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Rectal Temperature Cooling Using 2 Cold-Water Immersion Preparation Strategies

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Context: Cold-water immersion (CWI) is essential to treat patients with exertional heatstroke (EHS). Experts recommend that patients with EHS be immersed in water between 1.7°C and 15°C within 30 minutes of collapse. Some clinicians fill cooling tubs several hours before exercise, keep the tub in hot conditions, and then add ice in the event of an EHS emergency. No data exist on whether adding ice to water at the time of treatment is as effective as keeping water in the recommended range.

Objectives: To (1) compare the cooling rates of individuals immersed in a water bath kept at 10°C (CON) or 17°C water with 75.7 L (20 gal) of ice added to it immediately upon immersion (ICE) and (2) examine perceptual responses before, during, and after cooling.

Design: Crossover study.

Setting: Laboratory.

Patients or Other Participants: Twelve individuals (7 men, 5 women; age = 22 ± 2 years, height = 176.0 ± 12.8 cm, mass = 74.5 ± 10.6 kg).

Interventions: Participants exercised in the heat until rectal temperature was 39.5°C. They then immersed themselves in CON (initial water volume = 681 ± 7.6 L, 10.0°C ± 0.03°C) or ICE (initial water volume = 605.7 ± 7.6 L water at 17.0°C ± 0.03°C with 75.7 L ice) until rectal temperature was 38°C. Thermal sensation and environmental symptoms questionnaire (ESQ) responses were recorded before, during, and after exercise and cooling.

Main Outcome Measure(s): Rectal temperature cooling rates, thermal sensation, ESQ responses.

Results: Participants exercised for similar durations (CON = 39.6 ± 18.2 minutes, ICE = 38.8 ± 14.3 minutes, $Z_{11} = 0.94$, $P = .38$) and had similar thermal sensation and ESQ scores immediately postexercise each day (P values > .05). They cooled quickly and at similar rates in both conditions (CON = 0.20°C ± 0.06°C/min, ICE = 0.21°C ± 0.12°C/min, $t_{12} = 0.72$, $P = .49$). Perception data were similar between conditions during and after cooling ($P < .05$).

Conclusions: Clinicians can cool patients with EHS quickly by adding ice to water that has warmed to above expert recommendations. Adding ice to a water bath at the time of EHS emergencies could save time, energy, and resources instead of always maintaining water bath temperatures within expert-recommended ranges.

Key Words: environmental symptoms questionnaire, exertional heat stroke, thermal sensation

Key Points

- Following National Athletic Trainers' Association recommendations for water bath temperature produced excellent cooling rates.
- Time- or resource-burdened clinicians can successfully treat patients with hyperthermia by adding ice to warmer water baths at the time of an exertional heatstroke emergency.

When body core temperature exceeds 40.5°C (105°F) and central nervous system dysfunction occurs, exertional heatstroke (EHS) is a possibility.[1,2] Exertional heatstroke is a dangerous condition that has resulted in an average of 3 deaths per year since 1995, mainly in secondary school football players.[3,4] The morbidity and mortality of EHS are directly related to how long a person's body temperature remains >40.5°C.[1,5,6]

National best-practice EHS treatment recommendations include rectal temperature (T_{REC}) assessment to confirm an EHS diagnosis, followed by cold-water immersion (CWI) within 30 minutes of patient collapse.[1,2] Cold-water immersion is the criterion standard treatment for individuals with EHS because it has the fastest body temperature cooling rate of all cooling modalities as a result of its high heat capacity, thermal conductivity, and body surface area coverage.[1,7,8] Collectively, these factors effectively allow blood to return flow to the heart and reduce the hypermetabolic state of the internal organs.[9] Importantly, when best practices are performed, EHS survival rates are 100%.[5]

The National Athletic Trainers' Association (NATA)[1] recommended that patients with EHS be immersed in water between 1.7°C (35°F) and 15°C (59°F). Several research studies[7,8] have shown CWI cooling rates exceeding 0.20°C/min, but authors of many of these studies used circulated or temperature-controlled whirlpools. In the field, clinicians may not have access to circulating, temperature-controlled whirlpools. Instead, noncirculating stationary tubs, kiddie pools, or tarps are often used for CWI to treat EHS.[2,10]

