased plasma sodium and chloride concentration (Sawka et al. 2001), a decrement of local sweat secretion (Sawka et al. 2001), a decrease in plasma volume (Sawka et al. 2001), and an elevation of plasma lactic acid concentration which may lead to decreased heat capacity of circulating blood (Zurovski et al. 1991).

It is also reported that dehydration is associated with significant deterioration in mental function (Gopinathan et al. 1988, Serwah and Marino 2006) and decrements in exercise tolerance time (Noakes 1993; Sawka et al. 1992). Short-term memory was improved (Cian et al. 2001) and reaction time was significantly faster when subjects were hydrated (Solera et al. 1999). Schlader et al. (2017) reported that chronic kidney disease from workers who regularly undertake physical work in hot conditions was related to hyperthermia and dehydration. Even though some results showed no difference between dehydration and hydration, this inconsistency is due to the level dehydration and the severity of uncompensable heat stress (Cheung and McLellan 1998, McLellan et al. 1999). Providing cold drinking water to minimize dehydration can be an effective intervention strategy to offset the impact of heat stress. The effects of drinking ice slurry on the body temperature of cyclists has been documented (Mejuto et al. 2018). Faster reaction time when subjects were hydrated (Solera et al. 1999) might be extremely beneficial for firefighters who need to make prompt judgments under emergency situations. However, fluid ingestion on a regular base might not be feasible for firefighters during active firefighting due to the pressing situations they must respond to and due to firefighting tools in both hands.

As described above, beneficial effects of skin cooling and fluid ingestion during exercise in heat are supported by extensive researches, but few investigations were undertaken on whether or not the combined effects of skin cooling and cold water drinking are synergistic. In this regard, we developed a novel vest with double functions of skin cooling and cold water drinking for firefighters and also developed a cooling garment in shirt form made of Nomex fabric based on fire fighters' feed backs in the present study. We decided to fill the cooling packs melt when the subjects had participated in alleviate heat strain test. This is original contribution of the present study. When developing the vest, one of the main focuses was to limit the total weight of the vest within a certain range. Thus we decided to fill the cooling packs with frozen drinking water, so that firefighters can drink cold water as the cooling packs melt. And we had to make sure that the firefighter interrupted the movement while wearing a jacket. So it was conducted with the cooling garment improved to shirt form from vest form. Two experiments were conducted in this study. Part 1 was conducted to investigate the separate and combined effects of skin cooling and cold water drinking using the novel vest during exercise while wearing firefighters' turnout jacket and pants in a hot environment. From this investigation, Part 2 was conducted with confirming whether wearing the newly developed Nomex cooling shirt under the existing turnout gears hinders the work proficiency during performing simulated fire fighters' tasks. Currently working fire fighters as subjects, we conducted comparison test between two types of cooling vests found in market and the newly developed Nomex cooling shirts. We hypothesized that skin cooling only would be more effective to alleviate heat strain than drinking cold water only; and the combined impact of skin cooling with drinking cold water would be smaller than the sum of each single effect of skin cooling and cold water drinking; and wearing cooling garments will not cause a reduction in work efficiency.

2. Methods

2.1 Part 1. Alleviate heat strain test

2.1.1. Subjects

Eight healthy young males participated in this study (mean ± SD: 23 ± 2.5 yr in age, 171.9 ± 3.9 cm in height, 68.3 ± 7.6 kg in body weight, and 1.8 ± 0.1 m^2 in body surface area). Body surface area was estimated using the formula of Lee et al. (2008). Subjects were instructed to abstain from alcohol and strenuous exercise for 48 hr, along with food and caffeine for 3 hr prior to scheduled tests. Prior to obtaining written informed consent, the subjects were informed of the purpose and potential risks of the present study. This study was approved by the Institutional Review Board of Seoul National University (IRB #1803/001-002).

2.1.2 Developing of a novel vest and experimental procedures

Main fabric of a dual function vest (290 g in mass without cooling packs; 1.1 kg with four cooling packs) was mesh consisting of 70% polyester and 30% spandex. The vest had four pockets to keep disposable frozen packs of sports drink (200 ml per pack × 4 packs = 800 ml; 1.2% of body mass) and flexible straws from each frozen pack were interconnected inside so that the frozen sports drink (7.8% carbohydrate-electrolyte; Powerade Isotonic, Coca-cola company, Atlanta) was drinkable as it melted (Figure 2.1). The cooling packs were kept in a freezer at –20 °C overnight before experiments. The surface temperatrue of the frozen cooling pack was an average 6.9^{o}C upon the 33^{o}C skin-simulated hot plate surface at an air temperature of 30^{o}C with 50%RH for 60 min and the frozen pack started to melt from 40~50 min.

Subjects participated in the following four experimental conditions: control (CON), drinking only (DO), cooling only (CO) and both cooling & drinking (CD). The experimental order was counterbalanced to avoid any familiarization effect. Each condition was conducted on separate and nonconsecutive days at an identical time. For the control condition, subjects wore the vest without any cooling pack with firefighting turnout jacket and pants. In the DO condition, subjects wore the vest with not-frozen sports drink packs, while in the CO and CD condition subjects wore the vest with frozen sports drink packs but subjects did not drink from the vest. Subjects drank the sports water evenly from the exercise to recovery sessions in the DO condition, while in the CD condition subjects drank the sports drink starting from when the frozen packs were sufficiently melted. The temperature of sports water for the DO condition started at 19.1^{o}C when put into the vest and increased to 27.5^{o}C at the end of exercise.

Subjects were required to maintain their hydration state at a normal level for 24 hr prior and any drinking was prohibited for 2-hr before their participation. As soon as they arrived at the experimental room, we checked both their hydration state to make sure their urine specific gravity was within the normal range of 1.004 to 1.029 and their rectal temperature to make sure it was within the normal range of 37.0 ± 0.5^{o}C. All trials were performed in a climate chamber at an air temperature of 30^{o}C and a relative humidity of 50%. A trial consisted of a 10-min rest on a chair followed by 30-min 5.5 km hr^{-1} exercise on a treadmill and a 20-min recovery in a sitting position on the chair. Subjects wore cotton undershorts (80 g), cotton t-shirts (133 g), cotton short pants (157g), cotton socks (80 g), the dual function vest (290 g) and running shoes (600 g) with firefighting turnout jacket (3,398 g) and pants (1,781g). For the control condition, the estimated clothing insulation (I_T) was approximately 2.1~2.3 clo (ISO 9920, 2007) and total clothing and PPE weight was 6.52 kg. Trials were terminated when rectal temperature (T_{re}) reached 39.2^{o}C, heart rate (HR) reached 95% of their maximal heart rate or if any subject felt unable to continue the exercise.

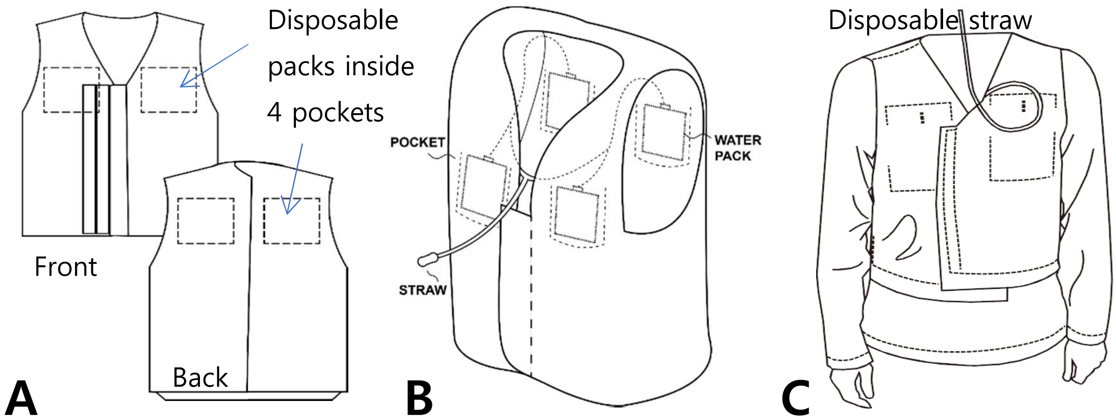

Figure 2.1. A newly-developed vest with dual functions of skin cooling and drinking water. Front and back view before putting water packs and tubing (A), side view with water packs and tubing (B) and front view with water packs and tubing.

2.1.3. Measurements

Rectal temperature (T_{re}) was measured every 5 s using a data logger (LT-8A, Gram Corporation, Japan) which was inserted around 16 cm beyond the anal sphincter. Ear canal temperature (T_{ear}) was measured using the same data logger with an earphone type sensor, which was inserted around 4 cm inside the ear canal. Skin temperatures (T_{sk}) were measured every 5 s using thermistor probes at 10 body regions [the forehead, upper chest, abdomen, upper back, forearm, dorsal hand, rear waist, thigh, calf, and dorsal foot] using the same type of thermistors that were used to measure T_{re}. Subjects weighed themselves on a calibrated body scale (F150S-*D2, Sartorius, Germany, resolution of 1 g) before and after each trial for estimating total sweat rate. To estimate the evaporative sweat rate, we measured experimental clothing before and after the trial as well. Local sweat rates were estimated on the back and chest using moisture absorptive papers (4 × 4 cm^2; 8 pieces for each region) through weighing the total mass before and after every trial on an electronic scale (AB204, Mettler Toledo, Switzerland) and the values were estimated for a 60-min value. Heart rate was measured on the chest every second using a chest belt and a watch (RC3, Poalr electro, Finland). Blood pressure was measured 4 times at the 0th min, 8th min, 40th min and 55th min using a digital blood pressure monitor and a cuff (HEM-7200, Omron, Japan). Urine specific gravity was measured using a device (ATAGO, Japan, PAL-10S) before and after the trial. Heart rate was recorded every 5 s throughout the trial using a heart rate monitor (RS400, Polar Electro Oy, Finland). Blood pressure was recorded four times at the 0th, 8th, 40th and 55th min for an hour trial.

Thermal sensation, thermal comfort, sweat sensation and thirst sensation were recorded every 10 min at the 6th, 17th, 27th, 37th, 47th and 57th min using the following categorical scales: 17-point thermal sensation with 9 categories (4 very hot, 3.5, 3 hot, 2.5, 2 warm, 1.5, 1 slightly warm, 0.5, 0 neutral, -0.5, −1 slightly cool, -1.5, −2 cool, -2.5, −3 cold, -3.5, −4 very cold); 7-point thermal comfort (3 very comfortable, 2 comfortable, 1 a little comfortable, 0 not both, −1 a little uncomfortable, −2 uncomfortable, −3 very uncomfortable), 7-point sweat sensation (3 very dry, 2 dry, 1 a little dry, 0 neither, −1 a little wet, −2 wet, −3 very wet) and 7-point thirst sensation with 7 categories (0 no thirsty, 0.5, 1 a little thirsty, 1.5, 2 thirsty, 2.5, 3 very thirsty). Subjects were asked about their thermal sensation, thermal comfort and sweat sensation for the overall, chest and back regions. During exercise, ratings of perceived exertion (RPE) which ranged from score 6 (no exertion at all) to 20 (maximal exertion) (Borg 1982) were recorded every 10 min. Subjects chose the category that matched their experience every 10 min and experimenters filled in their responses on experimental sheets. We interviewed subjects for information concerning their demographics and health habits, such as smoking/drinking/sleeping. The interview also included a self-health evaluation along with assessment of their expectations for their own fire protective helmets and hoods.

2.1.4. Data analysis

The weighted mean skin temperature was calculated according to a modified Hardy and DuBois' 12-point formula (Mitchell and Wyndham 1969):

$$T_{sk}=0.07T_{forehead} + (0.0875T_{chest} + 0.0875T_{abdomen} + 0.0875T_{upper\ back} + 0.0875T_{loin}) + 0.14T_{forearm} + 0.05T_{hand} + 0.19T_{frontal\ thigh} + 0.13T_{calf} + 0.07T_{foot.}$$

Physiological strain index (PSI) was calculated using Moran et al. (1998)'s equation:

$$PSI = 5(T_{ret} - T_{re0})\times(39.5 - T_{re0})^{-1} + 5(HR_t - HR_0)\times(180 - HR_0)^{-1}$$

The PSI values were calculated on a scale from 0 (no strain) to 10 (maximal strain). All quantitative data were expressed as the mean for the last 5 min of each period and standard deviation of the mean (mean ± SD). Repeated-measures analyses of variance (ANOVA) were used to identify differences in physiological responses among four conditions. Tukey's post hoc test was used to assess the parameters that displayed significant differences in ANOVA. Analysis of the rating scale measures (thermal, sweat and thirst sensation, thermal comfort, and RPE) was carried out using a one way repeated measures analysis of variance. Statistical analyses were performed with SPSS 23.0. Significance was set at $P < 0.05$.

2.2 Part 2. Simulated firefighters' task test

2.2.1. Subjects and experimental procedures

This experiment base consisted of 16 experienced healthy male firefighters from Seoul, Gwan-ak, Fire department (age 36.7 ± 8.0 yr, height 174.1 ± 5.4 cm, weight 76.7 ± 10.2 kg, BSA 1.95 ± 0.15 m2, BMI 25.2 ± 2.3 kg·m-2, experienced 9.5 ± 7.5 yr). Body surface area(BSA) is calculated by Lee et al. (2008) formula. All subjects were encouraged to refrain from alcohol use, and strenuous exercise for previous 24h, along with any food and caffeine for 3 h prior to their scheduled tests. The subjects were all informed of the content and consented, purpose and potential risks of this study.

2.2.2 Efficiency of simulated firefighters' task evaluation

2.2.2.1 Development of simulated firefighters' task protocol

In order to develop the simulated firefighters' task protocol, previous related studies were referred (Table 2.1). These tasks include 'hose carry, ladder climb and raise/down/carry, victim rescue, carry heavy weight, stair climb' among the common simulation in previous studies. After completing simulation task, we consulted the contents firefighters in real time (Figure 2.1). The eight firefighting tasks were immediately connected without rest, and firefighters were allowed to walk as fast as possible without running. After one circuit, they were rested in a chair for 5 minutes and then the same eight tasks were performed again, and this was repeated three times.

