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Effects of Cooling and Magnesium Supplementation on the Objective and Subjective Outcomes of Acute High-Intensity Rowing

A hűtés és magnézium-szupplementum hatása az akut, nagy intenzitású evezés objektív és szubjektív kimenetelére

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Abstract - Background: Body temperature and level of magnesium in the body can be important factors affecting the level of exercise activities. However, beneficial effects of body cooling and magnesium supplementation on acute high-intensity exercises have not yet been studied in large number of athletes. We hypothesized that cooling interventions and supplementation of magnesium will improve both objective and subjective outcomes of acute high-intensity exercises. Subjects and Methods: Twenty-four athletes with different backgrounds of sports were recruited (n = 24, all males; age 25 ± 4 years; weight 76 ± 10 kg; height 175 ± 5 cm). Indoor rowing was used as acute high-intensity exercise. Subjects were evenly and independently assigned to four groups, namely, (1) Group C: control group, (2) Group HC: hand cooling intervention (HC), (3) Group WBC: whole-body cryotherapy intervention, and (4) Group MgS: magnesium supplementation. Each group had three measurements: before exercise, during acute high-intensity 1000 m open-end rowing, and in the recovery period. During rowing, the power output and speed values were collected at every 200 m. Before and after rowing, the following six parameters were collected; objective outcomes: ammonia (NH3) and lactate (La) of blood plasma, heart rate (HR), whole-body temperature (TW), and subjective outcome: rate of perceived exertion (RPE) by standard questionnaire, and self-rated perception of thermal sensation (TS). Results: HC, MgS and WBC (which significantly lowered TW as compared to other groups ($p < 0.05$), but it did not elicit significant changes in the measured parameters (such as La, NH3, HR, RPE, rowing power, and rowing speed). In terms of TS, as the subjective outcome, we observed positive effects in response to all three interventions of HC, WBC, and MgS compared to Group C. We also observed a slight, yet significant difference of the RPE between interventions of HC and WBC. Conclusions: Data show that whole-body cryotherapy lowers body temperature and together with magnesium supplementation – without affecting objective outcomes - improve the thermal sensation. Thus, we propose that cooling intervention and magnesium supplementation - in certain conditions - can enhance output of acute high-intensity exercise, especially in warm environment. *Abbreviations: HC - hand cooling; WBC - whole-body cryotherapy; La - lactate; NH3 - blood ammonia; HR - heart rate; TS - thermal sensation; RPE - rate of perceived exertion; TW - whole-body temperature*

Keywords: cryotherapy, lactate, ammonia, heart rate, rate of perceived exertion, body temperature, rowing

Absztrakt - Háttér: A testhőmérséklet és a szervezet magnézium szintje fontos tényezők lehetnek, amelyek befolyásolják az edzési tevékenységek szintjét. Azonban a testhűtés és a magnézium-szupplementum jótékony hatásait az akut, nagy intenzitású teljesítményre nagyszámú sportolónál még nem vizsgálták. Feltételeztük, hogy a hűtési beavatkozások és a magnézium szupplementum javítja az akut, nagy intenzitású gyakorlatok objektív és szubjektív kimenetelét. Alanyok és módszerek: Huszonnégy különböző sportági hátterű sportolót vizsgáltunk (n = 24 férfi, életkor: 25 ± 4 év; súly: 76 ± 10 kg; magasság: 175 ± 5

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cm). A beltéri evezést akut, mint nagy intenzitású aktivitást használtuk. Az alanyokat egyenletesen és egymástól függetlenül négy csoportba osztottuk, nevezetesen: (1) C csoport: kontroll-csoport, (2) HC csoport: kézhűtés beavatkozás (HC), (3) WBC csoport: teljes testre kiterjedő hűtés (krioterápiás) beavatkozás és (4) MgS csoport: magnézium szupplementum. Minden csoportnál három mérést végeztünk: edzés előtt, akut, nagy intenzitású 1000 m-es nyíltvégű evezés során, valamint a felépülési időszakban. Evezés közben 200 méterenként mértük a teljesítmény és a sebesség értékeket. Evezés előtt és után a következő hat paramétert mértük meg: objektív: a vérplazma ammónia (NH3) és laktát (La), szívfrekvencia (HR), teljes testhőmérséklet (TW), valamint szubjektív: az észlelt terhelés mértéke (RPE) standard kérdőív alapján és önértékelés szerint észlelt hőérzet (TS). Eredmények: HC, MgS és WBC (ami szignifikánsan csökkentette a TW-t más csoportokhoz képest ($p < 0,05$), de nem váltott ki szignifikáns változást a mért paraméterekben (például La, NH3, HR, RPE, evezési erő és evezési sebesség). A TS-t tekintve, mint szubjektív eredmény, pozitív hatásokat figyeltünk meg mindhárom HC, WBC és MgS beavatkozásra a C csoporthoz képest. Az RPE esetében, enyhe, de szignifikáns különbségét figyeltük meg a HC és WBC tekintetében. Következtetések: Az adatok azt mutatják, hogy az egész testet érintő hűtés (krioterápia) csökkenti a testhőmérsékletet, és a magnézium-pótlással együtt – anélkül, hogy az objektív eredményeket befolyásolná – javítja a hőérzetet. Ezért feltételezhető, hogy a hűtési beavatkozások és a magnézium szupplementum - bizonyos körülmények között - növelheti az akut, nagy intenzitású edzés-teljesítményt, különösen meleg környezetben. *Rövidítések: HC - kézi hűtés; WBC - teljes test krioterápia (hűtés); La - laktát; NH3 - ammónia; HR - pulzusszám; TS - hőérzet; RPE - az észlelt terhelés mértéke; TW – teljes testhőmérséklet.*