Among secondary school athletic trainers (ATs), 52% prepared immersion tubs before practice as part of their EHS policy and procedures.[10] Consequently, it is possible that the water temperature in these baths rises beyond expert-recommended temperatures[1] for patients with EHS by the time they are needed, especially if exposed to hot, humid conditions and solar radiation for several hours. Anecdotally, many ATs immerse patients with EHS in the baths and plan to add ice in the event of an emergency. To our knowledge, no researchers have examined if adding ice to a water bath that is warmer than NATA water bath temperature recommendations[1] still results in cooling rates consistent with best practices.[5,11]

The purposes of our study were 2-fold. First, we compared T_{REC} cooling rates of 2 water bath preparation strategies. The first strategy used water kept at a temperature of 10°C (no ice added; CON). Our second strategy (ICE) used water starting at 17°C, but 75.7 L (20 gal) of ice was added when the individual entered the bath. Next, we determined if ICE cooling rates met the definition of *ideal* (ie, >0.15°C/min) or *acceptable* (0.08°C/min to 0.15°C/min).[11] We hypothesized that ICE cooling rates would be slower than CON cooling rates and that both water bath preparation strategies would cool at ideal rates.[11]

METHODS

Experimental Design

We used a randomized, counterbalanced, crossover design to guide data collection. Time and water bath preparation strategy were our independent variables. Our dependent variables were CWI duration, T_{REC} cooling rates, thermal sensation, and environmental symptoms questionnaire (ESQ) responses. We also measured environmental chamber temperature and humidity, ice volume, water bath volume, pre-exercise hydration status, and heart rate each day to ensure consistency between experimental days.

Participants

A convenience sample of 16 healthy men and women were recruited for this study. Three participants discontinued testing because of heat intolerance and 1 discontinued because of CWI intolerance on the CON day. Therefore, 12 participants finished our study (Table 1). Individuals were not permitted to participate if they self-reported the following: (1) a cold allergy; (2) a previous physician–diagnosed gastrointestinal, cardiac, musculoskeletal, respiratory, or neurologic illness; (3) use of medications that affect thermoregulation, fluid balance, or blood pressure; (4) a history of serious heat illness in the 6 months before the study; (5) a sedentary lifestyle (exercising fewer than 3 times a week for 30 minutes)[12]; (6) an injury that prevented them from exercising; (7) a COVID-19 diagnosis within 14 days of testing; or (7) pregnancy. All women were tested in their follicular phase of menses (ie, first 14 days after the onset of menstruation). All procedures were approved by Central Michigan University's institutional review board, and individuals provided written consent before participation.

Table 1. Participant Demographics and Hydration Information (N = 12)

	Group[a]	
	Control	ICE
Demographic		
Age, y	22 ± 2	
Men/women, No.	7/5	
Height, cm	176.0 ± 12.8	
Body mass index	24 ± 2	
Body fat, %	14 ± 10	
Body surface area, m^2	1.90 ± 0.20	
Hydration indices		
Pre-exercise urine specific gravity	1.005 ± 0.005	1.004 ± 0.006
Body mass, kg		
Pre-exercise	74.54 ± 10.58	74.74 ± 11.05
Postexercise	73.70 ± 10.44	73.86 ± 10.95
Sweat rate, L/h	1.29 ± 0.36	1.37 ± 0.45
Posttesting hypohydration, %	1.1 ± 0.3	1.2 ± 0.5

Abbreviation: ICE, Water bath with ice added immediately upon the participant's immersion.

[a] Data are mean ± SD except where indicated otherwise.

Procedures

Before testing days, we performed a pilot experiment to establish the starting water temperature for ICE. We attempted to simulate the ambient relative humidity and temperature on July 1, 2019, in Tampa, Florida, in our environmental chamber. We chose these specifications because Florida is a state that consistently struggles with high temperatures and humidity and patients with EHS.[13] We averaged hourly temperature and relative humidity data from www.timeanddate.com for 8:15 to 10:15 AM, 11:15 AM to 1:15 PM, and 2:35 to 4:15 PM. Then we set our environmental chamber to those temperatures and humidities for the 8-hour pilot. At the beginning of the pilot, we filled a standard 1135.6-L capacity, noncirculating water tub (model 4247; Rubbermaid) with 160 gal (605.7 L) of water from our cold water tap and monitored water temperature at 20 cm from the bottom of the tub over 8 hours. In essence, we tried to emulate a scenario in which an AT filled a cooling tub in the morning with the expectation of American football practice in the late afternoon. We also assumed that the clinician in this scenario would have at least 75.7 L (20 gal) of ice and water prepared in 2 coolers, possibly for hydration purposes. We observed a final water bath temperature of approximately 17°C and used this temperature for the ICE condition's starting water temperature.