Table 2.1. Simulated firefighting tasks for evaluating firefighting performance in previous studies

Reference (year) : Country	Task description
Mamen, Oseland & Medbo (2013): Norway	① Hose carry, ② Ladder raise and extension, ③ Hose pull, ④ Ladder climb, ⑤ Hose pull, ⑥ Force entry (hammering), ⑦ Victim rescue, ⑧ Work A on ladder, ⑨ Work B on ladder, ⑩ Carry heavy weight
Siddall, Stevenson, Turner, Stokes & Bilzon (2016): UK	① Hose run, ② 25 kg Equipment carry task, ③ Stair climb (SCBA+25 kg weight) ④ Casualt: (55 kg dummy) evacuation, ⑤ Wild-land fire task
Williams-Bell et al. (2009): Canada	① Stair climb, ② Hose drag, ③ 27 kg Equipment carry, ④ Ladder raise and extension, ⑤ Forcible entry, ⑥ Search (through a tunnel), ⑦ Rescue (75 kg manikin), ⑧ Ceiling breach and pull
Heimburg, Medbø, Sandsund & Reinertsen (2013): Norway	① Puzzle(mental challenge), ② Balance(walking on a pipe), ③ Hose dragging, ④ Hose connection and disconnection, ⑤ Carrying heavy cans (23 kg×4), ⑥ Tunnel crawling
Todd, Docherty & Peterson (2014): Canada	① One-arm hose carry, ② Ladder carry and raise, ③ Charged hose drag, ④ Ladder climb 1, ⑤ Weighted sled pull, ⑥ Forcible entry, ⑦ Victim rescue (80kg manikin), ⑧ Ladder climb 2, ⑨ Ladder lower and carry, ⑩ Equipment carry (36.4kg weight)
Louhevaar et al. (1994): Finland	① Walking with/without hose, ② Stair climbing and ascending, ③ Hammering the truck tire, ④ Going over and under bars, ⑤ Hose rolling
Kim and Lee (2016): Korea	① Hose carry (7 kg) with both arms, ② Stair climb with the hoses (7 kg), ③ 15 kg-ladder carry and raise on the wall, ④ Ladder lower and carry, ⑤ Stair going down with the hoses (7 kg), ⑥ Hammering on a tire, ⑦ Walking on a radiant heat, ⑧ 70 kg sled pull

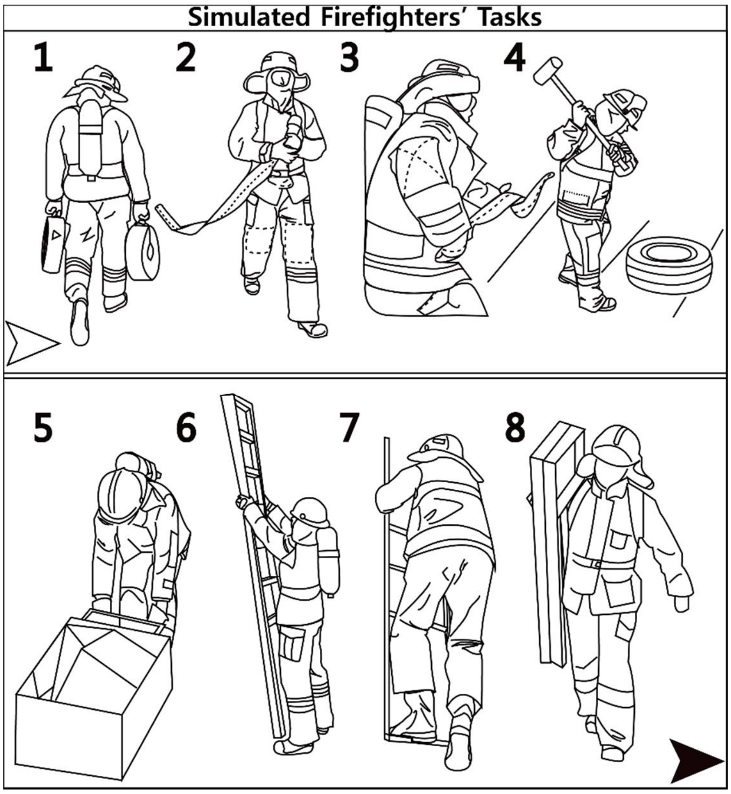

Figure 2.2. Simulated firefighting tasks used in the present study. ① Hose carry with two arms (65 mm, 7 kg each; 20 m × twice = 40 m) ② 10-m walking with the hose in use and 10-m walking without the hose ③ Rolling up the hose ④ Hammering (4.5 kg) and moving a tire (17 kg) (10 m × twice) ⑤ 70 kg sled pull (20 m moving) ⑥ Ladder(15 kg) carry (20 m) and raise on a wall ⑦ Stair climb (10 stairs×3 times) ⑧ Ladder down and carry (20 m × twice)

2.2.2.2 Experimental conditions and procedures

The experimental conditions were four types: FPPE (Control), cooling vest A (4 cooling packs, 13*10 cm/each pack), cooling vest B (6 cooling packs, 13*11/each pack), Nomex cooling shirt (4 cooling packs, 13*11 cm/each pack) (Figure 2.2). In this study, all conditions had same cooling packs to see the efficiency of operation work and subjects did not drink water during experiment. Cooling vest A is 780 g, cooling vest B is 1,250 and Nomex cooling shirt is 920 g , including cooling packs. The total mass of the experimental ensemble was 12,900 g, which consisted of FPPE (helmet, hood, bunker jackets and pants, boots, gloves, self-contained breathing apparatus (SCBA)), inner clothing (shorts, work shirts and pants-long types, socks). Control condition subjects wore is 12.9 kg, type A is 13.6 kg, type B is 14.1 kg, type NS is 13.8 kg. There was no wearing additional work shirts for Nomex cooling shirts. Before the each experiment, cold cooling packs were inserted into garment for at least 4 hours. All firefighters participated in all four experimental conditions in a random order and this experiment was included no drinking. All firefighters participated 2~4 times and in the case of participating two times a day, the rest interval between each experiment was at least 2 hours, rest period hear rate had under 90 bpm for 10 minutes, the experiment initiated (Chou et al., 2011; EN469).

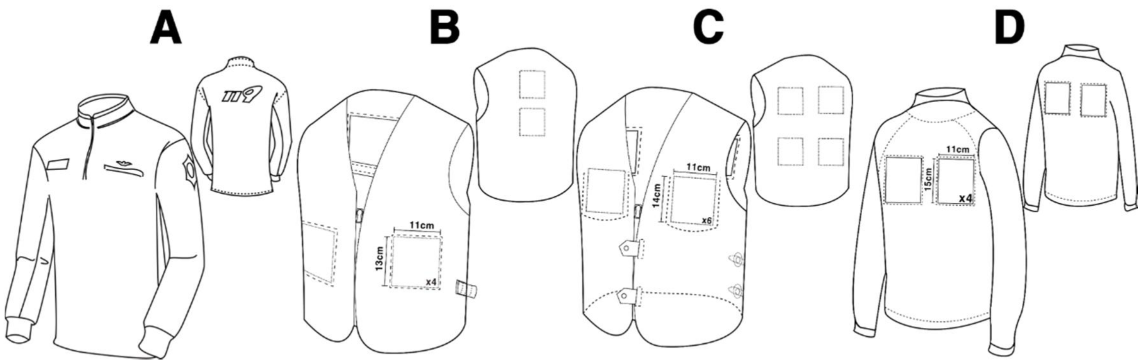

Figure 2.3. Cooling garments in the present study: A. Korean fire fighter PPE inside clothing B. Cooling vest type A (two cooling packs on the chest and the other two on the back; 130 g in the vest mass without cooling packs; strap belts on both sides), C. Cooling vest type B (four cooling packs on the back and two packs on the chest; 250 g in the vest mass without cooling packs; inside string). D. Newly developed Nomex cooling shirts (two cooling packs on the chest and the other two on the back, 275 g in the vest mass without cooling packs).

Participants were required to consume 300ml of water before each experiment's commencement and took a rest. Measurement of body mass was then obtained while wearing under wear and short pants. After wearing heart rate measurement belt on chest and monitor device on wrist. After sensor was attached to the chest to measure the clothing microclimate humidity of the chest, and subjects moved to experiment field and sat in the chair for 10 minutes while taking stable state. The bunker jacket was kept open with the zipper pulled down during the stabilization. The subjects went through enough interviews and explanations about the eight firefighting tasks, and the subjects were also made accustomed to the experiments by observing the experimenter performing eight simulations prior to the experiment. The simulated firefighting tasks were done outdoors and there were no rainy nor windy days during the experiment. The outdoor temperature and humidity measured at 5-second intervals using a thermo-hygrometer (TR-72U, T & D, Japan) were 32.7 ± 3.8°C and 53 ± 11% RH, respectively. Also ambient temperature (P = 0.680) and relative humidity (P = 0.815) was no significant difference among four conditions.

2.2.3. Measurements

Heart rate was measured on the chest every second using a chest belt and a watch heart rate (RC3, Polar Electro, Finland). Only a minimum number of sensors were attached so that the devices did not interfere with subject's firefighting task. Clothing microclimate humidity was attached device (TR-72U, T&D, Japan) to the chest for measuring every five second. Total sweat rate was estimated based on the change in total body mass before and after the experiment with shorts (F150S, Satorius, Germany). Blood lactate acid was measured from the fingertip after the completion of 3 repeated experiments and 2 minutes after during 5 minutes of recovery. (Lactate Pro, Arkray, Japan, resolution 0.1 mmol/l). Thermal sensation, thermal comfort, sweat sensation and rated perceived exertion were used as indexes for standardized questionnaire used before entering the experiment and at the end of the task) In this test, subjective perception was identical with alleviate heat strain test (see 2.1.3). In order to gather subjective opinions on cooling garments, firefighters were interviewed using the following questionnaire for each experiments (Appendix 1.). The questionnaire survey was developed based on what seems to be highly relevant to the simulated of the firefighters' task, study by Kim and Lee (2016) of Seoul National University and Clothing and Health Laboratories. The firefighter responded before and after participating in the experiment.

2.2.4. Data analysis

Repeated-measures analyses of variance (ANOVA) were used to identify differences in physiological responses among four conditions. Tukey's post hoc test was used to assess the parameters that displayed significant differences in ANOVA. The subjective perception (thermal, sweat and thirst sensation, thermal comfort, and RPE) was from Kruskal-Wallis test, and questionnaire was from Willcoxon Signed Ranked test. All quantitative data were expressed as the mean for the last 5 min of each period and standard deviation of the mean (mean ± SD). Statistical analyses were performed with SPSS 23.0. Significance was set at $P < 0.05$.

3. Results

3.1 Part 1. Alleviate Heat strain test

3.1.1. Rectal, ear canal and mean skin temperature (T_{re} , T_{ear}, and $\bar{T}_{sk}$)

This research is foucs on alleviate heat strain test by wearing novel vest with cooling and drinking. But there is no significant differences in rectal temperature (T_{re}) among the four conditions were found at rest, during exercise and recovery, showing average T_{re} of 37.8 ± 0.2°C (CON), 37.6 ± 0.2 °C (DO), 37.7 ± 0.3°C (CO) and 37.7 ± 0.2°C (CD) during exercise (Figure 3.1A). In recovery, T_{re} for DO, CO and CD declined, while T_{re} for CON maintained or showed a progressive rise (Figure 3.1B, P<0.05). There was a significant difference in mean skin temperature ($\bar{T}_{sk}$) among the four conditions (Figure 3.1A, P<0.05). At rest, $\bar{T}_{sk}$ was an average 1.3°C lower for CD (33.6 ± 0.6 °C) than for CON (34.9 ± 0.8 °C) (P < 0.05). During exercise and recovery, $\bar{T}_{sk}$ was significantly lower for CD and CO when compared to CON (P < 0.05) but no difference between CD and CO was found. Also there was no difference between DO and CON. In particular, $\bar{T}_{sk}$ during recovery fell (34.9 ± 0.5 °C) while $\bar{T}_{sk}$ for the other three conditions was maintained (P < 0.001). Ear canal temperature (T_{ear}) was lower for CD (36.4 ± 0.5 °C) than other three conditions but no significant differences were found among the four conditions (Figure 3.1B).

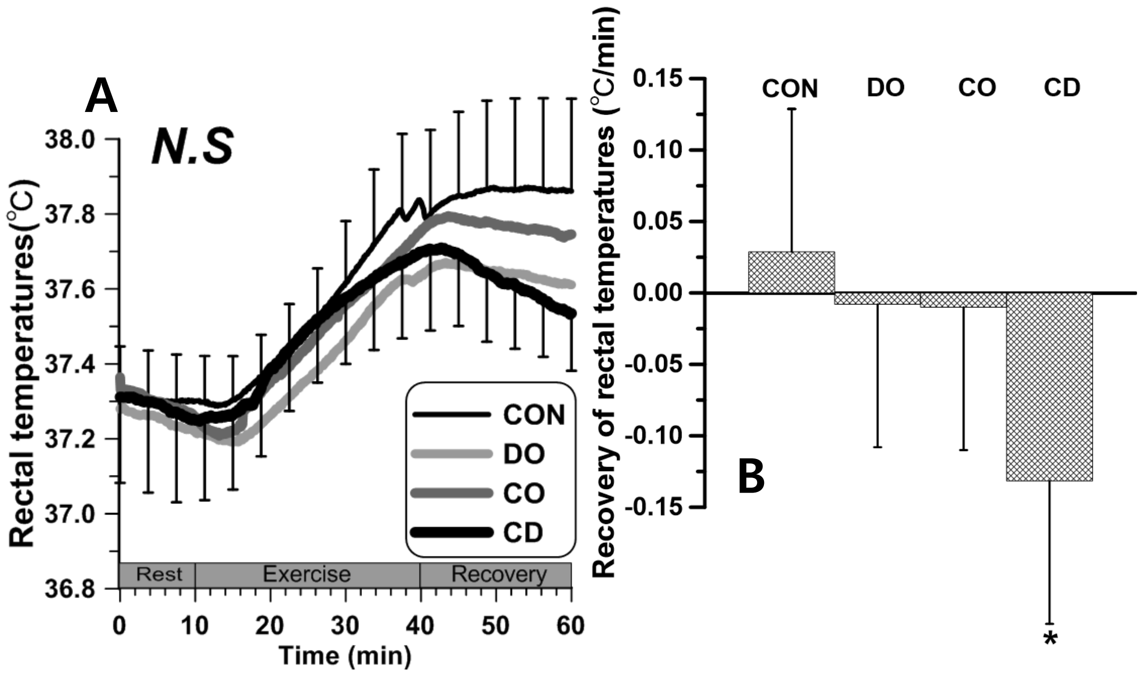

Figure 3.1. The time courses of rectal temperature (A) and the changes in rectal temperature for recovery (B). The CON, DO, CO and CD represent 'control', 'drinking only', 'cooling only' and 'cooling with drinking' conditions. **P*<0.05, ***P*<0.01, and ****P*<0.001.

3.1.2. Local skin temperatures (T_{sk})

Among the ten skin temperature measurements, trunk and thigh temperatures showed significant differences according to condition. Chest and thigh temperatures were significantly lower for CD and CO than DO and CON (Table 3.1, $P < 0.05$). Upper back temperature was lower for CD than for CON (Table 3.1, $P < 0.05$). Abdomen, waist, forearm and hand temperatures showed lower values for CD or CO compared to DO or CON, depending on the period of exposure (Table 3.1). Forehead, calf, and foot temperatures did not show any differences among the four conditions. For DO, there was no significant effect on skin temperatures.