Kulcsszavak: krioterápia (hűtés), laktát, ammónia, pulzusszám, az észlelt terhelés mértéke, testhőmérséklet, evezés

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Introduction

In elite sport it is essential to find novel methods and interventions, which can improve the physical and mental capacity of athletes. Indeed, in the past, various interventions have been proposed to increase the efficiency of sport activities. One of the interventions is cooling of the whole body or part of it aiming to avoid exercise-induced heat stress, thermal strain and thermoregulatory strain. Several studies have been conducted with the intervention of hand cooling to lower the core temperature. For example, Adams in 2016 (Adams et al., 2016) used the vacuum seal as the intervention of hand cooling and showed that this device might significantly increase efficiency of cooling effect, as opposed to other traditional ways of cooling.

Another form of cooling interventions is the use of palm cooling, but its beneficial effects are still unclear. In 2017, Bongers (Bongers et al., 2017) showed that cold water immersion delayed the onset of muscle soreness as a subjective outcome (i.e. self-perceived rate of muscle soreness). However, it did not affect objective outcomes; i.e. physiological parameters.

In contrast to hand and palm cooling, it has been shown that whole-body cryotherapy can effectively improve objective outcomes, such as muscle strength and inflammatory response during exercising (Pournot et al., 2011). Thus, whole-body cryotherapy has recently become popular in sport science, but its beneficial effects still need to be further studied.

There are several external factors in determining the actual effect of cooling interventions. For example, Nunnely (Nunnely, 1971) hypothesized that head cooling can only be beneficial at the ambient temperature above 40 °C. Recently, Kenny (Kenney et al., 2019) also suggested that pre-cooling intervention can be beneficial in hot ambient temperature, that is, the benefit of cooling interventions could possibly depend on external environment during sport activities

It is also important that the external environments also have influences on internal status of athletes. For example, loss of magnesium in the body is often associated with hot temperature (Consolazio et al., 1963). Consolazio showed that the loss of magnesium through sweating increased by a factor of 10 in the environment of 100 °F (corresponding to 38 °C). Whereas, Nielsen 2006 (Nielsen & Lukaski, 2006) also showed that exercise induces a redistribution of magnesium in the body to accommodate the altered metabolism. Magnesium is involved in various chemical processes affecting muscle function, including electrolyte balance, such as calcium (Nielsen & Lukaski, 2006). In this regard, supplementation of magnesium has been proposed to improve the status of athletes for better sport performance. It is interesting to note that the supplementation of magnesium has been widely studied in athletes with magnesium deficiencies, while its beneficial effect on individuals with an adequate level of magnesium has not been clarified (Nielsen & Lukaski, 2006). Thus whether or not magnesium supplementation has a positive effect on the performance of athletes remains unclear.

In this study, we aim to investigate the effects of cooling and magnesium supplementation on the performance and recovery of the athletes after acute high-intensity exercise. Specifically, we use the 1000 m indoor rowing (hereafter rowing) as ta reference for the acute high-intensity sport. This is because the rowing highly demands adenosine triphosphate to supply contractile activity of skeletal and cardiac muscles, resulting in an ideal representative of high-intensity exercises. For the form of the cooling intervention, we investigate hand cooling (HC) and whole-body cryotherapy (WBC). To study the effect of magnesium supplementation (hereafter MgS), we use 400 mg magnesium tablet taken orally with 250 ml water before rowing.

Subjects and Methods

1.1 Subjects

In this study, 24 recreational athletes with different backgrounds of sport activities were recruited, as subjects of this study. Their mean age, was 25 ± 4 years; weight 76 ± 10 kg; height 175 ± 5 cm, respectively. Participants were evenly distributed into four groups based on their regular rowing power outputs (see Section 2.2). Specifically, the participants were evenly assigned to groups of 6 as follows:

- Group C: Control group without any intervention,
- Group HC: With intervention of hand cooling
- Group WBC: With intervention of whole-body cooling
- Group MgS: With supplementation of magnesium

All participants were informed about the procedure of the experiment and signed the letter of consent. The study was approved by the Institutional Review Board of the Fu Jen Catholic University, New Taipei City 242062, Taiwan (R.O.C.)