Participants reported for testing on 2 days separated by at least 48 hours. We instructed them to avoid caffeine, tobacco, alcohol, and exercise 24 hours before testing. They were told to drink water before testing to ensure their urine was clear to light yellow in color. We also instructed participants to fast for 2 hours before testing and sleep at least 7 hours the night before.

Upon arrival, participants read and signed an informed consent and answered questions regarding their health history and activity levels during the preceding 24 hours. They also drew a number to determine testing order. After they voided their bladder completely, we assessed a spot urine specific gravity using a refractometer (model SUR-Ne refractometer; Atago USA Inc). If a participant was not

Table 2. Exercise and Cooling Data[a]

Variable	Group: Control	Group: ICE
Exercise conditions		
Exercise duration, min	39.6 (18.2)	38.8 (14.3)
Environment temperature, °C	38.3 ± 0.3	38.4 ± 0.3
Environment relative humidity, %	45 ± 1	45 ± 1
Cooling descriptives		
Preimmersion water temperature, °C[a]	10.02 ± 0.04	17.01 ± 0.03
Postimmersion water temperature, °C[a]	10.79 ± 0.17	12.92 ± 0.30
Water volume at onset of cooling, L[a]	681 ± 7.6	605.7 ± 7.6
Ice volume added to tub, L[a]	0	75.7
Rectal temperature cooling rate, °C/min	0.20 ± 0.06	0.21 ± 0.12
Participants who self-reported shivering during or after cold-water immersion, No./Total[b]	9/12	6/12
Time to shivering onset, min[b]	6.7 ± 1.7	7.2 ± 1.7

Abbreviation: ICE, Water bath with ice added immediately upon the participant's immersion.

[a] All data are mean ± SD except for exercise duration, which is reported as median and interquartile range (N = 12).

[b] Data reported descriptively and not statistically analyzed.

adequately hydrated (urine specific gravity >1.020),[14] testing was rescheduled for at least 48 hours later. Participants then were weighed nude to the nearest 0.01 kg (model Defender #5000; Ohaus Corp), inserted a rectal thermistor 15 cm past the anal sphincter[15] (YSI 4600 Precision Thermometer with model 401 probe; Advanced Industrial Systems), and donned athletic clothes (ie, crew socks, shorts, T-shirt, sports bra [if female]). We measured skinfolds in triplicate at the thigh, abdomen, and chest (men) or thigh, abdomen, and triceps (women).[16] Participants donned a heart rate monitor (Polar Electro) and a rain poncho to expedite the increase in T_{REC} during exercise.

They entered the environmental chamber, stood on a treadmill for 10 minutes to acclimate, and then reported how they felt by answering an ESQ and giving a thermal sensation score from 0 (*unbearably cold*) to 8 (*unbearably hot*).[17] The 16-item ESQ is rated on a 5-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*). After acclimation, individuals walked at 3 mph (4.8 km/h) for 3 minutes, followed by 2 minutes of running at a self-selected pace that elicited heart rate values between 80% and 90% of maximum. This process was repeated until T_{REC} reached 39.5°C. The T_{REC} was recorded every 5 minutes. Once T_{REC} was approximately 39.42°C, participants were given another ESQ survey and asked their thermal sensation score. Then they removed the poncho and their shoes before entering the water bath. For ICE trials, we kept the 605.7 ± 7.6-L (160-gal) water bath at approximately 17°C and added 75.7 L (20 gal) of ice once the individual was immersed up to the neck. We stirred the bath every 2 minutes. Participants reported when they began to shiver so that we could determine whether shivering-induced thermogenesis affected cooling. The T_{REC} was recorded every 30 seconds, and participants were removed from the bath when it reached 38.0°C. The CON procedures were the same except that the starting water temperature was approximately 10°C and water volume was 681 ± 7.6 L (approximately 180 gal). No ice was added after participant immersion on CON days. No fluids were given to individuals once they entered the environmental chamber. Testing sessions occurred at approximately the same time each day.