Table 3.1. Regional skin temperatures of the four conditions: control, drinking (DO), skin cooling (CO) and drinking (CD)

	Phase (min)	Control	DO	CO	CD	*P*-value
Forehead temp. (°C)	Rest (5~10th)	35.9±0.4	35.8±0.3	36.0±0.3	35.8±0.3	*N.S*
	Exercise (35~40th)	36.6±0.5	35.2±2.3	36.3±0.3	36.1±0.3	*N.S*
	Recovery (55~60th)	36.3±1.2	35.6±1.4	36.0±0.5	35.5±0.7	*N.S*
Chest temp. (°C)	Rest (5~10th)	34.4±1.3^{b}	33.1±1.2^{b}	29.5±2.5^{a}	28.6±3.0^{a}	$P < 0.001$
	Exercise (35~40th)	36.5±0.5^{b}	35.6±0.4^{b}	29.0±4.6^{a}	29.4±4.2^{a}	$P < 0.001$
	Recovery (55~60th)	36.9±0.4^{b}	35.9±0.4^{b}	31.9±2.6^{a}	29.4±4.2^{a}	$P < 0.001$
Abdomen temp. (°C)	Rest (5~10th)	35.5±0.5^{b}	34.5±1.0^{ab}	34.1±1.3^{a}	33.9±0.7^{a}	$P < 0.05$
	Exercise (35~40th)	35.6±0.4	35.1±1.1	34.2±1.2	34.2±1.1	*N.S*
	Recovery (55~60th)	36.8±0.4	35.8±0.8	35.0±1.4	33.9±0.8	*N.S*
Upper back temp. (°C)	Rest (5~10th)	35.7±0.6^{b}	35.0±0.4^{ab}	34.8±0.5^{ab}	34.1±1.1^{a}	$P < 0.05$
	Exercise (35~40th)	37.2±0.3^{b}	36.3±0.8^{ab}	36.1±1.0^{ab}	35.8±0.9^{a}	$P < 0.05$
	Recovery (55~60th)	37.1±0.3^{b}	36.4±0.2^{b}	36.1±1.1^{ab}	35.2±1.5^{a}	$P < 0.05$
Forearm temp. (°C)	Rest (5~10th)	34.9±1.0	34.5±0.8	34.2±1.0	34.3±0.9	*N.S*
	Exercise (35~40th)	36.4±0.5	35.9±0.4	36.0±0.6	36.0±0.5	*N.S*
	Recovery (55~60th)	36.6±0.4^{b}	35.9±0.3^{ab}	35.8±0.5^{a}	35.5±0.7^{a}	$P < 0.05$
Hand temp. (°C)	Rest (5~10th)	34.8±0.9	34.6±0.6	34.4±1.4	34.5±0.9	*N.S*
	Exercise (35~40th)	35.5±1.	34.9±0.9	34.9±1.1	34.7±1.0	*N.S*
	Recovery (55~60th)	35.9±0.7^{b}	35.4±0.6^{b}	35.3±0.4^{b}	34.4±0.7^{a}	$P < 0.05$
Waist temp. (°C)	Rest (5~10th)	35.4±0.8^{b}	34.9±0.7^{ab}	34.2±0.8^{a}	34.2±0.7^{a}	$P < 0.05$
	Exercise (35~40th)	36.9±0.8	36.1±0.7	36.2±0.5	35.8±0.8	*N.S*
	Recovery (55~60th)	37.1±0.5^{b}	36.4±0.3^{ab}	36.4±0.4^{a}	36.2±0.6^{a}	$P < 0.05$
Thigh temp. (°C)	Rest (5~10th)	34.6±1.1^{b}	33.4±0.7^{ab}	33.3±0.9^{a}	33.4±0.7^{ab}	$P < 0.05$
	Exercise (35~40th)	36.5±0.5^{b}	35.9±0.4^{ab}	35.6±0.9^{a}	35.4±0.7^{a}	$P < 0.05$
	Recovery (55~60th)	37.1±0.4^{b}	36.2±0.5^{ab}	36.1±0.7^{a}	36.1±0.4^{a}	$P < 0.05$
Calf temp. (°C)	Rest (5~10th)	34.7±0.6	34.2±0.5	34.1±0.5	34.2±0.7	*N.S*
	Exercise (35~40th)	35.5±1.9	36.0±0.4	36.1±0.4	35.3±0.8	*N.S*
	Recovery (55~60th)	36.6±0.8	36.1±0.6	36.4±0.5	35.2±1.6	*N.S*
Foot temp. (°C)	Rest (5~10th)	34.0±1.6	33.6±1.7	34.2±1.5	33.8±1.8	*N.S*
	Exercise (35~40th)	36.6±1.1	36.8±0.7	36.6±0.7	36.6±0.5	*N.S*
	Recovery (55~60th)	36.7±0.5	36.2±0.3	36.5±0.2	36.4±0.3	*N.S*

Note: Data are expressed as means and standard deviations (SD);
DO, CO and *CD* represent 'Drinking only', 'Cooling only', and 'Cooling with Drinking', respectively.
N.S No significant; ^{a,b} and ^{ab} represent significant differences among the four conditions by a Tukey's post hoc.

3.1.3. Heart rate and blood pressure

Heart rate (HR) did not show any significant differences among the four conditions at rest and during exercise, but was lower for the CO, DO, and CD than for the CON during recovery (Figure 3.2, $P < 0.05$; last 5 min average was 110 ± 16 bpm for CON, 95 ± 10 bpm for DO, 94 ± 13 bpm for CO, 89 ± 15 bpm for CD). There were no significant differences in blood pressure among the four conditions, but systolic pressure for recovery was greater for CON at 146 ± 16 mmHg than for the other three conditions (139 ± 9 mmHg for DO, 138 ± 10 mmHg for CO, and 137 ± 8 mmHg for CD).

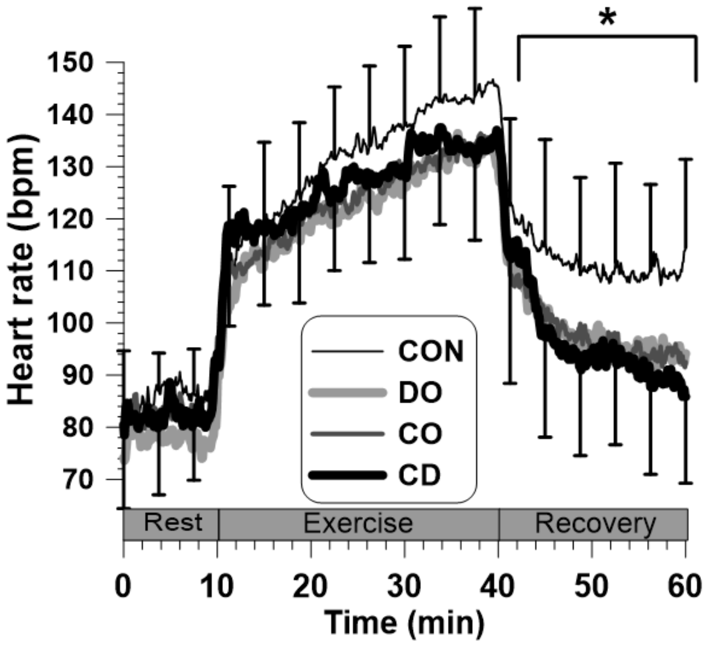

Figure 3.2. Time courses of heart rate. The CON, DO, CO and CD represent 'control', 'drinking only', 'cooling only' and 'cooling with drinking' conditions. *P<0.05, **P<0.01, and ***P<0.001.

3.1.4. Sweat rate and urine specific gravity

There were no significant differences in total sweat rate between the four conditions (472 ± 219 g h^{-1} for CON, 549 ± 284 g h^{-1} for DO, 329 ± 133 g h^{-1} for CO, and 400 ± 96 g h^{-1} for CD). Local sweat rates on the back (1.2 ± 0.6 g h^{-1} for CON, 1.5 ± 0.7 g h^{-1} for DO, 1.3 ± 0.8 g h^{-1} for CO, 1.3 ± 0.7 g h^{-1} for CD) and the chest (1.4 ± 0.6 g h^{-1} for CON, 1.8 ± 0.6 g h^{-1} for DO, 1.3 ± 0.6 g h^{-1} for CO, 1.1 ± 0.8 g h^{-1} for CD) did not show any differences between the four conditions. Urine specific gravity increased after the 60-min exposure for CON and decreased for DO, CO and CD, but no statistical significant differences were found in urine specific gravity among the four conditions (After the 60-min exposure: 1.021 ± 0.01 g h^{-1} for CON, 1.013 ± 0.01 g h^{-1} for DO, 1.017 ± 0.01 g h^{-1} for CO, and 1.016 ± 0.01 g h^{-1} for CD).

3.1.5. Subjective perceptions

Subjects felt less hot or cooler for CD compared to CON ($P < 0.05$) and the difference became greater for recovery than for exercise (Overall thermal sensation at the end of exercise: 2.9 ± 0.4 for CON, 1.9 ± 1.0 for DO, 2.1 ± 1.3 for CO, and 0.3 ± 1.0 for CD) (Figure 3.3A). Thermal sensation on the chest was lower than the values on the back for CO and CD (Figure 3.3BC). Subjects expressed less discomfort for CD than for CON on both the chest and back regions ($P < 0.001$). Also, subjects felt less sweat on both chest and back regions when compared to CON ($P < 0.05$). For thirst sensation, subjects felt less thirsty for DO and CO compared to CON and CO ($P < 0.001$). For the ratings of perceived exertion (RPE), no differecnes were found between the four condtions (at the last of exercise: 13.8 ± 2.1 for CON, 12.5 ± 2.1 for DO, 12.8 ± 1.8 for CO, and 12.0 ± 1.5 for CD).

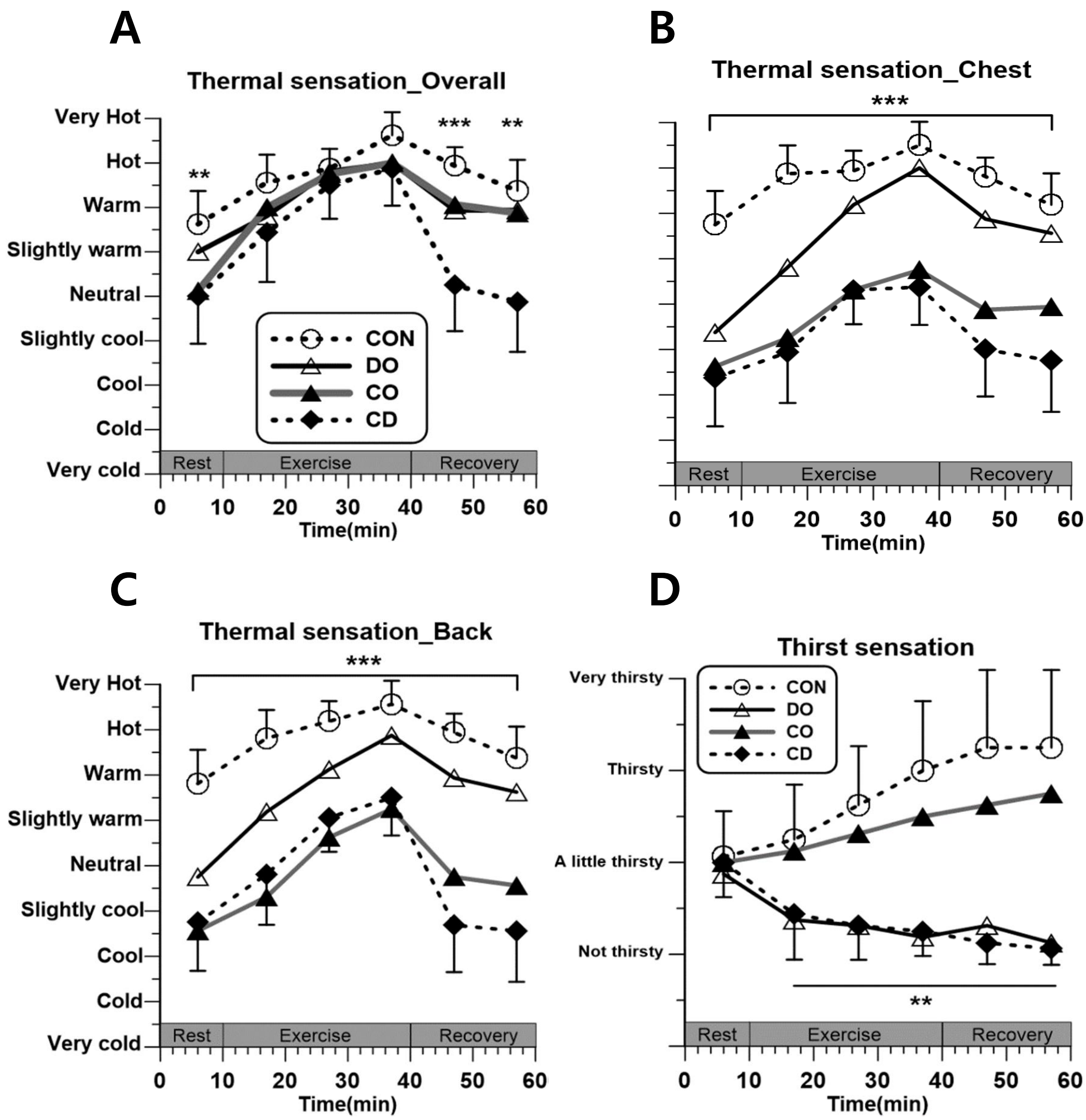

Figure 3.3. Time courses of thermal sensation of overall (A), chest (B), back (C) and thirst sensation (D). The CON, DO, CO and CD represent 'control', 'drinking only', 'cooling only' and 'cooling with drinking' conditions. *P<0.05, **P<0.01, and ***P<0.001

3.1.6. Physiological strain index (PSI)

PSI did not show any significant differences at rest and during exercise, but PSI was lower for CON than for CD during recovery (*P* < 0.05; CON 2.5 ± 1.2, DO 1.5 ± 0.9, CO 1.5 ± 1.0 and CD 0.9 ± 0.7)(Figure 3.4).

