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Research article

Intermittent Cooling Reduces Perceived Exertion but Has No Effect on Baseball Hitting or Defense Performance in a Hot Environment

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Abstract

Hot environments can impair the complex cognitive functions that are crucial to baseball hitting and defense. This study investigated the effects of intermittent forehead and neck cooling on the hitting and reactive agility of baseball players in hot environments. Ten male collegiate baseball players played 7-inning intrasquad games in a hot environment (31.1°C - 33.4°C), completing one cooling and one control trial in a randomized crossover design. In the cooling trial, the participants placed ice-cold towels on their forehead and neck for 3 min during offensive half innings. Hitting and reactive agility tests, a go/no-go task, and the Stroop Color and Word Test were administered before and after each game. The games in the hot environment significantly increased rectal temperatures to the same level in the control (38.15°C ± 0.31°C, $p < 0.001$) and cooling (38.08°C ± 0.24°C, $p < 0.001$) trials. Intermittent cooling significantly reduced forehead and tympanic temperatures, perceived exertion, and thermal sensation during the game. Swing power significantly increased after the game, but the exit velocity of batted balls did not significantly differ in both trials. Reactive agility was significantly impaired after the game in the control trial (before: 0.367 ± 0.109 s, after: 0.491 ± 0.212 s, $p = 0.008$) but displayed a trend of decrease in the cooling trial (before: 0.390 ± 0.183 s, after: 0.518 ± 0.282 s, $p = 0.066$). The game and cooling intervention had no significant effects on the reaction time or error rate in the go/no-go task and Stroop Color and Word Test. The results showed that intermittent cooling during a baseball game in a hot environment reduces perceived exertion and thermal sensation but has no significant effect on hitting, defense performance, or cognitive function.

Key words: Reactive agility, swing power, exit velocity, cognitive function, forehead and neck cooling, go/no-go task.

Introduction

Baseball is usually played outdoors during warm months. Hot environments can impair complex cognitive functions (Schmit et al., 2017). It has been shown that visuo-motor tracking performance was reduced after exercising in a hot environment (Piil et al., 2017). It is estimated that an increase of 1°Cin core temperature would delay complex visuo-motor reaction time by 40 ms in collegiate football players (Bandelow et al., 2010). Hitting requires high levels of visual–motor skills and inhibitory control (Laby et al., 2018; Takeuchi and Inomata, 2009). Batters must anticipate the trajectory of the pitched ball with optimal eye movements and make quick and accurate decisions about the timing and direction of their bat swing. Batters also require inhibitory control mechanisms to prevent themselves from swinging the bat when the pitched ball is not within the strike zone or cannot be hit with decent contact. Therefore, an elite baseball player's cognitive load is high during the trajectory prediction and execution processes because the cerebral cortex and medial and lateral cerebellar networks are activated (Owens et al., 2018). Superior visual–motor reaction times, trajectory prediction, and inhibitory control are associated with improved hitting performance in elite baseball players (Laby et al., 2018; Owens et al., 2018). Due to the high cognitive demands, it is possible that hitting performance could be deteriorated in hot environments, although the empirical data is lacking.

All batters except designated hitters must play defense. However, the literature has overlooked defense performance and abilities affecting it. Baseball defense requires a high level of reactive agility, that is, a perceptual decision-making process in response to a stimulus leading to a change in the speed or direction of body movement (Sheppard and Young, 2006). Reactive agility in response to sport-specific stimuli is a separate ability from the agility involving planned direction changes (Scanlan et al., 2016). Cognitive function is the major determinant of reactive agility, and hamstring strength is the major predictor of performance in conventional agility test (Naylor and Greig, 2015). Reactive agility tests using a live opponent as the target can distinguish players by performance level in team sports, whereas the 10-m sprint and conventional agility tests cannot (Henry et al., 2013; Serpell et al., 2010; Sheppard et al., 2006). These results highlight the importance of reactive agility in team sports.