1.2 Experimental Procedure

For each subject, the experiment consisted of two phases: the pre-test and the main experiment. The first phase, the pre-test, was used to assess each subject's regular rowing power output, as a guidance of group assignment (see Section 2.1). The pre-test was carried out in one day: each subject performed 400 m rowing for homogeneity analysis. After group assignment, subjects entered the second phase, the main experiment (see Figure 1). In the main experiment, each group independently participated in only one type of intervention, including Group C with no intervention. The main experiment lasted for four days in total, with one day for each group. The experiment procedure in each group consisted of three sections, namely, pre-exercise, the acute high-intensity exercise of 1000 m open-end rowing (until exhaustion) and a recovery period (post-exercise). The experimental procedure for each group was as follows.

- **Group C** (control group): The subjects had a static rest (seated) one hour before the exercise and another static rest (standing) 15 minutes after the exercise in a quiet and peaceful room while all their biological parameters were obtained. This procedure prevents the effect of any extra physical activities on baseline level.
- **Group HC and Group WBC (cooling groups):**
  - › Group HC: This group used hand cooling as an intervention. As a pre-exercise, hands were immersed in ice water (temperature: 10 °C to 2 °C) three times, each followed by a 90-second resting period. After the 1000 m rowing, four cycles of post-exercise hand cooling was applied for 10 seconds, followed by a resting period of 90 seconds. The procedure is shown in Figure 1.
  - › Group WBC: This group used the whole-body cryotherapy as an intervention. As a pre-exercise, the whole body of the subject

except the head was placed into a cold chamber (air temperature: 140 °C to 120 °C) for 90 seconds, followed by a 90-second resting period. After the rowing, this cooling intervention was performed in four cycles, which consisted of a 60-second cooling cryotherapy and then a 90-second resting period. The procedure is shown in Figure 1.

- **Group MgS (magnesium supplement group):** This group used magnesium supplementation (MgS) as an intervention. The subjects were instructed to take 400 mg magnesium an hour before the 1000 m rowing. The rest of the procedure is the same as tin Group C. The procedure can be seen in Figure 1.

1.3 Parameters measured

We measured the following parameters to quantify the sport performance and recovery of each subject: lactate (La), NH3, heart rate (HR), rate of perceived exertion (RPE), whole-body temperature (TW), and thermal sensation (TS). La and NH3 are measured by taking the blood plasma. Hereafter, we denote the "m" minute after the exercise as Em for simplicity. The parameters of La and NH3 were measured at rest (R), E1, E6, and E15. At the time of E1, E3, E6, E7, and E15, we measured the HR and RPE. The TW and TS were measured at the time of R, 15 minutes before the 1000 m rowing (R2), E1, E3, E6, E7, and E15. The score of TS were rated by each subject with a standard scale of seven points in answering the question "How are you feeling now?". They were informed to answer by giving a number ranging from 1 to 7 (1 = very cold, 2 = cool, 3 = slightly warm, 4 = neutral, 5 = slightly warm, 6 = warm, 7 = hot).

All subjects performed 1000 m rowing at full intensity until they were exhausted. During rowing, the output power (in Watt) and speed were measured at every 200 m. We expressed the speed in the unit of second/0.1 mile, namely the second a subject would complete the 0.1 mile rowing. The lower the value of this quantity, the faster it is. These parameters with the time were collected and are also indicated in Figure 1.

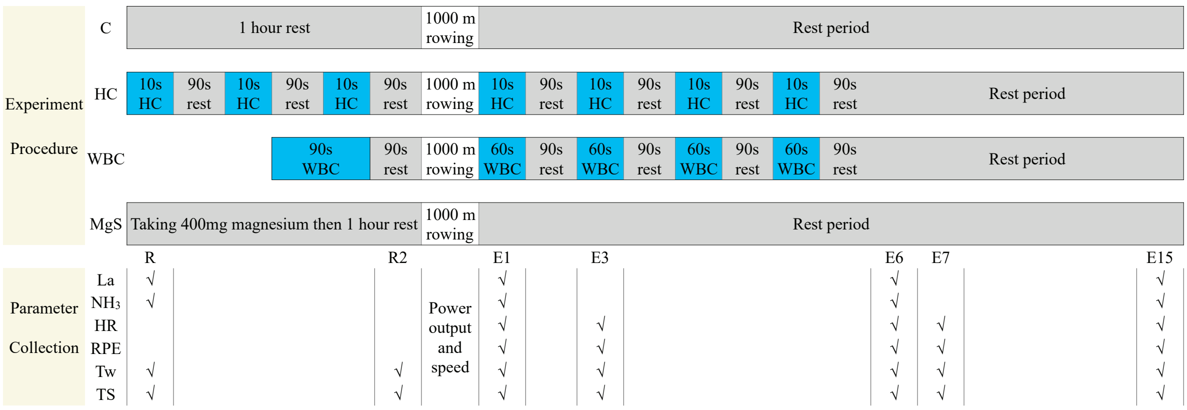

Figure 1. Design of the main experiment. The upper part of this figure shows the experimental procedure of Group C, HC, WBC, and MgS (from top to bottom). The grey colour indicates the resting period with the amount of time marked in the figure. The blue colour shows the period of cooling indicated with the type of interventions and the amount of time allocated. 1000 m open-end rowing is shown in white. Lower part of this figure (Parameter Collection) shows what and when parameters were measured.