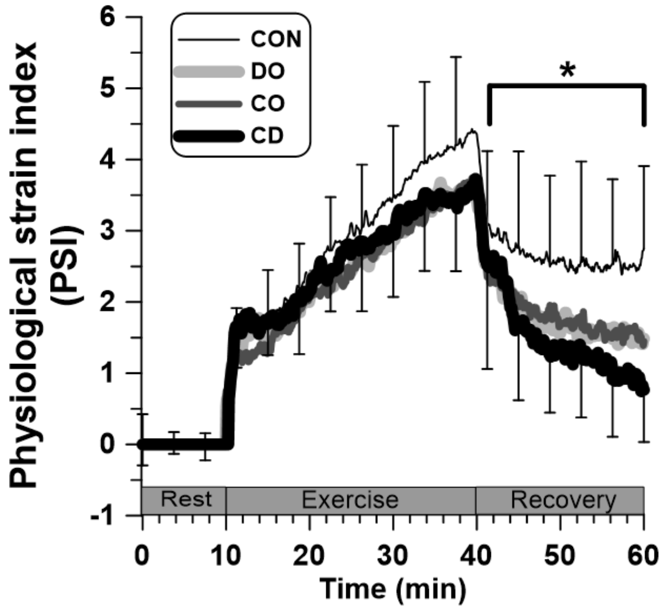

Figure 3.4. Time courses of PSI change. The CON, DO, CO and CD represent 'control', 'drinking only', 'cooling only' and 'cooling with drinking' conditions. **P*<0.05, ***P*<0.01, and ****P*<0.001

3.2 Part 2. Simulated firefighters' task test

3.2.1. Completion time of simulated firefighters tasks

The time required to repeat one circuit of eight tasks three times (except for 5 minutes between each break) ranged from 12 ~ 14 minutes on average (Table 3.2). It took the least time on Nomex cooling shirt (12.9 ± 2.0 min), the longest time under the control conditions (13.9 ± 1.8 min), however, there were no significant differences between the four conditions (*P* = 0.350). During the completion of each circuit (1st circuit, 2st circuit, 3st circuit), there were no significant differences in four conditions. As a result of analyzing the time required for each of the eight task, the completion time for 'ladder down and carry with ladder (tasks number 8)' was the longest from 47 seconds to 50 seconds and 'rolling up the hose (tasks number 3)' was the shortest from 11 seconds to 13 seconds (Table 3.3).

Table 3.2. Completion time of simulated firefighting tasks for the 4 experimental conditions

Time (sec)	Control	Vest A	Vest B	Nomex Cooling Shirts	P value[a]
1st circuit	288.4 ± 38.9	267.6 ± 44.1	268.9 ± 33.8	262.5 ± 43.2	0.163
2nd circuit	274.9 ± 41.0	254.0 ± 34.7	256.3 ± 31.8	255.7 ± 39.6	0.342
3rd circuit	271.6 ± 37.2	254.0 ± 33.6	253.2 ± 38.7	256.0 ± 40.7	0.474
Total sum	835.0 ± 112.6	775.7 ± 109.9	778.5 ± 102.0	774.2 ± 120.9	0.350
P value[b]	0.444	0.576	0.408	0.921	

[a] differences between the 4 cooling garment conditions; [b] differences between the 3 circuits.

Table 3.3. 3-circuit averaged completion time (sec) of each task for the 4 experimental conditions

Task	Control	Vest A	Vest B	Nomex Cooling Shirts	P value
1. Hose carry	36.7 ± 5.2	35.1 ± 4.7	35.6 ± 5.0	35.9 ± 6.3	N.S
2. One arm hose carry	20.1 ± 4.1	19.0 ± 3.0	18.7 ± 3.1	19.4 ± 3.4	N.S
3. Hose drag	13.0 ± 3.6	12.7 ± 4.4	12.7 ± 4.1	11.8 ± 3.9	N.S
4. Tire strike and drag	41.5 ± 10.8	37.5 ± 8.6	37.0 ± 8.6	36.5 ± 8.6	N.S
5. Pulling a victim	35.6 ± 6.6	33.2 ± 7.0	32.1 ± 6.4	33.7 ± 7.3	N.S
6. Carry and raise ladder	40.7 ± 11.0	34.8 ± 7.4	36.4 ± 6.4	35.0 ± 6.8	N.S
7. Ladder climb	40.3 ± 5.1	37.9 ± 6.0	39.1 ± 4.6	37.9 ± 4.7	N.S
8. Ladder lower & carry	50.3 ± 5.0	48.0 ± 7.0	48.3 ± 5.1	47.5 ± 6.1	N.S
Total completion time	278.5 ± 37.5	258.5 ± 36.6	260.2 ± 33.8	258.0 ± 40.3	0.350

3.2.2. Heart rate

There were no significant differences in heart rate among the four conditions, but Nomex cooling shirts had the lowest heart rate (129 ± 14 bpm) while cooling vest B condition had greater rate (131 ± 18 bpm) during 1st circuit (Figure 3.5). The second circuit also showed the lowest heart rate (148 ± 16 bpm) under Nomex cooling shirt and showed the highest heart rate under the cooling vest B. In the third circuit also the cooling vest B showed the highest HR but no significant difference between the four cooling garments were found. Even with the overall average value of the whole circuits, no significant difference was found between the four experimental cooling garments (Control 163.8 ± 17.2, Vest A 168.3 ± 17.9, Vest B 168.4 ± 14.1, Nomex cooling shirt 165.0 ± 16.7 bpm). However, as the number of repetitions increased, the heart rate tended to increase. At the time of the eighth task, the average heart rate of the four garments was 153.6 ± 11.3 bpm (1st circuit), 169.7 ± 10.8 bpm (2st circuit), 175.8 ± 11.3 bpm (3rd circuit) significantly increased ($P < 0.001$). The maximum heart rate circuit was found in the 3rd circuit, eighth task. The 5 second average at the time of showing the maximum heart rate was Control 176.5 ± 12.5, Vest A180.5 ± 13.1, Vest B 181.7 ± 8.4, Nomex cooling shirt 177.2 ± 12.6 bpm. All of the four experimental conditions showed a significantly higher heart rate in the 3rd circuit than in the 1st circuit in the eight task ($P < 0.001$).

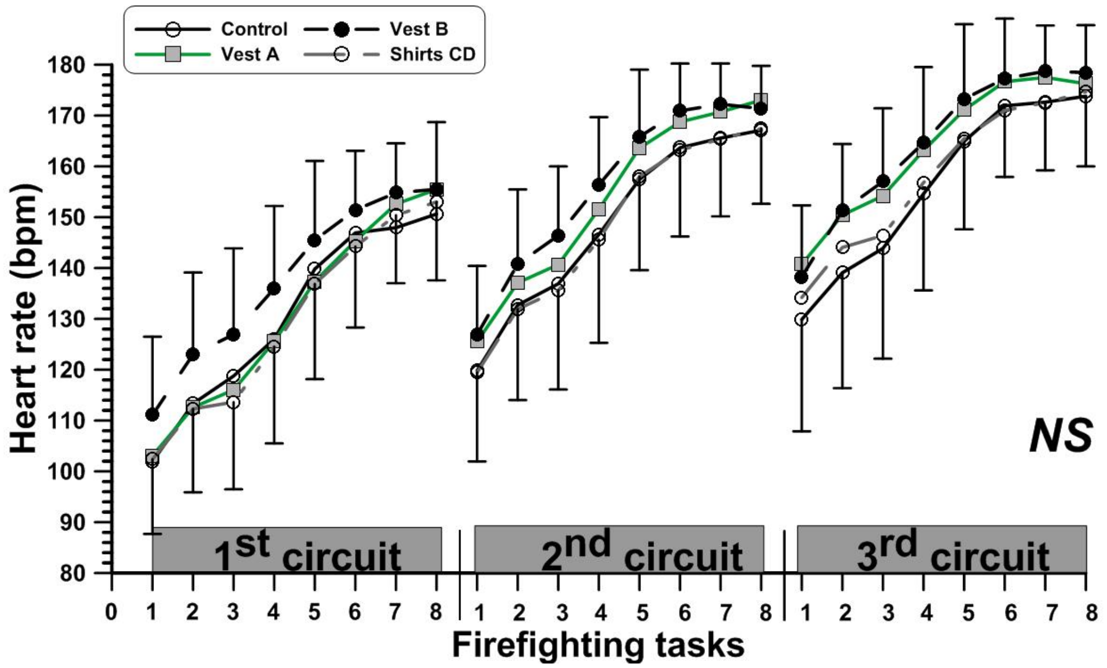

Figure 3.5. Heart rates while doing the 8 simulated firefighting tasks for each circuit. Task 1~8 are one circuit. NS represents that there were no significant differences between the four clothing conditions every circuit.

3.2.3 Total sweat rate, clothing microclimate humidity, blood lactate acid

The total sweat rate was control (604 ± 157 g / h), vest A (583 ± 120 g / h), vest B (537 ± 70 g / h) and Nomex cooling shirt (540 ± 156 g / h). There was no statistically significant difference (P = 0.568), regardless of wearing cooling garment (P = 0.568). Total completion time was less than 43 minutes (42.2 ~ 42.6 minutes) under all conditions, total sweat rate in this study was estimated to be 42 minutes instead of 60 minutes.

The temperature in the chest regions was the highest in control condition: Average 33.6 ± 0.8°C, vest A (33.5 ± 0.9°C), vest B (32.5 ± 0.8°C) and Nomex cooling shirts (31.2 ± 1.1°C) respectively. Nomex cooling shirt showed statistically lower temperature than control and vest A (P < 0.001, Figure 3.6A). However, the humidity in the chest region under the clothing showed an average humidity of 80%RH or higher that no significant differences were noted among the four experimental conditions (Control 84 ± 6 %RH, vest A 84 ± 11 %RH, vest B 81 ± 8 %RH, Nomex cooling shirt 81 ± 10%RH) (Figure 3.6B). For blood lactate acid measured after completion of all circuits, all of the four conditions showed 7 $mmol \cdot l^{-1}$ or higher, but there was no significant difference in the anaerobic fatigue between the four conditions (Control 7.1 ± 3.0, vest A 7.0 ± 2.8, vest B 8.3 ± 2.0, Nomex cooling shirts 7.4 ± 3.8 $mmol \cdot l^{-1}$).

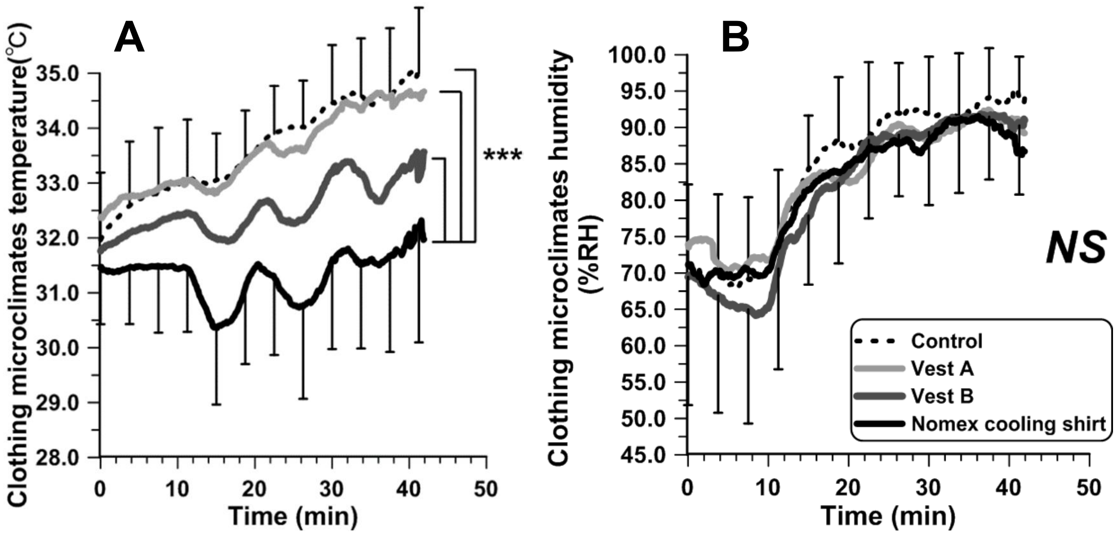

Figure 3.6. Clothing microclimate temperature (A) and humidity (B) on the chest.

3.2.4 Subjective perceptions

In the case of thermal sensation, there was a difference between the experimental conditions in overall. Chest regions and back regions were divided into groups with cooling garments (vest A, vest B, Nomex cooling shirt) and control groups (*P* = 0.002, Table 3.4). During measurement of thermal sensation of chest area, the subjects felt higher expressed heat in control condition (1.9 ± 1.1) than the cooling vest B (-0.2 ± 1.2) and Nomex cooling shirts condition (-0.6 ± 1.4) (*P*<0.001). After the third circuit, control conditions expressed (3.3 ± 0.7) between 'hot' and 'very hot'. In Nomex cooling shirt, vest B and vest A condition expressed close to 'slightly warm' (*P*<0.001, Table 3.4). Thermal sensation of back regions expressed as same as chest regions. Overall thermal comfort did not show any significant difference between the four experimental conditions after the second and third circuits, but the thermal comfort of the chest and back regions was significantly expressed less uncomfortable with Nomex cooling shirts and vest B than control (*P*<0.01, Table 3.4). Overall sweat sensation showed 'wet (2 points)', 'a little wet (1 point)' without significant difference between the four experimental conditions during three repetitions. The tendency to feel more humid by the addition of cooling garments was not found. On the contrary, in case of sweat sensation in the chest and back region, it was found that the control condition was expressed 'wet' than the cooling garment wearing condition (*P* <0.01, Table 3.4). There were no differences in ratings of perceived exertion (RPE) between the four conditions. As the repetition increased, the score tended to increase by 1 point from 14 points to 16 points. On average, 14 points were answered in all four conditions (Table 3.4).