Statistical Analysis

We statistically compared T_{REC} at times common to all participants. Means and SDs were calculated for each dependent variable and assessed for normality. Separate dependent *t* tests were used to examine T_{REC} cooling rates, pre-exercise urine specific gravity, and environmental conditions. Exercise duration was assessed with a Wilcoxon signed rank test because normality was violated, and the data are reported as median and interquartile range.

For the ESQ responses, we summed the scores for the 16 items and created a new cumulative score.[18] The cumulative scores were analyzed with a repeated-measures analysis of variance (ANOVA). Although thermal sensation scores are ordinal in nature, we used a repeated-measures ANOVA to analyze these data because they are prone to ties, and ties reduce the robustness of nonparametric statistical models.

We also conducted repeated-measures ANOVA to analyze T_{REC} during exercise, cooling, and recovery between conditions. Sphericity was evaluated with the Mauchly test. Geisser-Greenhouse adjustments to *P* values and degrees of freedom were made if the sphericity condition was violated. With significant interactions or main level effects, we applied Tukey-Kramer post hoc tests to identify differences between cooling methods at each time point. Significance was accepted when $P < .05$ (version 2007; Number Cruncher Statistical Software).

RESULTS

All participants self-reported compliance with testing instructions each day. They were well hydrated before exercise ($t_{11} = 0.61$, $P = .56$; Table 1). They exercised for similar durations ($Z_{11} = 0.94$, $P = .38$) and in similar environmental heat ($t_{11} = 1.6$, $P = .15$) and relative humidity ($t_{11} = 1.0$, $P = .33$; Table 2) each day.

Rectal temperatures were comparable between conditions during exercise, and all participants finished exercise when their T_{REC} reached 39.5°C (Figure 1). They cooled at ideal rates[11] in both conditions (Table 2), but no differences in cooling rates were observed between water bath preparation strategies ($t_{11} = 0.72$, $P = .49$).

Thermal sensation differed between conditions over time ($F_{3,33} = 3.8$, $P = .02$; Figure 2). Both CON and ICE

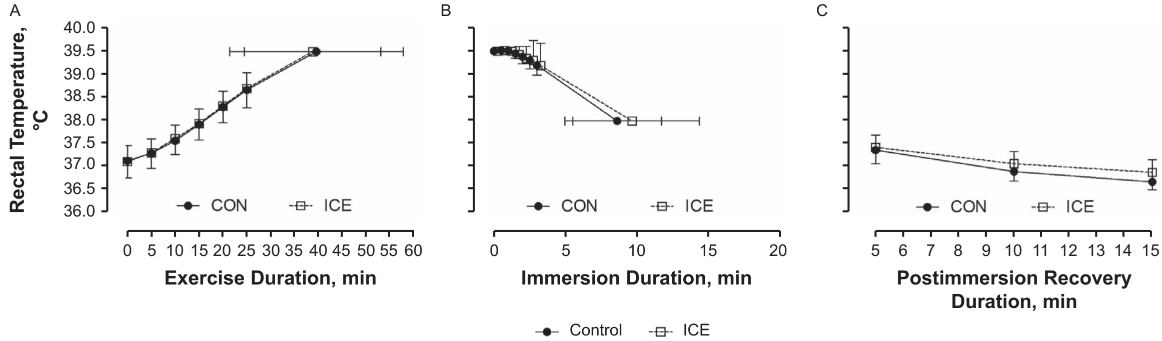

Figure 1. Time 0 indicates the start of exercise or cooling. X-axis error bars in exercise duration indicate the median and interquartile range. X-axis error bars for immersion duration and all other data in Figure 1 are reported as mean and SD. Abbreviation: ICE, 17°C water with ice added upon immersion.

thermal sensations at pre-exercise differed from all other measurement times in their respective conditions. Thermal sensation was higher immediately postexercise compared with when T_{REC} was 38.75°C and postimmersion on each day. Postimmersion thermal sensation was also higher than when T_{REC} was 38.75°C for each condition ($P < .05$).