1.4 Statistical analysis

All subjects were treated independently. The two-way mixed Analysis of Variance (ANOVA) and the Tukey's post hoc test were used to determine whether set of the parameters between two groups is statistically significant. Specifically, we first performed the two-way mixed design ANOVA on the dependent variable (e.g., La) to investigate whether a significant interaction exists between the within-group factor (i.e., the time) and the between-group factor (i.e., the type of interventions). If there is a significant interaction, the Tukey's post hoc test is used to quantify the significance between each pair of interventions. The statistical analysis was conducted by using Pingouin (Vallat, 2018) an open-source statistical

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package in Python. The standard significance level was set at α = 0.05.

Results

The mean and standard deviation of each measurement (or variable) as a function of time and intervention are included in Table 1 and Table 2. The results can be seen in Figure 2 and Figure 3.

Table 1. Measurements of each parameter of Group C, HC, WBC, and MgS

Mea-sure-ment	Group	R	R2	E1	E3	E6	E7	E15
La	C	1.27±0.34	-	10.90±1.31	-	11.95±1.67	-	9.72±1.28
	HC	1.19±0.46	-	11.55±2.49	-	14.22±3.30	-	13.30±4.53
	WBC	1.38±0.27	-	11.05±2.43	-	11.66± 3.10	-	9.97±3.78
	MgS	1.20±0.27	-	11.85±0.95	-	13.19±1.46	-	11.04±1.89
NH3	C	45.67±11.03	-	89.83±34.18	-	100.00±30.23	-	67.83±21.08
	HC	41.33±11.77	-	129.67±56.36	-	118.17±33.29	-	119.00±34.66
	WBC	49.50±18.00	-	113.67±41.21	-	97.33±32.70	-	91.33±48.42
	MgS	50.17±9.19	-	104.33±32.37	-	113.33±25.88	-	98.50±29.78
HR	C	-	-	175.83±9.67	146.50±18.21	135.17±14.90	130.00±13.50	116.17±10.12
	HC	-	-	172.17±14.75	133.00±14.82	125.83±17.83	116.83±15.10	106.67±18.62
	WBC	-	-	181.67±9.41	130.83±20.09	120.17±15.77	116.00±20.19	109.50±16.94
	MgS	-	-	180.33±11.77	138.67±20.75	124.33±13.44	118.83±14.46	114.00±6.95
RPE	C	-	-	18.17±0.69	14.17±0.90	12.17±1.07	11.67±1.49	10.00±1.73
	HC	-	-	17.33±0.75	14.83±1.07	13.83±0.69	12.83±0.69	12.33±1.49
	WBC	-	-	17.17±1.34	13.33±3.14	11.83±2.85	10.00±1.91	7.67±1.11
	MgS	-	-	17.50±1.26	13.67±2.13	12.17±2.91	11.67±2.75	10.50±2.36
Tw		35.43±0.80	33.42±0.96	31.86±0.91	32.50±0.91	32.72±0.61	32.78±0.66	33.25±0.59
		35.85±0.69	34.84±1.21	33.28±1.31	33.56±1.26	33.32±1.22	33.45±1.02	34.20±0.70
		34.74±1.47	29.72±0.69	31.37±1.15	29.05±1.52	27.13±1.46	26.41±1.35	29.99±1.48
		35.22±0.78	34.51±0.54	33.22±0.83	33.70±1.11	33.75±0.97	33.73±0.91	33.86±0.78
TS	C	4.33±0.47	5.33±0.75	6.33±0.75	5.50±1.26	5.17±0.69	5.17±0.69	4.50±0.50
	HC	4.00±0.82	3.83±0.90	6.17±0.69	5.17±0.69	4.33±0.94	4.00±0.58	3.33±0.47
	WBC	4.00±1.53	2.00±0.82	4.50±0.50	2.67±0.47	2.33±0.47	1.67±0.47	3.83±1.21
	MgS	4.17±0.37	4.17±0.37	5.50±0.76	4.67±0.47	4.50±0.50	4.33±0.47	4.17±0.37