Table 3.4. Subjective responses for the 4 experimental conditions

	Body region	Circuit	Control	Vest A	Vest B	Nomex Cooling Shirts	P value
Thermal sensation	Overall body	1st	2.1 ± 1.0	0.6 ± 1.0	0.3 ± 1.3	0.4 ± 1.5	0.0001
		2nd	2.7 ± 0.6	1.6 ± 1.1	1.3 ± 1.5	1.6 ± 1.5	0.013
		3rd	3.4 ± 0.6	2.3 ± 1.5	2.4 ± 1.4	2.3 ± 1.4	0.041
		Averaged	2.7 ± 0.7	1.5 ± 1.2	1.4 ± 1.4	1.4 ± 1.5	0.002
	Chest	1st	1.9 ± 1.1	0.1 ± 1.0	-0.2 ± 1.2	-0.6 ± 1.4	0.0001
		2nd	2.6 ± 0.6	0.9 ± 1.4	0.4 ± 1.1	0.7 ± 1.5	0.0001
		3rd	3.3 ± 0.7	1.8 ± 1.6	1.6 ± 1.4	1.4 ± 1.5	0.001
		Averaged	2.6 ± 0.8	0.9 ± 1.3	0.6 ± 1.2	0.5 ± 1.5	0.0001
	Back	1st	1.9 ± 1.0	-0.3 ± 1.1	-0.3 ± 1.3	-0.4 ± 1.4	0.0001
		2nd	2.6 ± 0.6	0.9 ± 1.5	0.1 ± 1.1	0.6 ± 1.5	0.0001
		3rd	3.3 ± 0.8	1.7 ± 1.6	1.4 ± 1.5	1.4 ± 1.4	0.0001
		Averaged	2.6 ± 0.8	0.8 ± 1.4	0.4 ± 1.3	0.5 ± 1.4	0.0001
Thermal comfort	Overall	1st	-1.3 ± 0.7	-0.8 ± 0.9	-0.4 ± 0.8	-0.6 ± 1.0	0.018
		2nd	-1.8 ± 0.7	-1.3 ± 1.1	-1.1 ± 1.2	-1.0 ± 1.1	0.160
		3rd	-2.1 ± 0.8	-1.3 ± 1.6	-1.4 ± 1.1	-1.3 ± 1.4	0.214
		Averaged	-1.7 ± 0.7	-1.1 ± 1.2	-0.9 ± 1.1	-1.0 ± 1.2	0.073
	Chest	1st	-1.2 ± 0.8	-0.2 ± 1.0	0.2 ± 0.8	0.3 ± 0.9	0.0001
		2nd	-1.7 ± 0.7	-0.7 ± 1.0	-0.1 ± 1.0	-0.3 ± 1.1	0.0001
		3rd	-1.9 ± 0.8	-0.9 ± 1.2	-0.9 ± 0.9	-0.8 ± 1.1	0.003
		Averaged	-1.6 ± 0.7	-0.6 ± 1.1	-0.3 ± 0.9	-0.3 ± 1.0	0.0001
	Back	1st	-1.4 ± 0.9	-0.1 ± 1.0	0.4 ± 0.8	0.2 ± 0.8	0.0001
		2nd	-1.8 ± 0.7	-0.4 ± 1.1	-0.1 ± 0.8	-0.3 ± 1.1	0.0001
		3rd	-2.0 ± 1.0	-0.6 ± 1.1	-0.6 ± 1.0	-1.0 ± 1.0	0.002
		Averaged	-1.7 ± 0.9	-0.4 ± 1.1	-0.1 ± 0.9	-0.4 ± 1.0	0.0001
Humidity sensation	Overall	1st	1.5 ± 1.1	1.0 ± 0.9	1.1 ± 0.7	1.1 ± 1.0	0.123
		2nd	1.8 ± 1.2	1.5 ± 1.1	1.7 ± 0.9	1.4 ± 1.0	0.617
		3rd	2.1 ± 1.2	1.9 ± 1.1	2.1 ± 1.1	1.9 ± 0.9	0.689
		Averaged	1.8 ± 1.2	1.5 ± 1.0	1.6 ± 0.9	1.5 ± 1.0	0.336
	Chest	1st	0.4 ± 0.9	0.7 ± 0.7	0.6 ± 0.5	0.6 ± 0.7	0.002
		2nd	1.4 ± 1.2	1.0 ± 0.9	1.0 ± 0.6	0.7 ± 1.1	0.046
		3rd	1.5 ± 1.3	1.7 ± 0.9	1.3 ± 0.9	1.3 ± 0.9	0.033
		Averaged	2.0 ± 1.1	1.1 ± 0.8	0.9 ± 0.7	0.9 ± 0.9	0.006
	Back	1st	1.4 ± 1.0	0.8 ± 0.6	0.6 ± 0.5	0.5 ± 0.7	0.006
		2nd	1.6 ± 1.2	1.1 ± 0.8	0.8 ± 0.8	0.7 ± 1.1	0.022
		3rd	2.1 ± 1.4	1.4 ± 1.1	1.1 ± 0.9	1.5 ± 0.8	0.019
		Averaged	1.7 ± 1.2	1.1 ± 0.8	0.8 ± 0.7	0.9 ± 0.9	0.007
Ratings of Perceived Exertion (RPE)		1st	13.0 ± 1.6	12.9 ± 1.5	12.6 ± 0.9	12.9 ± 2.0	0.756
		2nd	14.2 ± 1.4	13.8 ± 2.2	13.9 ± 1.4	14.1 ± 2.0	0.602
		3rd	15.6 ± 1.5	15.3 ± 2.2	15.2 ± 2.0	14.9 ± 2.2	0.677
		Averaged	14.3 ± 1.4	14.0 ± 1.9	13.9 ± 1.3	13.9 ± 2.0	0.768

3.2.5 Experimental cooling garment evaluation – Interview

Below is the summary of the results of interviews about the thermal sensation, thermal comfort, wet sensation of cooling garment, mass perception, stiffness and fitness of the vest A, B and Nomex cooling shirts just before and after the evaluation of the simulated firefighters' task. Before and after the experiment, subjects answered vest B and Nomex cooling shirt were cooler than vest A. Thermal comfort showed the highest score for Nomex cooling shirt but sweat sensation did not show any difference between the three cooling garments. In the question of mass perception, the three cooling garments were answered to not have any significant difference as results being 'normal' and 'slightly light' before and after the experiment. Among the three types of cooling garments, vest B was recognized as the heaviest. In the case of stiffness, vest A and B were became less flexible after experiment. However, Nomex cooling shirt was shown to be 'slightly soft' before and after experiment. For the fitness question, the cooling packs were evaluated as 'fit (4 points) ~ a little big (5 points)' on average, regardless of whether they were melted or not. For the 'Satisfaction of the clothing design' question, there were statistically significant differences among the three conditions. For vest A, the response was 'normal (4 points)', vest B average 4.6 points which is close to 'some dissatisfied (5 points)' but Nomex cooling shirt showed an average of 3.4 points (some satisfied, 3 points) (P = 0.042). In the case of Quick don and doff, all three conditions resulted close to 'normal (3 points)' without any significant difference. In the question of appropriateness of the cooling packs of the cooling garments, there was a significant difference among the three conditions (P = 0.002). The response for vest A was 2.8 points, close to 'slightly disagree (3 points)', and for Nomex cooling shirt was answered 3.8 points, close to 'normal (4 points)'.

Table 3.5. Results of the questionnaire after the simulated tasks

Question		Vest A	Vest B	Nomex cooling shirt	P value
10. Thermal sensation	Before	4.4 ± 1.6	3.2 ± 0.5	3.1 ± 0.9	0.007
	After	5.4 ± 1.8	4.9 ± 4.6	4.8 ± 1.9	0.448
	P value	0.005	0.001	0.005	
11. Thermal comfort	Before	4.9 ± 1.0	5.4 ± 0.9	5.8 ± 0.7	0.051
	After	4.1 ± 1.0	4.3 ± 1.1	4.8 ± 0.8	0.101
	P value	0.006	0.002	0.002	
12. Wet sensation	Before	3.9 ± 0.7	4.1 ± 1.0	4.1 ± 1.1	0.839
	After	4.6 ± 1.4	4.8 ± 1.1	4.9 ± 0.9	0.734
	P value	0.061	0.003	0.003	
13. Weight sensation	Before	4.8 ± 1.1	4.2 ± 0.8	5.1 ± 1.1	0.043
	After	4.7 ± 1.1	4.2 ± 1.2	5.3 ± 1.1	0.028
	P value	0.557	0.861	0.317	
14. Stiffness	Before	4.8 ± 1.5	4.1 ± 1.3	5.1 ± 1.5	0.129
	After	4.3 ± 1.5	3.8 ± 1.3	5.4 ± 1.0	0.003
	P value	0.052	0.234	0.541	
15. Fitness	Before	4.4 ± 0.8	4.1 ± 0.9	4.0 ± 0.5	0.056
	After	4.4 ± 0.8	3.9 ± 1.0	4.0 ± 0.5	0.151
	P value	0.655	0.257	1.000	
16. Design satisfaction		4.0 ± 1.6	4.6 ± 1.4	3.4 ± 1.3	0.042
17. Don & doff		3.4 ± 0.6	3.3 ± 0.9	3.1 ± 0.7	0.321
18. Positions of cooling packs		2.8 ± 0.9	3.4 ± 0.6	3.8 ± 0.4	0.003

Below is the summary of the descriptive responses (inadequacies of the cooling pack positioning, inconvenience during the firefighting tasks such as pressing/ friction / jamming / catching / pulling, advantages/disadvantages/improvement needed when applied to the real situations et cetera) from the questionnaire.

The disadvantage of vest A was that the position of the cooling packs at breast area when the vest was worn was too below the heart, that many of the subjects thought the packs should be placed higher. There were also responses that wearing the vest felt hot and not so cool as expected. Some subjects felt uncomfortable at breast region and answered that part of the vest poked when they bended over. The vest was also reviewed being difficult putting on and off, did not feel easy due to the weight and was disturbing their performance. Others answered the cooling packs were too hard that they lacked sense of unity and that the packs could be bothering since they had to be replaced and since they turned wet after melting.

The good sides of vest A were that though the body was wet after running the tasks, subjects felt that their upper body, protected by the vest, was slightly fresh and thought their heart rate recovered faster during the rest interval as a result of body cooling. There were comments that the use of the cooling vest was required to prevent the heat stress during summer and that to fulfill the use, the cooling garment needed to be lighter weighted and must be easy to pull on and off.

For improvements, there were requests for designs that can be worn over the FPPE that are not in a vest form, requests for more specified sizes so that the vests can fit fire fighters with any physical conditions. Also, there were needs for softer and smaller sized cooling packs that can make smoother moves and needs for changing the opening with Velcro than with zippers to achieve faster donning and doffing.

Disadvantages of vest B is that the cooling packs attached to the back was not tight to body that the cooling effect was less than that of the breast region and the packs were moving making frictions (along with jamming, catching and pulling). Especially, there were feed backs that SCBA pressed the cooling packs at back that it was comfortable when bending down. Opening and closing the zipper took time that quick donning and doffing was difficult. Subjects answered there was no sense of unity and worried the hard face of the packs may have bad effect to the skin. They also felt the vest bothering due to the additional weight even though it was not very heavy. Another concern was that having to wear an extra clothing inside their gears could be a burden when called for duty in haste.

Vest B had advantages as it made subjects feel thermally comfortable and subjects assumed their fatigue after long hours of tasks could be eased as the body heat got lower and that sustainable task would be possible at incident scenes in summers. Improvements asked were that subjects wanted new designs looking closer to uniforms and much specified sizes to be supplied that can fit any fire fighters. The garment openings were preferred in Velcro or snaps to zippers so the vest weighed lighter. Softer materials, cooling garments for lower body, thinner packs that can elevate the flexibility when wearing were requested and there were also ideas of design where cooling packs could be planted in the FPPE tops or work shirts that there is no need to wear an extra vest.

Nomex cooling shirt had disadvantages that the cooling packs would have been better placed higher at breast and subjects' back felt sore when wearing SCBA. Call outs were also made that it was inconvenient freezing and inputting the cooling packs each time and it was uncomfortable wearing and taking off the shirt.

As advantages, subjects replied they could reduce the exhaustion of physical strength as the mobility was good, felt cooler than expected. Subjects thought their clothing temperature was lower and though it was cold before starting the task, it felt pleasant afterwards. The shirt form gave comfort as if wearing an underwear, was light, well attached to the skin for the shirt contained spandex and was commented that it would help control the body temperature working at scenes in the summer. Moreover, there were feed backs that the nomex quality made the subjects feel safer after being exposed to fire scenes.

It is an inevitable shortcoming of cooling packs that arranging and inputting the packs require additional time compared to wearing basic gears only. However the responses were there are more pluses during hot waves such as this year's summer.

Improvement requests were made on having different thickness of Nomex fabric per season, applying materials that have sweat evaporation function in case the garment gets heavier due to perspiration, making more pockets for cooling packs, changing the long sleeve to non-sleeve and the neck line to scoop neck so the garment can be worn faster and cooler. Combining the technique to currently worn work shirts was another idea so that can release the burden of wearing another piece of clothing and make the use of cooling pack easier. Putting all the reviews on the three cooling garments from the fire fighters together, all three cooling garments were commented to be inconvenient for managing the cooling packs but opinions were greater that compared to the pre –existing cooling vests, the newly developed shirt type is cooler with better attachment to skin, lighter, more flexible and is easier to take on and off. Ultimately, there was a need for developing a design where cooling garment is integrated with the work shirt.

4. Discussion

4.1 Part 1. Alleviate Heat strain test

The separate effects of either wearing cooling garments or ingesting fluids under heat stress have been well-documented. The present study is, however, original in that it explores the combined effect of skin cooling and cold fluid ingestion on alleviating heat strain. This idea could be most effectively applied to workers who have poor access to drinking water under heat stress. The first hypothesis of this study, skin cooling would be more effective to alleviate heat strain than fluid ingestion, was accepted from the reduced skin temperature and concomitant improvements in thermal sensation and comfort. However, skin cooling or fluid ingestion had similar positive influences of lowering increased heart rate and phsyiological strain index (PSI), while drinking fluid was more effective for relieving thirst sensation than skin cooling. The second hypothesis, the combined effect of skin cooling and cold fluid ingestion (CD condition) would be weaker than the sum of the individual effects in the CO and DO conditions, was also partially accepted. More detailed discussion are as follows.

4.1.1. Cardiovascula and muscle fatigue due to wearing of cooling garment

There was no statistically significant difference in heart rate between the four experimental clothing conditions, but the heart rate was the lowest when wearing Nomex cooling shirts. Regardless of wearing cooling garments, the heart rate increased as the number of times of circuit increased. At the end of 3rd circuit, the maximum heart rate is 177bpm, which is equal to or greater than 96% of the maximum heart rate estimate (220-age). And anaerobic fatigue was 7 mmol·l-1 or more in all conditions. It proved that just by carrying out simulated firefighters' tasks with an average of 12 to 14 minutes duration, one can reach at one's maximum cardiovascular capacity value. This suggests that it is necessary to take measures to reduce the burden on the heart-blood relationship and anaerobic fatigue of the firefighter when working on the actual site. According to Lee et al. (2012), due to wearing FPPE, the maximum work execution time decreased by 35% while working on the slope and 52% while running on the flat. At the same time, the maximum oxygen uptake decreased by 5% and 3% respectively. During the maximum exercise, energy consumption increased by 33% and 22% due to the wearing of 'FPPE + SCBA' compared to the same time priod. Wearing about 15 to 25 kg of fire protection personal equipment thus significantly increases human energy metabolism. However, as in this study, wearing a cooling garment around 1 kg was evaluated as having no influence on work completion time and heart rate.