The ESQ scores were similar between conditions over time ($F_{3,33} = 0.6$, $P = .62$; Table 3), and we did not observe a main effect of water bath preparation condition ($F_{1,11} = 2.1$, $P = .18$). However, we did note a main effect of time ($F_{3,33} = 30.1$, $P < .001$). The ESQ scores at pre-exercise and postexercise were different than those at all other measurement times (P values $< .05$).

DISCUSSION

To our knowledge, we are the first to examine whether a secondary school water bath preparation strategy can lower T_{REC} at expert-recommended rates.[11] Our main findings were that T_{REC} cooling rates for both CON and ICE were excellent, met the definition of ideal,[11] and were not different. Encouragingly, the cooling rates we demonstrated were consistent with the cooling rates of patients with EHS who were treated with CWI and survived without sequelae of injury.[5] Moreover, our participants were able to cool effectively without any clinically meaningful differences in thermal sensation or ESQ scores. These results suggest that time- or resource-burdened clinicians can successfully treat patients with EHS even if their water baths are exposed to prolonged periods of high heat and humidity so long as ice is added to the water bath at the same time as the patient.

Our ICE protocol was designed to emulate a scenario in which a clinician could not maintain the water bath temperature according to NATA recommendations[1] (1.7°C–15°C) until it was needed to treat an individual with EHS. Despite using a higher starting water temperature of 17°C with approximately 76 L (20 gal) of ice, the ICE protocol quickly lowered T_{REC} (0.21°C ± 0.12°C/min). This cooling rate was faster than that of other researchers[19–21] who performed temperate water immersion to treat hyperthermia. Proulx et al[8] used circulating water baths at 8°C, 14°C, or 20°C to treat hyperthermic participants; the cooling rates were 0.19°C ± 0.07°C/min, 0.15°C ± 0.06°C/min, and 0.19°C ± 0.10°C/min, respectively. Miller et al[19] used 21°C water to cool individuals with hyperthermia wearing an American football uniform. With the uniform donned during cooling, the cooling rate was 0.12°C ± 0.05°C/min; it was only slightly faster when the uniform was removed (0.13°C ± 0.05°C/min). When hyperthermic participants (T_{REC} = 40.1°C ± 0.67°C) were immersed in a 26°C water bath, they cooled at 0.10°C ± 0.02°C/min.[21] Collectively, these data[8,19,21] suggest that even if the starting water

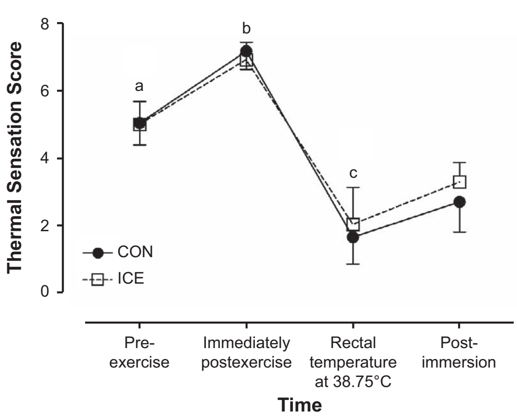

Figure 2. Thermal sensation scores with 2 water bath preparation strategies. [a] Water bath kept at 10°C (CON) and 17°C water with ice added upon immersion (ICE) conditions at pre-exercise differed from all measurement times within their respective conditions. [b] CON and ICE conditions immediately postexercise different from rectal temperature (T_{REC}) at 38.75°C and postimmersion within their respective conditions. [c] CON and ICE conditions at T_{REC} at 38.75°C different from postimmersion within their respective conditions. All superscripts indicate $P < .05$.

Table 3. Environmental Symptoms Questionnaire Responses (N = 12) With 2 Water Bath Preparation Strategies[a]

	Group	
Variable	Control	ICE
Pre-exercise[b]	3 ± 3	2 ± 2
Postexercise[c]	26 ± 10	26 ± 10
Rectal temperature at 38.75°C during cold-water immersion	16 ± 10	15 ± 12
Postcooling	12 ± 9	9 ± 10

Abbreviation: ICE, water bath with ice added immediately upon the participant's immersion.