Table 2. Measurements of rowing output power and speed

Measurement		200 m	400 m	600 m	800 m	1000 m
Output power [Watt]	C	213.17±12.69	211.17±8.63	211.17±9.87	234.33±27.01	231.33±23.69
	HC	229.17±52.52	226.33±55.58	211.17±46.74	253.17±53.81	246.83±52.93
	WBC	214.67±29.34	205.83±36.35	208.50±31.95	253.83±32.70	264.00±44.33
	MgS	239.33±28.56	233.00±22.19	230.50±35.19	248.67±53.17	247.17±44.82
Speed [second/0.1 mile]	C	32.83±2.41	32.17±2.19	32.17±2.41	33.67±2.49	33.67±3.99
	HC	34.33±3.20	32.50±2.93	32.00±3.65	35.33±3.30	34.83±3.39
	WBC	31.33±3.54	30.50±3.50	29.83±4.22	31.67±2.56	32.83±3.67
	MgS	33.00±5.26	30.67±4.57	31.00±4.32	32.50±4.07	32.50±5.02

The output power is given in Watt. We express speed as elapsed time in second the subject would complete the 0.1 mile rowing, in the unit of second/0.1 mile. That is, the lower the value, the faster it is. We list the measurements according to the four groups and at every 200 m. The quoted number and uncertainty are, respectively, the mean and the standard deviation of the measurements among the subjects in the group.

We observed no significant interaction (with $p > 0.05$) between the within-group factor, i.e., the time and the between-group factor, i.e. the type of intervention, for the variables of La, NH3, HR, rowing output power and the rowing speed. Thus interventions of HC, WBC, and MgS had no significant effects on the values of La, NH3, and the HR, and on the performance of 1000 m rowing (in terms of output power and speed).

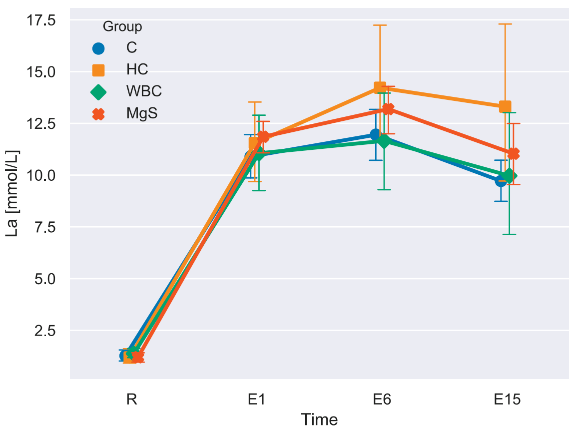
On the other hand, there were significant effects of interventions on variable of TW, TS and RPE ($p < 0.05$). We therefore further performed the Tukey's post hoc test on these three parameters and present the results. Degree of significance in the difference between the two intervention groups, in terms of p-value and the Hedges' g effect size, is presented in Table 3. We discuss these results according to each variable as follows.

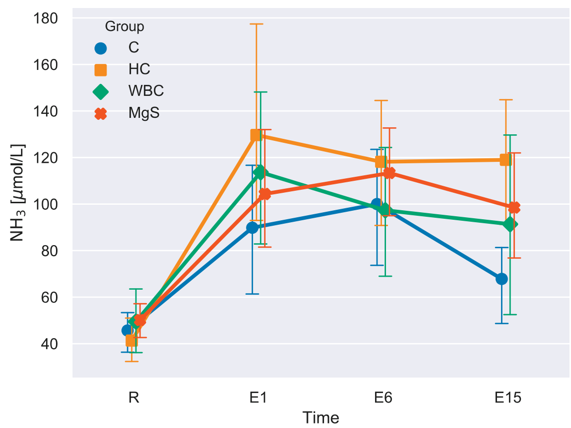
TW We observed that TW of WBC group was significantly lower than those from other three groups (C, HC, and MgS), with p-value all smaller than 0.05. To be exact, the Hedges' g effect size between WBC and C (HC, MgS) groups is 1.815 (2.32 and 2.281). This implies that TW of WBC group is lower than those for the other three groups at a level of statistically high significance. Meanwhile, the TW of other three groups (C, HC, and MgS) are all statistically consistent with each other, as shown in Figure 2. That is, intervention of WBC is the dominating factor in the difference among the four groups.

TS Except the pair of HC and MgS groups, we observed statistically significant difference existing in other pairs, as seen in Table 3. The WBC group has the lowest score in the TS scale, suggesting that WBC could significantly improve thermal sensation compared to the other three interventions. The effect size of C (HC, MgS) and WBC groups is 2.011 (1.290, 1.377). Meanwhile, interventions of HC and MgS could also help to increase thermal sensation compared to the control group. This is quantified by the effect size of the pair of C and HC (MgS), as 0.721 (0.634). As also seen in Figure 2, the difference among the four interventions is dominated by Group WBC.