4.1.2 Dominant effect: trunk skin cooling

Table 3.6 summarizes previous studies over the past 20 years reporting the effects of cooling garments in hot environments. The cooling effects have been examined using cooling scarfs, vests or shirts at an air temperature of 30~45^{o}C with air humidity of 30~70%RH through pre-, mid-, and/or post-cooling when wearing shorts only or encapsulated PPE on students, workers or sports players at light, middle or high intensity of exercise. On the whole, wearing cooling garments are effective for lowering the rise of regional skin temperature where the garment's contacted and improve thermal sensation or perceived exertion. However, the effects on core body temperature, sweat rate and cardiovascular responses are inconsistent according to cooling capacity, duration of cooling (pre-, mid-, and/or post-cooling), intensity of exercise, or the degree of heat stress.

In particular, the cooling capacity is one of the important factors for alleviating heat strain. It is no wonder that greater cooling capacity could have greater cooling efficacy, but additional weight load would cause metabolic burden for workers which induce rises in body heat storage. Therefore, we need to tradeoff cooling capacity and total clothing mass. It has been reported that the total mass of cooling garments ranges from 1 to 4.5 kg (Table 3.6). Smolander et al. (2004) reported the mean heat losses from the torso due to the ice vest were 74 W/m^2 (42W, 272 kJ). The melting of the ice takes about 40–45 min and requires about 334 kJ. Another study reported heat capacity of 80~143 cal/g (assumes skin temperature of 36°C) (Webster et al. 2005). According to Kamon et al. (1986), a1-kg ice vest would give about 10% improvement in performance time during work in the heat.

It must be kept in mind that the vest was light and had moderate cooling capacity when discussing the effects of skin cooling. It is well known that skin cooling induces reduction in HR (Bomalaski et al. 1995, Nishihara et al. 2002, Richardson et al. 1988). The present results are in agreement with the previous findings. HR for recovery was lower on average 89 ± 15 bpm for CD and 94 ± 10 for CO when compared to the HR for CON. Under heat stress, the cutaneous blood vessels are vasodilated, venous return and stroke volume are decreased, which results in the rise in HR (Bomalaski et al. 1995, Constable et al. 1994, Richardson et al. 1988). Similarly, in hot environments, HR decreases from body cooling. Cold-induced cutaneous vasoconstriction elicits increases in cardiac filling, thus allowing better maintenance of cardiac output via stroke volume. Subsequently, this results in reduced cardiovascular strain during exercise under heat stress along with faster recovery. Shvartz (1970) reported that HR was less when wearing a cooling hood than in the absence of cooling. House et al. (2013) also demonstrated significantly decreased HR at the end of exercise and during recovery when wearing cooling vests in the heat. Furthermore, we found the reduction in HR for DO as well as CD and CD. During hypohydration, decreased blood volume reduces central venous pressure and cardiac filling which reduces stroke volume and increases HR (Sawka et al. 2001). The mechanism of reduction in HR for DO in the present study could be conversely inferred from the description of the influence of hypohydration on heart rate.

Another interesting finding from the present results is the significant effect of trunk cooling on thigh temperature. Wearing the cooling vest induced lower thigh temperature during all phases when comapred to the values for CON or DO (Table 3.1). Similar phenomena was found in Choi et al. (2008) as well. By wearing a cooling vest, thigh temperature was approximately

1.0°C lower than values at the absence of cooling, whereas no significant influences were found in arm, hand, calf, and foot temperatures (Choi et al. 2008). Lowered thigh temperature starting from the rest phase might be due to the reduction in temperature of cutaneous blood supply from the heart imposed by cooling the trunk region, which would in turn cool the blood returning to the heart from the thigh. If we could measure esophagel temperature, the lowered thigh temperature could be explained on more with clear evidence. As most reduction in the present study occurred within 10 min of wearing the cooling vest, the cooling benefit would be evident durng a subsequent bout of leg work. Namely, firefighters can start working with expanded heat storage capacity because cold tissues act as a heat sink storing greater amounts of heat generated and delaying heat transfer to the core.

A moot point on cooling effects is whether the core body temperature is affected or not. As demonsatred in Table 3.6, the outcomes about core body temperature differ per studies. The present study found that wearing the cooling vest lowered the rise of T_{re} during recovery rather than during exercise, and the beneficial influence became greater when adding cold fluid ingestion. A considerable investigations reported the beneficial effect of wearing cooling garment on core body temperature during exercise or recovery (Bennett et al. 1995, Choi et al. 2008, Epstein et al. 1986, Webster et al. 2005), claiming that it leads to reduce PSI (McFarlin et al. 2016) and increase exercise tolerance time (Hasegawa et al. 2005), but another numbers of other researches did not find any benefit of wearing cooling garments on core body temperature (Duffield et al. 2003, Hamada et al. 2006, Lopez et al. 2008). We assume that wearing the cooling vest might be effective to T_{re} during exercise as well if the cooling capacity were greater than now.

Lastly, it is well established that skin cooling reduces total sweat rate in hot environments (Constrable et al. 1994, Frim 1989, Richardson et al. 1988). Shvartz (1976) mentioned that sweat rate in hot environments decreased by about 16–22% from neck cooling, which inhibits sudomotor activity (Veghte and Webb 1961). This decrease in sweat rate is directly proportional to the area of the skin cooled (Banerjee et al.1969). However, the results of the present study do not agree with these previous reports, and this may be due to moderate intensity of exercise and heat stress resulting in a 0.7% loss of total body mass of the present study.

Table 3.6. Studies on the influence of cooling garments on alleviating heat strain duringe exercise and recovery in heat.

Author (year)	Subjects	Experimental condition	Cooling method (total clohting mass)	T_a(°C) H_a(%RH)	Experi-mental clothing	Exercise mode	Main outcomes by cooling
Nishihara et al. (2002)	4 males	①no cooling, ②cooling vest A ③cooling vest B	[Cooling vest A] Ice vest with 6 bags [120g/bag] on chest and 10 bags [100g/each] on back) (2.1kg)	30°C, 37%	Long shirt and pants (0.88 clo)	10-min rest, 90-min walking, 10-min rcv (110min)	· Lower chest temp. · TS, SS, TC improved
Sigurbjo¨rn et al. (2004)	17 runners	①no cooling, ②cooling vest during warm-up (precooling)	Ice vest with 8 ice packs (450-500 ml/pack); 2 on chest, 2 on stomach, 2 on shoulder and 2on lower back (4.5 kg)	30°C, 50%	T-shirts & short pants	38-min warm up, 5-km run	· Blunting increases of Tre & HR · TC improved · Run time shorten
Smolander et al. (2004)	4 firefighters	①no cooling, ②ice cooling vest	Ice vests with 5 packs (1.0~1.1 kg)	45°C, 30%	Firefighter's PPE (21~23 kg)	30-min waking ×4 times with 5-min rest for each	· 10 bpm lower HR & 13% smaller TSR (approx.50g) · lower trunk temp; · no effect on extremity temp, VO_2 & Tre. · RPE improved (score 1) & TS improved (score 1)
Webster et al. (2005)	16 athelетes	①no cooling, ②ice vest A, ③ice vest B, ④ice vest C (precooling)	(2.8~3.0 kg)	37°C, 50%		30-min run (70%VO_{2max})	· Lowered Tre, Tsk · TSR(10~23%) · No effect on HR · Tolerance time,TS & SS improved
Yoshida et al. (2005)	6 males	no cooling, water perfused suit and vest with water temp of 14, 20, and 26°C (7 conditions)	Water suits (86% CBSA); Water vest (25% CBSA)_	WBGT 28°C	Fencing uniforms	20-min cycling ×3times (250 W/m²)	· Lowered Tre, Tsk, HR & TSR · TS improved
Hamada et al. (2006)	7 males	①fan cooling (2.5m/s), ②ice cooling (last 20-min exe cooling)	ice pack on the bilateral carotid (500 g)	30°C, 40%	Trunks	40-min bicycle	· Lowered Tty, SR and HR · no effect on Tre · TS improved
Choi et al. (2008)	12 males	①no cooling, ②③2 Cooling scarfs, ④cooling hat, ⑤cooling vest, ⑥⑦ combinations	Scarf A (0.07kg, 0.4%BSA cooled); Scarf B (0.2 kg, 0.8%); Hat (0.5kg, 0.8%); Vest (0.8kg)	33°C, 65%	Long sleeved shirts & pants	120-min simulated red pepper harvest work	· Vest: lowered Tre, Tsk, and HR · lowered PSI · TS improved
Kenny et al. (2011)	10 males	①seminude with no cooling, ②NBC suit with cooling vest, ③NBC suit without cooling	Ice packs (4.1 kg)	35°C, 65%	NBC protective suit	120-min walking	· Lowered in Tes (0.3°C) and HR (10 bpm) · TS, RPE (2 scores), & Tolerance time improved
Stannard et al. (2011)	8 male runners	①no cooling, ②cooling vest (precooing)	4 pockets (2 on chest, 2 on back)	24~26°C, 29~33%	T-shirts & short pants	10-km running (about 42 min)	· No effect on Tre, HR, RPE & TS
Luomala et al. (2012)	7 male cyclists	①no cooling, ②ice cooling vest	4 packs (1 kg)	30°C, 40%	Cycle wear	Cycling at 80%VO_{2max}	· No effect on Tre & Tsk · Lowered trunk temp · 21.5% Tolerance time improved
House et al. (2013)	10 males	①no cooling, ②③④⑤PCM cooling vests with 0,10,20,30°C melting points	2 packs (1kg/pack)	40°C, 46%	Firefighting clothing	45-min stepping and 45-min recivery	· Lowered in Tre, Tsk, HR & TSR
Teunissen et al. (2014)	9 males	①no cooling, ②③ 2 cooling vests	4 cool pads (1 kg); Water perfusion (4 kg)	30°C, 50%	EU firefighters' coverall	30-min walking and 10-min recovery	· Lowered Tsk & TSR · No effect on Tre, HR · TS improved
Butts et al. (2017)	16 males	①no cooling, ② PCM cooling vest	8 pockets (chest, abdomen, back, thighs amd hamstrings) with melting point at 10°C	35°C, 53%		55-min exercise	· Lowered Tre & Tsk · Ts improved

			(~3.6 kg)				
Bartkowiak et al. (2017)	6 adults	①no cooling, ②cooling vest	Liquid cooling (cooling capacity 300 W)	30°C, 40%	Aluminized PPC	45-min walking	· Lowered Tsk · TS improved
Chan et al. (2017)	140 construction workers	①no cooling, ②cooling vest (break-cooling)	8 PCM packs cooling vest with 2 ventilation fans; 80g/pack. Melting point 28°C. 2 on the chest, 2 on the abdoment, 4 on the back (1.26 kg)	WBGT 29-31°C	Work wear (field study)	Construction work	· RPE 0.93~1.34 improved
Butts et al. (2017)	20 males	①no cooling ②phase change material (PCM) cooling vest	Set to change phase at 10°C (~3.6 kg)	34°C, 55%	Coverall suit	20-min simulated work×2 times	· Lowered HR, Tsk, Tre, PSI, PeSI, & HS · RPE, thirst, TS improved
Mejuto et al. (2018)	7 cyclists	①fluid inghestion, ②ice slurry ingestion (pre), ③ice slurry ingestion (pre+mid)	-1°C ice slurry	32°C, 50%	Cycle wear	45-min cycling×3 times at 70%VO_{2max}	· Lowered in Tre · No effect on tolerance time · RPE improved

4.1.3 Additional effect: cold fluid ingestion

It is thought that heat stress, itself, is a stronger stressor than dehydration because hyperthermia is more fatal than dehydartion for workers in hot environments. However, heat strain and dehydration are strongly interrelated, and may act synergistically. Cheuvront et al. (2003) suggest that the physical proximity of thermosensitive and osmosensitive neurons in the preoptic anterior hypothalamus (Silva and Boulant 1984) is central for the interaction between thermoregulation and fluid balance (Sawka 1992). In this context, the impact of fluid ingestion for workers in hot envirnments can be synergic to body cooling. McLellan et al. (1999) found that sweat rate was greater for the euhydrated condition than 2.3% dehydrated condition. It is clear that progressive body water losses induce hypertonic-hypovolemia (i.e., increased plasma tonicity and decreased blood volume), which reduces dry and evaporative heat loss through alterations in the core temperature threshold for initiation of skin blood flow and sweating along with changes in the sensitivity of the initiation of skin blood flow and sweating (Cheuvront et al. 2003, Sawka et al. 2001). Many studies have observed a greater rise in core body temperature during exercise in hot environments for hypohydrated participants than for euhydrated participants (Gonzalez-Alonso et al. 2000, Sawka and Toner 1983, Fortney et al. 1981, Montain and Coyle 1992). Resting plasma volume decreases in a linear manner that is proportionate to the hypohydration level and plasma osmolality increases because sweat is ordinarily hypotonic relative to plasma (Sawka et al. 2001). Reduced of sweating conserves body fluid and results in reduced heat loss and increased hyperthermia. Taken together, sweating decreases proportionally to the degree of body water deficit.

However, we found no signifiacnt differences between total and local sweat rates or between skin and rectal temperatures in the four conditions. This lack of difference could be a result of the milder level of heat stress and exercise intensity of the present study (total sweat rate 472 ± 219 $g \cdot h^{-1}$, 0.7% body mass; 37.8 ± 0.2 °C in rectal temperature at the end of exercise for the control) compared to the levels of dehydration of previous studies. Also, participants in the present study were rehydrated with the 800 ml cooling packs (1.2% BM). ISO 7933 (2004) and ISO 9886 (2004) allow a maximum sweat loss of 1.3 kg per hour. Similar body mass loss was found in Chou et al. (2008) and they showed a 1.3 kg loss from wearing aluminized firefighters' turnout jacket and 0.8 kg loss for wearing general turnout gear. Hypohydration of 2~3% has little or no measurable effects on physiological strain and no effect of on psychophysical strain or performance (152-156 in Akerman et al. (2016)). A milder level of hypohydration (2.3~2.5% BM) impaired tolerance time while wearing PPE in heat but core temperature was not affected by the level of hypohydration (Cheung and McLellan 1998). Akerman et al. (2016) concluded that a 2% BM hypohydration does not measurably exacerbate heat-induced reductions in cerebral perfusion during passive heat stress but a 3% BM exacerbates orthostatically-induced reductions in perfusion when normothermic upon standing, independently of blood pressure. Dehydration begins to present a problem when body water loss exceeds 3% of body weight (Nadel 1988). In sum, there would be no effect of mild level of dehydration (~3% BM) on core body temperature. In this regard, the present results agree with the previous results. In general, increases in core body temperatures are associated with increases in metabolic rate and/or decreases in evaporative heat dissipation. No difference in the changes in rectal temperature are reasonable because dehydration has very little influence on total sweat rates for DO were statistically identical as the value of CON or CO.