[a] Data are mean ± SD. The 16-item environmental symptoms questionnaire is rated on a 5-point Likert scale with scores ranging from 0 (*not at all*) to 5 (*extreme*). Superscripts indicate post hoc test results for the main effect of time ($P < .05$).

[b] Pre-exercise < all other times.

[c] Postexercise different from all other times.

bath temperatures are somewhat higher than those in our study, the cooling rates of patients with EHS will still likely meet the definition of acceptable or ideal,[11] especially if ice is added when the patient is immersed.

For 3 reasons, our ICE cooling rates were likely higher than those of other investigators[8,19,21] who used temperate water immersion. First, ice gradually lowered the water bath temperature, creating a greater thermal gradient and increasing the conductive heat exchange. Second, ice requires approximately 80 times more energy to melt (ie, the latent heat of melting) and undergo a phase change than it does to increase water temperature. Third, some authors[21,22] have argued for using temperate water immersion instead of CWI to reduce shivering and vasoconstriction of blood vessels in the skin. Reducing shivering and vasoconstriction would enhance heat exchange because of less shivering-induced thermogenesis, promoting a beneficial thermal gradient to allow heat exchange. Our data support this, as more people shivered in CON than in ICE. Although most participants who shivered in CON also shivered in ICE (n = 6), 3 individuals shivered only in CON. None of our participants shivered only in ICE. Moreover, shivering onset was delayed in ICE, which may have also contributed to the quick cooling rates observed in that condition. Importantly, shivering did not impair cooling effectiveness in any meaningful way, and shivering is considered only a minor factor in cooling because of the larger conductive and convective heat loss from the CWI.[9] However, our shivering data should be interpreted cautiously, because of their self-reported and descriptive nature.

We also noted excellent cooling with CON. Clinicians capable of monitoring water baths and keeping them consistent with NATA recommendations[1] in hot conditions are to be commended. In several studies[8,15,23,24] and systematic reviews,[7,11] the researchers agreed that CWI resulted in some of the fastest T_{REC} cooling rates and has saved lives in real EHS scenarios.[5,25] For example, patients with EHS who had an average initial T_{REC} of 41.11°C ± 0.63°C cooled at rates of 0.22°C ± 0.11°C/min when immersed in ice and water. Therefore, clinicians who have access to ice and the resources to provide CWI according to the NATA's recommendations for water temperature[1] will cool these individuals quickly.

Our study had several additional strengths. We used standardized water and ice volumes and temperatures on each day of testing with little variability in preimmersion bath temperatures. We also recorded participants' perceptions of thermal sensation and ESQ scores. Both subjective indicators were important for understanding how participants felt before, during, and after exercise and CWI. The thermal sensation and ESQ data suggested that they felt similarly in both CON and ICE during water immersion and postcooling. Thus, we infer that the body encountered no additional stress when ice was added to the water bath at the time of immersion and that ICE was experienced in much the same way as in cold water without ice.

We recognize the limitations of our work. First, for safety reasons, we were not able to study the effects of ICE protocol on participants with higher body temperatures or individuals with impaired central nervous systems. Second, we were not able to simulate the radiative effects of the sun on our water bath when determining the ICE starting water bath temperature. However, we used weather data from a state that is a location with many cases of EHS (ie, Florida)[26,27] to see how the temperature and humidity conditions affected the water bath temperature. Third, we did not measure the skin temperature of participants during exercise and cooling, which prevented us from performing heat balance and exchange estimates during each condition. Yet all individuals completed the exercise in similar environmental conditions with similar exercise durations and to the same internal body core temperature. Finally, we used the rough volume indicators inside our 10-gal coolers to determine how much ice to add for the ICE condition. Even though we used crushed ice, air was likely present between the ice cubes. Hence, the volume of water in the ICE stationary tub may have been slightly less than that in CON.

CONCLUSIONS

Despite using water that started 7°C warmer than CON, our ICE water-bath preparation strategy cooled participants with hyperthermia at ideal cooling rates[11] for patients with EHS. If clinicians lack the resources to maintain water bath temperature consistent with NATA guidelines,[1] they can add ice to the water while the patient is immersed. The added ice will increase the thermal gradient between the bath and patient while also absorbing more energy than water alone. Future authors should examine whether adding ice to even warmer water (>17°C) can still elicit ideal cooling rates of hyperthermic individuals.

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