RPE Except the pair of HC and WBC groups, we observed no significant difference in other pairs of interventions. Interestingly, the difference between HC and WBC groups was slight but significant ($p < 0.05$). It is clear that interaction between time and type of interventions is completely driven by the difference between the HC and WBC groups. Our results suggested that the WBC could help to slightly lower RPE. However, a much larger sample size is necessary in future study to verify this result.

In summary, intervention of WBC could significantly lower TW and the scale of TS. Meanwhile, interventions of HC and MgS could also help in lowering TW and scale of TS, but less effectively compared to WBC. Our result suggests a slight difference in RPE between interventions of HC and WBC. WBC is the dominant factor in causing the difference among the interventions. Based on these results, we suggested that WBC could be used to prevent dropout cases in sport and could further facilitate continuation of training programs. On the other hand, interventions of HC, WBC, and MgS have no statistically significant effects on the variables of La, NH3, HR, and on the rowing output power and speed.





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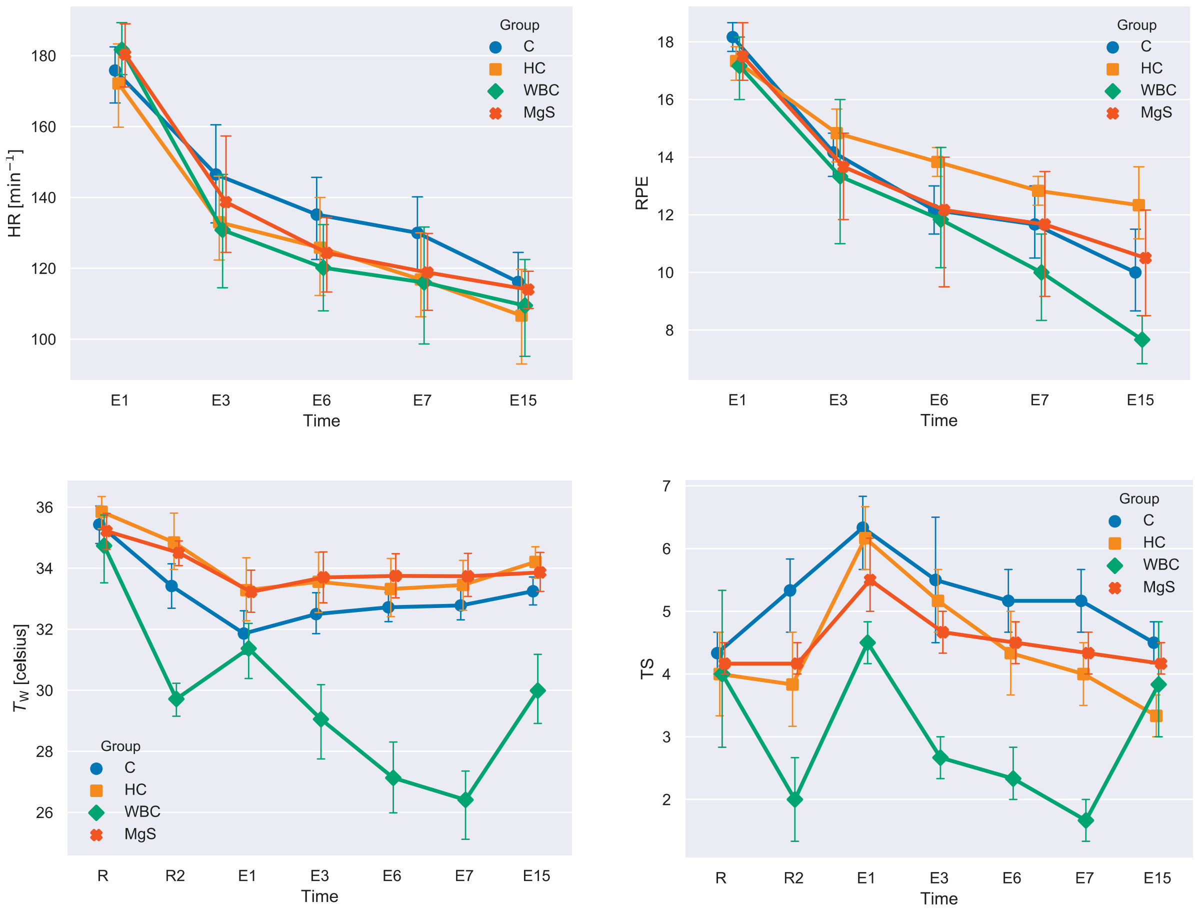

Figure 2. Measurements of (a) La, (b) NH3, (c) HR, (d) RPE, (e) TW, and (f) TS as a function of intervention and time. Data points and error bars are, respectively, the mean and the standard deviation of measurements among subjects in the group. Different groups are marked by different colours, as shown in the box.