There are similar studies reporting the effect of ice slurry ingestion on the reduction of rectal temperature, heart rate and skin temperature (0.8% ~ 1.4% BM) (Mejuto et al. 2018, Siegel et al. 2010, Siegel et al. 2012, Takeshima et al. 2017). However, those studies were conducted on cyclist wearing light clothing. The effect of air flow and ice slurry on skin and core body temperature when cycling wearing light sport wear can be exaggerated. The increase in heart rate for dehydrated condition under heat stress is explained by a fluid deficit induced decrease in cardiac output, which is compensated by the increased HR. Hypohydration elicits an increase in HR and decrease in stroke volume during submaximal exercise (Sawka et al. 2001). It is of interest to note that the reduction in HR for DO occurred in recovery without any difference in total body mass loss compared to CON. Morris et al. (2015) found a tendency for lower skin blood flow after ice slurry ingestion, which may be associated with the reduction of HR for DO.

Another interesting finding was that cold fluid ingestion relieved thirst sensation even though total sweat rates were identical. That is, subjects sweated at a similar level for the four conditions but they felt less thirst for the DO and CD when compared to CON and CO. This indicates that thirst sensation is not linearly related to the total body fluid but might be more related to local sensation inside the mouth.

4.1.4 Limitations and suggestions

One of limitations of the present study was that the exercise intensity was not severe but of a middle intensity, showing rectal temperature of 37.8 ± 0.2 °C at the end of exercise for CON. Subjects wore firefighting turnout gear without their self-contained breathing apparatus (SCBA). A SCBA (approximately 11~15 kg) had a significant effect on the oxygen consumption and metabolic rate (Bakri et al., 2012). The second limitation was associated with the ergonomic design of the vest. We originally designed the vest to closely adhere to the surface of the skin using stretchable mesh spandex fabric and adjustable Velcro tape, but the back regions might have some space between cooling packs and the skin during body movement. This might be one of the reasons that the chest temperature was lower than the back temperature during trials. However such space could be reduced when wearing the SCBA. A moot point is the amount of cooling packs. The present study provided 800 ml $\cdot hr^{-1}$ (1.2% of body mass) in total. The amount was appropriate for the current protocol because subjects sweated on average of 472 g h^{-1} for the control condition. In terms of the additional weight burden, the 1.1 kg (800 ml water + 290 g vest) is not a significant increase in load for wearers. However, in case of exposer to more severe intensity work under uncompensable heat stress (about 3~5% body mass loss), the 800 ml-water supply would be not sufficient. Administrative experts need to consider firefighters' work and rest schedule when deciding the total amount of the cooling packs for drinking. Lastly, we did not find any positive effect of cooling or drinking on rectal temperature during exercise, but we might have different results in core body temperature if we measure esophageal temperature as the core temperature because the vest covers the trunk and cold fluid directly affect the esophagel region.

4.2 Part 2. Simulated firefighters' task test

This study is distinguished from other previous studies that it shows wearing extra cooling garment under FPPE does not disrupt the efficiency of the fire fighters performance by using the self developed simulated firefighter's task protocol. The study also showed that the cooling shirt made of Nomex quality is favored by fire fighters and that it does not disrupt the mobility through the comparison between Nomex cooling shirt and other two types of cooling vest found in the market.

The study resulted that there is no significant difference between time consumed to complete the simulated firefighting tasks under the three conditions where cooling garments were worn and where the cooling garments were not worn (Control).

Yet there was no significant difference, considering the fact that the longest time was spent under control condition(13.9 ± 1.8 min) while the shortest time was spent under Nomex cooling shirt condition (12.9 ± 2.0 min), it can be suggested that wearing cooling garment under the FPPE does not have negative effect on the duration of completing firefighting tasks and the cooling garment could furthermore improve the work efficiency by reducing muscle fatigability as the garment eases the heat of the upper body.

4.2.1. Cardiovascula and muscle fatigue due to wearing of cooling garment

There was no statistically significant difference in heart rate between the four experimental clothing conditions, but it was the lowest when wearing Nomex cooling shirts. Regardless of wearing cooling garments, the heart late increased as the number of times of circuit increased. The maximum heart rate at the 3^{th} circuit was four conditions averaging 177 bpm and the maximum heart rate estimation value (220-age), 96% of the maximum heart rate or more, and anaerobic fatigue is 7 $mmol \cdot l^{-1}$ or more in all conditions. It was showed that the maximum cardiouvascular capacity value of an individual simply by carrying out the simulated firefighters' protocol for an average of 12 to 14 minutes It suggests that it is necessary to take measures to reduce the burden on the heart-blood relationship of the firefighter and anaerobic fatigue when working on the actual site. According to Lee et al. (2012), due to wearing FPPE, the maximum work execution time decreased by 35% while working on the slope and 52% while running on the flat. At this time, the maximum oxygen uptake decreased by 5% and 3% respectively. During the maximum exercise, energy consumption increased by 33% and 22% due to the wearing of 'FPPE + SCBA' compared to the same time priod. Wearing about 15 to 25 kg of fire protection personal equipment thus significantly increases human energy metabolism. However, as in this study, wearing a cooling garment around 1 kg was evaluated as having no influence on work completion time and heart rate.

4.2.2. Discussion on the validity of the Simulated firefighters' tasks

Top of all, there is a need to discuss the validity of the evaluation protocol of the simulated fire fighters' tasks developed of this study.

Total of eight tasks consist the evaluation protocols conducted in this study: Transporting fire hose, Winding and Unwinding the fire hose, Demonstrating forcible entry, Demonstrating personnel recovery, Transporting/Setting/Climbing up and down ladder. These tasks were selected for being the common tasks from the previous studies.

Other special actions can be found in previous studies. Kim & Lee (2016)'s study includes walking before a full face radiant heat source copying a fire environment. Louhevaar, etc (1994, Finland)'s study tested crawling through a bar installed 60cm above the ground then going over the bar and going up and down stairs instead of a ladder. Williams-Bell (Canada, 2009) conducted reaching up and pulling the ceiling and in Boyd, Roger, Docherty and Petersons(Canada 2015)'s study and Todd, Docherty and Peterson(Canada, 2015)'s study, examined transporting the fire hose with one hand instead of two, actions repeated by the other hand, and dragging a fire hose full with water. Siddall, Stevenson, Turner, Stokes and Bilzon(United Kingdom, 2016) had running with a fire hose instead of walking and Mamen, Oseland and Medbo(Norway, 2013) conducted pulling a nylon rope after attaching an item of certain weight. Taylor, Fullager, Mott, Sampson and Groeller (Australia, 2015)'s study supposes a lifesaving action at a car accident situation where the subject has to speedily remove the car door. The firefighting action evaluation protocol suggested in Heimburg, Medbo, Sandsund and Reinertsen (Norway, 2013)'s study starts and ends the evaluation by solving a specific puzzle (matching pieces) to describe the mental stress of the fire fighters and it examines their body balance by having them walk on a balancing stand, crawling inside a mock up tunnel of the interior of a falling construction, working inside a heat chamber maintained at 120 ~ 140^{o}C, full of smoke and et cetera.

The protocol of this study was composed of the common tasks among such various firefighting works suggested in previous researches. The time consumed for these eight tasks repeated three times with recession included (5 mimute x 2 rounds = 10 minutes) was 22 ~ 24 minutes in average, meaning that the protocol reflects the fire fighters' general duration of one circuit (a 30 minute SCBA wearing work). Furthermore, as the fire fighter's heart rate has reached its lowest point as mentioned above, the simulated firefighters' task protocol can be said to have appropriately shadowed the hardness of the fire fighting task.

4.2.3. Subjective perception per condition of upper body cooling

The interesting point of this research result is that though there was no meaningful variance in the clothing climate at breast area and also in the total sweat rate under the four experiment conditions, when subjects were questioned on the sweat sensation at breast area, they have answered that they felt much humidness under control condition than when wearing the cooling garment. Unlike the expectation that the humidity of the clothing climate would rise by wearing extra clothing at a hot and wet environment, subject's responses were that the extra wearing of the cooling garment actually did not make the area wetter nor made them feel wetter. Rather, they felt much humid when the cooling garment was not worn.

This is believed to have connection with the fact that the humidity of the clothing climate under the four experiment conditions was already over average 80% RH. In other words, this result can be interpreted that the wearing of the cooling garment may drive the clothing climate somewhat wetter, but as the climate is already too humid that the wearing could not have critical affect on sweat sensation and rather it can make the climate less humid as the cooling garment limits the perspiration at breast area.

The clothing temperature at breast area was lower by over 2^{o}C in average when Nomex cooling shirt was worn compared to when other cooling vests were worn. Since it was taken with special care that the sensor does not directly touch the refrigerant during the experiment, this observation can be implicating that the effect is due to cooling packs of the shirt type cooling garment is better attached closely to the skin. Usage of the cooling garment has shown positive effects both on thermal sensation and thermal comfort at upper body under all three conditions and this proposes that wearing of cooling garment during firefighting in summer seasons should be highly recommended.

4.2.4. In-depth interview and required improvements

It was found through the in-dept interview conducted after the simulated fire fighters' task evaluation that it is important to minimize the movement of refrigerant, have it stay tightly attached at the top of the breast that it does not fall down when various motions are made.

The cooling garments used in this experiment each weighed type A 780g, type B 1,250g, Nomex cooling shirt 920g, all including the cooling pack. Since no subjects felt the cooling garment as a weight burden, the weights used in this study can be referred to when producing cooling garments in the future.

Since the cooling pack is hard, it could be thought that minimizing the refrigerant size as much as possible might help the performance efficiency. However subjects responded that the Nomex cooling shirt was not stiff but slightly soft (flexible must be used) though they did not drink water during the experiment. This means that if the cooling shirt or vest is made of material that fits well to skin, the disturbance of the hard refrigerant to firefighters' tasks can be minimized.

Nonetheless, the most important point to be considered when supplying the cooling garments in fire fighting scenes is the convenience of taking on/off the cooling garment and its size. It is necessary to found a way to minimize the time spent wearing the cooling garment with refrigerants equipped as the action can delay the fire fighter's move out timing more than a few seconds at urgencies when there is no moment to lose. One option is to apply the Nomex cooling shirt technique to the design of the top part of the activity suits or station uniform currently worn at fire stations during summer. This application can not only cool the body during urgencies but also during less urgent situations. Another way is to prepare a freezer only for keeping the cooling garments that the fire fighters can take and wear the garments out of the freezer right before the emergency call without having to replace the cooling packs. The cooling garments with front or side openings should have velcros instead of zippers or snap so that least time is consumed wearing the garment.

The discussion of the size suitability of the cooling garment has been raised for a long time, especially on the cooling garments based on cooling packs that utilize the heat loss by conduction occurred when they are attached to body. These types of garment show huge differences per size, even though they are of same design. Since it is crucial how much the cooling packs are tightly attached to the skin, a flexible material must be chosen and the size system must reflect the body size of current Korean fire fighters. Cooing packs at back could be uncomfortable as the SCBA may give pressure when folding the back but this may also make the refrigerant better attach to the back skin so more discussions are to be made on which is the best area to cool the back side.

5. Conclusions

'Part 1', investigation on alleviate heat strain, evaluated the separate and combined effects of skin cooling and cold fluid ingestion using a novel vest for firefighters on alleviating heat strain during exercise and recovery in heat. The thermoregulatory advantage of skin cooling and cold fluid ingestion was more evident during recovery than during exercise. As expected, skin cooling was more effective for alleviating heat strain than cold fluid ingestion, but cold fluid ingestion had synergic advantage when combined with the skin cooling in lowering rectal temperature during recovery.

'Part 2', covering simulated firefighter's task, had significant meaning showing that wearing of the cooling clothing in FPPE did not hinder the work efficiency of firefighters while carrying out the firefighters' protocol of task evaluation. This was confirmed by circuit completion time, heart rate, blood lactate acid, total sweat rate, micro clothing climate and subjective perception. In addition, it can be expected that the new protocol developed in this study is utilized based on the existing simulated fire fighting work protocols. Because the cardiovascular burden of the firefighters has reached the maximum level by the protocol of this study, it can be inferred that the cardiovascular burden of the firefighters will reach the maximum level in the actual field. Findings of the present study therefore are of interest for workers who have poor accessability to drinking water and wearing cooling garment under heat stress.

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Appendix 1.
Questionnaire (in Korean)

서울대학교 의류학과 의복과 건강 연구실

http://comfortlab.snu.ac.kr

1. 이름 :	2. 작성일시: (　　)월 (　　)일 (　　)시		
3. 특기: ①진압 ②구조 ③응급	4. 출생연도 (　　)년	5. 키 (　　)cm	6. 체중 (　　)kg
7. 소방서 근무 기간 (경력) 총 (　　)년	8. 한 달 평균 출동 횟수 평균 (　　)회		
9. 인터뷰 응답 실험 조건: ① 냉각조끼 A ② 냉각조끼 B ③ 개발 노맥스 셔츠			

#	질 문	응 답	
		실험 시작_착용 시 느낌	실험을 진행하면서 느낀 느낌
10	지금 착용한 냉각의류의 시원함은 어느정도입니까?	① 매우 춥다 ② 춥다 ③ 시원하다 ④ 약간시원하다 ⑤ 보통이다 ⑥ 약간 따뜻하다 ⑦ 따뜻하다 (약간 덥다) ⑧ 덥다 ⑨ 매우 덥다	① 매우 추웠다 ② 추웠다 ③ 시원했다 ④ 약간시원했다 ⑤ 보통이었다 ⑥ 약간 따뜻했다 ⑦ 따뜻했다 (약간 더웠다) ⑧ 더웠다 ⑨ 매우 더웠다
11	지금 착용한 냉각의류의 열적 쾌적감은 어느 정도입니까?	① 매우 불쾌하다 ② 불쾌하다 ③ 약간 불쾌하다 ④ 보통이다 ⑤ 약간 쾌적하다 ⑥ 쾌적하다 ⑦ 매우 쾌적하다	① 매우 불쾌했다 ② 불쾌했다 ③ 약간 불쾌했다 ④ 보통이었다 ⑤ 약간 쾌적했다 ⑥ 쾌적했다 ⑦ 매우 쾌적했다
12	지금 착용한 냉각의류의 습윤감은 어느 정도입니까?	① 매우 건조하다 ② 건조하다 ③ 약간건조하다 ④ 보통이다 ⑤ 약간 습하다 ⑥ 습하다 ⑦ 매우 습하다	① 매우 건조했다 ② 건조했다 ③ 약간 건조했다 ④ 보통이었다 ⑤ 약간 습했다 ⑥ 습했다 ⑦ 매우 습했다
13	지금 착용한 냉각의류의 중량감(무게감)은 어느 정도입니까?	① 아주 무겁다 ② 무겁다 ③ 약간 무겁다 ④ 보통 ⑤ 조금 가볍다 ⑥ 가볍다 ⑦ 아주 가볍다	① 아주 무거웠다 ② 무거웠다 ③ 약간 무거웠다 ④ 보통이었다 ⑤ 조금 가벼웠다 ⑥ 가벼웠다 ⑦ 아주 가벼웠다
14	지금 착용한 냉각의류의 착용감은 어떻습니까?	① 아주 뻣뻣하다 ② 뻣뻣하다 ③ 약간 뻣뻣하다 ④ 보통 ⑤ 조금 부드럽다 ⑥ 부드럽다 ⑦ 아주 부드럽다	① 아주 뻣뻣했다 ② 뻣뻣했다 ③ 약간 뻣뻣했다 ④ 보통이었다 ⑤조금부드러웠다 ⑥ 부드러웠다 ⑦ 아주 부드러웠다
15	지금 착용한 냉각의류의 맞음새는 어떻습니까?	① 아주 작다 ② 작다 ③ 약간 작다 ④ 잘 맞는다 ⑤ 조금 크다 ⑥ 크다 ⑦ 아주 크다	① 아주 작았다 ② 작았다 ③ 약간 작았다 ④ 잘 맞았다 ⑤ 조금 컸다 ⑥ 컸다 ⑦ 아주 컸다