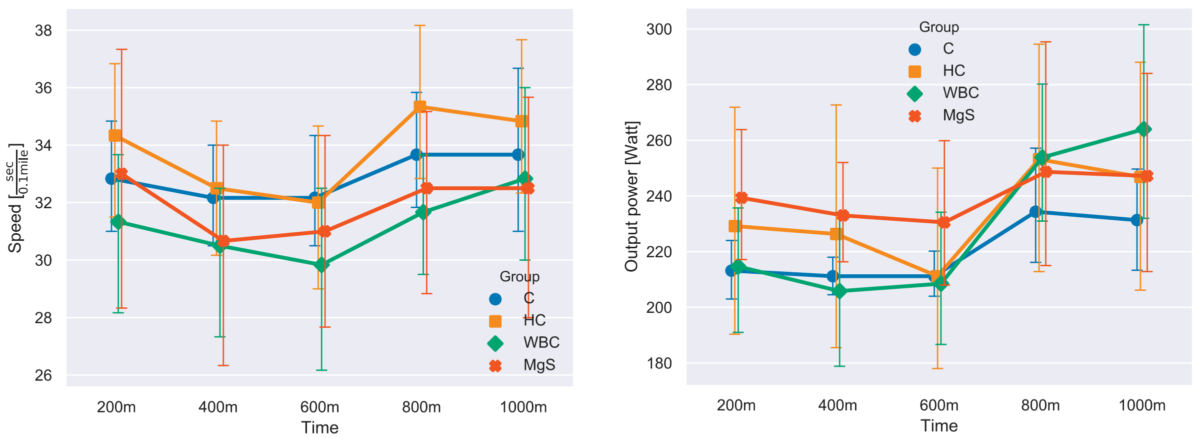

Figure 3. Rowing performance in terms of (a) output power and (b) speed as a function of intervention group in every 200 m. Data points and error bars are, respectively, the mean and the standard deviation of measurements among subjects in the group. Different groups are marked by different colours, as shown in the box.

Table 3. Measurements of Tw, TS, and RPE

Parameter	Pair of interventions		p–value of Tukey's test	effect size (Hedges' g)
Tw	C	HC	0.090754	-0.505
	C	MgS	0.137496	-0.466
	C	WBC	< 0.001	1.815*
	HC	MgS	0.900000	0.040
	HC	WBC	< 0.001	2.320*
	MgS	WBC	< 0.001	2.281*
Ts	C	HC	0.004948	0.721*
	C	MgS	0.018306	0.634*
	C	WBC	< 0.001	2.011*
	HC	MgS	0.900000	-0.087
	HC	WBC	< 0.001	1.290*
	MgS	WBC	< 0.001	1.377*
RPE	C	HC	0.609819	-0.306
	C	MgS	0.900000	0.041
	C	WBC	0.449297	0.378
	HC	MgS	0.519952	0.347
	HC	WBC	0.037640	0.684*
	MgS	WBC	0.542420	0.337

Results of Tukey's post hoc test on variables (TW, TS, and RPE), which showed statistically significant interaction between the within-group factor (time) and the between-group factor (type of interventions). Second and third columns show pairs of interventions, with p-value from Tukey's test shown in the fourth column. Fifth column presents Hedges' g effect size. Star indicates the pair which has difference in parameter at a statistically significant level ($p < 0.05$).

Discussions

Below we are discussing our results together with the findings in the literature. In the present study, we found that the cooling intervention of WBC could lower temperature TW and significantly improve TS of the athletes ($p < 0.05$). Meanwhile, intervention of HC and MgS significantly improved TS, but not TW, of the subjects. Additionally, WBC had the strongest effect on the TW and TS among those three interventions. We did not observe statistically significant effects in response to these three interventions (HC, WBC and MgS) on other objective outcomes, such as La, NH3 and RPE, as well as the sport performance in terms of rowing power and speed. Thus results suggest that interventions of HC, WBC and MgS improve primarily subjective outcomes of athletes.

Potential role of cooling

During exercise – depending on the intensity – La can accumulate, which could lead to unbalanced biochemical reactions limiting the sport performance (Ahmad et al., 2019; Liesen, 1983). Meanwhile, level of NH3 in blood is typically used to distinguish whether an athlete is physically fatigued. The combination of the La and NH3 measurements gives quantitative assessments on athletes, especially in the recovery period after exercises. Body temperature has been considered to be the deciding factor in affecting these parameters. Thus, one of the proposed methods to reduce accumulation of lactate is to lower body temperature in order to avoid heat stress (Kenney et al., 2019). So, intervention of cooling in various

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forms (see review article of (Bongers et al., 2017) was suggested to improve thermoregulation of athletes (Reilly et al., 2006).

Although some studies suggest that cooling could effectively reduce the level of La and NH3, we did not observe any statistically significant effect in response to HC and WBC in the present study. Our results are in line with those of Hohenauer et al (Hohenauer et al., 2015), showing no evidence that cooling improves recovery parameters, such as blood lactate, in various exhaustive exercises. This finding is in good agreement with the recent work of (Krueger et al., 2019), where they found no effects of WBC on improving objective outcomes after the running exercise. Our result is also in agreement with those of James et al. (James et al., 2015), who found no improving effect of external cooling on running speed at a fixed level of La. Also, that both internal and external pre-cooling interventions could significantly reduce TS (James et al., 2015), which is consistent with our finding. It is worth mentioning that Wilson et al (Wilson et al., 2018), found that WBC has a negative impact on muscle function compared to those with cooling by cold water immersion. That is, WBC appears not to be the most ideal way to improve sport performance or other objective outcomes.

However, magnitude of cooling effect on objective outcomes depends on several factors, such as nature of sports or the way intervention is conducted. Tyler et al. (Tyler et al., 2015) found that pre-cooling intervention could reduce performance of sprint exercises, while performance of prolonged exercises could be improved. Meanwhile, they also found that ambient temperature is the most important factor in determining the effect of cooling. Cooling during exercising could only improve sport performance at a statistically significant level in a warm or hot environment (Tyler et al., 2015; Wegmann et al., 2012). For example, a previous study (Kay et al., 1999) found that pre-cooling could efficiently reduce thermal strain and further increase the distance of cycling in a period of half hour in a warm environment (31°C). The fact that we carried out rowing experiment indoors in a cool environment (27°C) might be responsible for the finding that cooling did not induce improvements in sport performance. In other words, our results support the idea that cooling interventions do not have positive effects on sport performance in a non-hot environment. Nevertheless, we still observed that cooling interventions could significantly lower TW or improve TS compared to other groups even in a non-hot environment. This implies that training conducted in a non-hot environment would still benefit by cooling interventions to avoid exercise-induced heat stress or thermoregulatory failures of athletes.

Limitations of the study: The ambient temperature was lower than 27 °C on each day in our experiments, which did not present an extreme hot condition. Thus, we assumed that subjects were not heat acclimatized.

Potential role of magnesium

Interestingly, a recent study (Siquier-Coll et al., 2019) found that exercise in warm conditions could result in a re-distribution of magnesium in the body, as opposed to normal temperature environments. As magnesium involved in many enzymatic reactions, a deficiency of magnesium – especially caused by high temperature – may reduce sport performances. A meta-analysis (Heffernan et al., 2019) summarized that supplementation of magnesium and iron – among other minerals and trace elements – is able to improve athletic performance. On the other hand, others claimed (Finstad et al., 2001) that the effects of magnesium supplementation found by previous work largely depend on many factors, such as exercise modes and/or selection of subjects. Therefore, they concluded that there is no sufficient evidence supporting the idea that magnesium supplementation has positive effects. Nevertheless, to draw a definite conclusion, a more thorough study with careful control of the experiments is clearly warranted in the future.

It is important to mention that duration and amount of Mg dosage also play an important role in determining its effect (Finstad et al., 2001). In the present study, we did not observe any positive effect of MgS on measured objective outcomes compared to control group. One explanation is that supplementation of magnesium took place only one hour before exercise, which is substantially shorter than a 4 weeks-period used in previous work. For example, Setaro (Setaro et al., 2014) found that magnesium supplementation over a period of four weeks could improve anaerobic metabolism by decreasing lactate production in volleyball players, whereas others (Çınar et al.,

2006) also found that magnesium supplementation of four weeks period similarly decreased the level of La in case of Tae-Kwan-do sport. Thus our results together with that of literature data suggest that intake of magnesium must be regularly taken – at least over a long period as multiple weeks – in order to achieve positive effect on objective outcomes in sport performance.

Conclusion

We investigated the effects of three interventions, such as hand cooling (HC), whole-body cryotherapy (WBC) and supplementation of magnesium (MgS) on acute high-intensity exercise, specifically, on 1000 m indoor rowing. We have found that WBC lowered body temperature, but other than that, these interventions did not elicit positive effects on objective performance of 1000 m indoor rowing, (for example, plasma lactate level compared to control group). However, WBC HC and MgS improved the subjective outcome, i.e. thermal sensation of subjects. This is likely due to the fact that 1000 m rowing took place in a low ambient temperature indoor environment, suggesting that positive effect of cooling, if exists, can only be present in a warm, or hot environment.

The finding that magnesium supplementation had no effects on objective outcomes of 1000 m indoor rowing is likely be explained that Mg was applied just before the exercise. Thus studies with supplementation of magnesium must be conducted on a regular basis over a long period of time, multiple weeks before high intensity exercise. The interesting finding that intake of magnesium one hour before rowing improved thermal sensation of subjects could be due to a placebo effect.

In addition, ambient temperature of the environment where experiments or sport activities are planned is an important factor to be considered for studying the beneficial effects of various cooling interventions in future studies. By highlighting these issues, we believe that present study paved the way for future experimental studies regarding the role and modulation of thermal stress in exercise and sport activities.

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