1

#	질 문	실험 마친 후 응답
16	지금 착용한 냉각의류의 디자인은 마음에 듭니까?	① 매우 만족 ② 만족 ③ 약간 만족 ④ 보통이다 ⑤ 약간 불만족 ⑥ 불만족 ⑦ 매우 불만족
17	지금 착용한 냉각의류를 신속히 입고 벗을 수 있습니까?	매우 그렇지않다 (1) — 그렇지 않다 (2) — 보통 (3) — 그렇다 (4) — 매우 그렇다 (5)
18	지금 착용한 냉각의류의 냉각팩 위치는 적절하다 생각합니까?	매우 그렇지않다 (1) — 그렇지 않다 (2) — 보통 (3) — 그렇다 (4) — 매우 그렇다 (5)
18-1	**[주관식 서술]** 그렇지 않다면 그 이유를 적어주십시오	
19	**[주관식 서술]** 지금 착용한 냉각의류로 인해 동작 중 불편함(예: 눌림, 쓸림, 끼임, 걸림, 당김 등)이 있었습니까?	*있었다면 구체적으로 서술해 주세요.
20	**[주관식 서술]** 지금 착용한 냉각의류를 실제 소방 작업 (진압, 구조, 구급) 현장에서 착용한다고 할 경우 **장점**은 무엇이라고 생각합니까?	
21	**[주관식 서술]** 지금 착용한 냉각의류를 실제 소방 작업 (진압, 구조, 구급) 현장에서 착용한다고 할 경우 **단점**은 무엇이라고 생각합니까?	
22	**[주관식 서술]** 지금 착용한 냉각의류를 실제 소방 작업 (진압, 구조, 구급) 현장에 보급하기 위해 **개선해야 할 점**은 무엇이라고 생각합니까?	
23	**[주관식 서술]** 지금까지 답변한 질문 이외에, 지금 착용한 냉각의류 제품에 대한 의견이나 개선점이 있다면 자유롭게 서술해 주세요	

응답해 주셔서 감사합니다. 담당: 김도형 연구원 (02-880-8744)

초록

소방용 개인보호구는 소방헬멧, 방화두건, 개인용 산소호흡기, 방화복, 장갑 그리고 안전화로 구성되어 있다. 이는 출동 및 화재진압 시 항시 착용되는 보호구로서 환경온과 더불어 고열의 작업환경에 노출되어 탈진 및 생리적 부담에 영향을 준다. 본 연구는 여름철 소방활동 시, 개인소방보호장비 안에 냉각의류를 입고 서열부담 경감 및 작업능률을 생리적 반응과 모의 소방 훈련시간을 통해 평가하였으며 두 부분으로 구성되어 있다.

Part 1 에서는 냉각과 음수가 동시에 가능한 냉각조끼를 개발하였다. 이를 착용하여 환경온도 30°C , 50%RH 에서 소방 방화복 착용 시 피부냉각, 차가운 음료의 음수 그리고 동시에 이루어진 조건에서 서열부담경감 효과를 살펴보았다. 안정기 10 분, 5.5km/h 빠른 트레드밀 걷기 30 분 그리고 회복기 20 분 프로토콜로 진행되었다. 조건은 다음과 같다. 대조군[CON], 음수조건[DO], 냉각조건 [CO], 냉각과 음수조건[CD]. 결과, 회복기일 때의 직장온도(T_{re}), 평균피부온도(T_{sk}), 그리고 심박수(HR)는 CON 조건에서 보다 CD 조건에서 더 낮은 수치로 나타난 반면(P < 0.05), 운동 중일 때는 4 가지 조건 간에 유의한 차이가 발견되지 않았다. CO 조건에서 평균피부온도 T_{sk} 와 HR 는 유의하게 안정화 되었으며 한서감각에서 다른 조건에 비해 나음을 보였다. DO 는 회복기에서의 갈증감 해소와 HR 수치 감소에 효과적이었다. CD 조건은 평균 피부온도에서 CON 조건에 비해 평균 1.5 ± 0.2°C 유의하게 낮은 값을 보였다.

Part 2에서는 새로 개발된 노멕스 냉각 셔츠를 개인소방방화복 안에 입고 모의소방동작을 실행했을 때의 동작효율성에 관한 것이다. 16명의 소방관들이 다음 4가지 조건 하에서의 실험에 참여했다. 소방복 (Control), 냉각조끼 A + 소방복 (Vest A), 냉각조끼 B + 소방복 (Vest B) 그리고 노멕스 쿨링 셔츠 + 소방복 (Nomex cooling shirt). 결과, 완료시간, 심박수, 총 발한량 그리고 젖산 농도에서는 4가지 조건 모두 유의한 차이를 보이지 않았다. 가슴부위의 의복내온도는 노멕스 냉각 셔츠(31.2 ± 1.1oC)가 CON (33.6 ± 0.8oC) 과 Vest A (33.5 ± 0.9oC) 착용 조건보다 더 낮았다. (P < 0.001). 4가지 조건 간 의복내습도와 습윤감에서는 차이가 나타나지 않았다. 소방관들은 Vest A, 대조군과 비교했을 때 노멕스 냉각 셔츠와 Vest B가 덜 덥고, 덜 불편하다고 느꼈다. (P < 0.05). Vest A, Vest B 그리고 노멕스 냉각 셔츠 모두 무게감에 있어서 유의한 차이는 없었으나, Vest A와 Vest B보다 노멕스 냉각셔츠가 더 부드럽다고 인식되었다.

종합하면, 우리는 소방관들을 위한 피부냉각과 음수용 냉수공급의 양기능을 가진 새로운 조끼를 개발하였으며 본 연구에서 얻은 소방관들의 의견을 반영하여 노멕스

원단으로 만든 셔츠 형태의 냉각의류를 개발하였다. 첫 실험에서는 새로운 조끼를 입었을 때 피부냉각와 음수가 회복기에서의 직장온도(T_{re}), 평균피부온도(T_{sk}), 그리고 주관감에 효과를 주었다는 점을 살펴보았다. 두번 째 실험은 조끼형태에서 셔츠형태로 개선된 형태로, 개인소방보호복 안에 노멕스 냉각셔츠를 입는 것이 소방관들의 동작성을 저해하지 않으며 가장 낮은 심박수를 보여주었다.

주요어 : 냉각조끼, 피부 냉각, 음수, 소방관, 서열부담
학번 : 2017-20127

Acknowledgements

감사의 글

감사의 글에 앞서 이 순간까지 올 수 있게 도와주신 모든 분들께 항상 행복이 깃들길 바라며 시작하겠습니다.

학부를 졸업하며 매번 석사 진학에 대한 열망은 가슴 한가득 있었습니다. 이러한 마음이 한 해가 지나갈 수 록 줄어들더니 어느 순간 기억 끝에 걸쳐있는 목표를 보며 초심을 가졌던 그 시절의 저에게 질문을 하게 되었습니다. 무엇을 위해 공부를 더 하고 싶은지 왜 하고 싶은지 그리고 외람된 이야기지만 그 순간의 선택이 미래의 나를 먹여 살릴 수 있는지에 대해 깊은 고민을 시작하였습니다. 그러던 찰나 이주영 교수님을 뵙게 되면서 이러한 질문의 답을 찾으려는 저의 모습이 죄송할 만큼 학업을 진행할 수 있는 동기를 끊임없이 주셨습니다.

지도교수님이 되어주신 이주영 선생님께서는 2 년동안 교육자로서 혼신을 대해 학생들에게 넘치는 교육을 해주셨으며 연구자로서 가져야할 덕목과 마음가짐을 그리고 가지고 계신 지식에 대해 아낌없이 전달해주셨습니다. 덕분에 자신을 갖고 학업에 임할 수 있었던 2017 년과 2018 년을 보내었습니다. 제게 기회가 온다면 그 기회를 통해 교수님께 항상 보답하고 싶은 마음 그리고 가슴 깊이 은사님으로 남을 수 있는 공부할 시기를 만들어주신 교수님께 다시 한번 감사의 말씀 드립니다.

비록 많은 시간을 함께하지 못하였지만 중간발표, 최종발표, 특강에서 뵐 때마다 나오시는 지식의 전달과 그리고 깊은 성품을 보여주신 남윤자 교수님, 김주연 교수님께 감사함을 전달합니다. 최종심사 요청에도 기쁘게 받아주시며 날카로운 비평과 함께 주신 연구방향은 앞으로도 깊게 간직하고 기억하며 지내겠습니다.

더불어 '의복과 건강' 연구실에서 보이지않는 지원을 해주신 세 분의 박사님들께도 많은 감사 드립니다. 셀로판지로 벽을 치셨지만 늦은 밤 질문에도 항상 답변을

주신 귀여운 세 아이의 어머니 김도희 박사님, 무심한듯 남들 몰래 생일도 챙겨주신 백윤정 박사님, 작은 고충도 귀 기울여 주신 박준희 박사님께 다시 한번 감사의 말씀 드립니다. 그리고 선배이자 서로 귀찮게 하며 서로의 학업을 복돋아 주었던 다희에게 감사하며 2 학기때 홀로 연구실에 남아있을 때 든든한 지원군으로 남아주었던 호기심 많은 규태, 알게 모르게 공부벌레 철승, 막내이자 운동을 심히 좋아하는 상현에게도 매우 고맙다고 전하고 싶습니다. 여러 인턴을 거쳐 마지막 선택을 위해 고민했던 예린이는 특히 기억에 남습니다. 가장 오랜시간 동안 옆에서 도움을 주었으며 구조적 배치와 색감이 부족한 발표자료를 본인이 바쁜 와중에도 열심히 챙겨주고 서로 겹치는 실험은 한적 없지만 각자의 실험도 기꺼이 참여해주고 늦은 밤까지 준비과정도 도와준 매우 고마운 후배이자 연구자로 기억에 남으며 매우 감사함을 전합니다. 마지막으로 재연이는 실물로 보게 될 마지막 후배일 듯 합니다. 작고 큰 마음고생이 있었겠지만 강한 정신력으로 꿋꿋이 헤쳐나가는 모습을 보며 배울점이 많은 친구입니다. 힘든 시기에 많은 도움을 주지는 못하고 도움만 요청하여 미안함과 감사함이 묻어나는 후배입니다. 그리고 GAP 의 인연으로 같이 지낸 허윤정선생님께 감사합니다. 학생들의 멘토이자 나이스한 매너, 끝내주는 업무 진행은 만약 직장에서 사수로 만났더라면 하나부터 열까지 배우고 싶은 분입니다. 끝으로 만담꾼이자 테니스의 왕자인 강준이와 저의 첫 실험의 피험자로 와준 본준에게 올 해 2019 년 좋은 일이 꼭 있으리라 믿으며 고맙다는 말을 전합니다.

대학원 생활에 있어 많은 시간을 보내지는 못했지만 힘든 시기에 서로 가진 전공에 대한 지식을 공유하며 이뤄지지 않은 종강파티를 약속한 슬기, 세영, 송미, 영훈에게도 꼭 다같이 함께 종강파티를 할 수 있는 날을 기대하며 다들 수고했고 이루고자 하는 방향 꼭 나아가자는 말 직접 전하지 못해 미안하다.

덧붙여 졸업 전임에도 불구하고 팀원으로 받아주신 (재)FITI 시험 연구원 연구개발본부 융복합연구팀 김종훈 팀장님께 그리고 연구 진행 시 막힘에 온라인으로 본인 일처럼 붙들고 같이 고민해준 최지영박사님, 카라이프에 끊임없는

조언과 지식을 전달해준 효근, 40 도가까이 되는 폭염 속, 전날의 철야에도 불구하고 달려와서 피험자로서 실험에 임해주신 강철의 관악 소방서 소방관님들 그리고 마지막으로 관심없이 지켜봐준 북일고등학교 친구들에게도 감사의 말씀 올립니다.

사실 경제적 활동을 접고 학업에 진학을 하기란 쉽지 않은 선택입니다. 이러한 선택을 믿어주시고 주저없이 응원과 지원을 해주신 매일 사랑을 주신 사랑스러운 어머니, 저의 롤모델로 든든한 어깨의 아버지 그리고 하나밖에 없으며 항상 형의 투덜거림을 받아주고 성숙한 인형이에게 매일 매일 고마움을 전달드리지 못한점 죄송하며 오늘을 있게 만들어주셔서 매일 감사드립니다. 그리고 저의 짝꿍이자 배우자가 될, 언제 봐도 사랑스러운 예지에게 너무, 정말 고맙습니다. 학생일 당시 저를 만나준 것부터 시작하여 서로가 함께 할 수 있는 시간과 믿음을 의심치 않고 기다려준 예지는 저에게는 가장 소중한 사람이자 유일한 사람입니다. 그리고 이러한 저를 믿어주신 미래의 장인어른, 장모님께 그리고 귀여운 유찬이와 막내이모께 감사함을 돌립니다. 앞으로 저희 둘이 이뤄나갈 시간과 과정을 서로가 더욱 응원해주고 감싸주도록 살아가겠습니다.

끝으로 다시 한번 저의 지도교수님 이주영 교수님께 많은 점을 가르쳐 주셔서 진심으로 감사드립니다. 한국에서 접할 수 없는 실험실, 학생들이 서로 으쌰으쌰할 수 있는 연구분위기, 국내 및 국외로 나갈 수 있는 다수의 학회경험을 통해 견문의 넓힘을 제공해주셔서 고맙습니다.

석사의 졸업과 함께 교수님의 가르침과 모든 분들의 응원은 오늘과 함께 마음속에 간직하고 잊지 않겠습니다.

감사합니다.

2019.01.24

서울대학교 생활과학대학 의류학과 의복과 건강 연구실 김도형 올림