Several cooling methods have been developed to alleviate the impairments in muscular and cognitive function that occur in hot environments (Tyler et al., 2015). Reducing regional skin temperature during exercise, breaks, or timeouts can alleviate the negative effects of hyperthermia on muscular and cognitive performance (Lee et al., 2014; Schlader et al., 2011a, 2011b). Cooling the forehead and neck in particular may be especially effective for thermoregulation because these regions are more sensitive to cold than arms and legs are (Cotter and Taylor, 2005). A meta-analysis revealed that cooling the head and neck during exercise significantly improved exercise performance despite no changes in core temperature or heart rate (Douzi

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et al., 2019). Other studies have also reported that cooling the neck during exercise in hot environments alleviated declines in cognitive function and physical performance. These effects were mediated by reduced perceived exertion and thermal sensation because no changes in core temperature or other physiological variables were observed (Lee et al., 2014; Sunderland et al., 2015).

Cooling during baseball games can be practical because of the alternation between defense and offense each half inning. Several studies have reported positive effects of intermittent cooling on core temperature, heart rate, and perceived exertion in catchers and on pitch velocity in pitchers in hot environments (Bishop et al., 2016; Bishop et al., 2017). However, the effects of intermittent cooling on crucial factors for game outcomes, such as hitting and defense performance, have not been examined. The aim of this study is to investigate the effect of intermittent cooling of the forehead and neck in hitting and defense performance in collegiate baseball players. Cooling with cold towels was selected for its practicality and convenience.

Methods

Experimental approach to the problem

This study used a randomized crossover design to minimize the individual difference among the participants. Each participant completed a cooling trial and a control trial in a random order, separated by a 20-day washout period. Each trial included a 7-inning intrasquad game played in a hot environment. Intermittent cooling was applied in offensive half innings to simulate real game situations. Hitting, reactive agility, and cognition were tested before and after the game. Exit velocity of batted balls was used as an indicator for hitting performance. The time from bat–ball contact to the participant's first definitive defensive movement in the intended direction was used as an indicator for reactive agility. Cognitive functions were estimated with go/no-go task and the Stroop Color and Word Test (SCWT). Go/no-go task was selected because of its similarity to baseball hitting. Rectal, forehead skin and tympanic temperatures were measured to estimate the effect of intermittent cooling on core and superficial temperature. Perceived exertion and thermal sensation were measured during the game to estimate the subjective effects of intermittent cooling.

Subjects

Ten male collegiate baseball players, consisting of five infielders and five outfielders, were recruited from National Taiwan University of Sport. The participants were aged 20.30 ± 0.48 years and had a height of 1.77 ± 0.04 m, weight of 79.09 ± 8.32 kg, and body mass index of 25.27 ± 2.09 kg/m^2. All participants had at least 6 years of experience in baseball training and had competed nationally. All participants were heat acclimatized from outdoor training in spring and summer before this study. Participants were excluded if they had cardiovascular or other known chronic diseases, were taking any medication, or had experienced musculoskeletal injury in the preceding 2 months. The participants were encouraged to maintain their regular training schedules and lifestyles during the study period. All participants provided written informed consent after the experimental procedure and potential risks were explained by research personnel. The study protocol was approved by the Antai-Tian-Sheng Memorial Hospital Institutional Review Board (18-076-A) and registered in ClinicalTrials.gov (NCT05068804).

Procedures

The experimental procedure is illustrated in Figure 1. The participants arrived at the baseball stadium at National Taiwan University of Sport at 07:00 after an overnight fast. The participants consumed a standardized breakfast comprising 1.2 g/kg white bread, 0.1 g/kg jam, 0.1 g/kg butter, and 5 mL/kg soybean milk (6.2 kcal/kg, containing 1.0 g/kg carbohydrate, 0.24 g/kg protein, and 0.14 g/kg fat). After finishing breakfast, the participants' had their rectal temperatures measured and completed a go/no-go task and the SCWT. After the cognitive tests, the participants moved to the field for self-selected warmups followed by the hitting and reactive agility tests. After the intrasquad game, the participants had their rectal temperatures measured, then repeated the hitting, reactive agility, and cognitive tests. The reactive agility test was carried out after all participants had finished hitting test. The participants sat in the shaded dugout while waiting for their turns in hitting and reactive agility tests. The participants could drink water ad libitum during the experimental period.

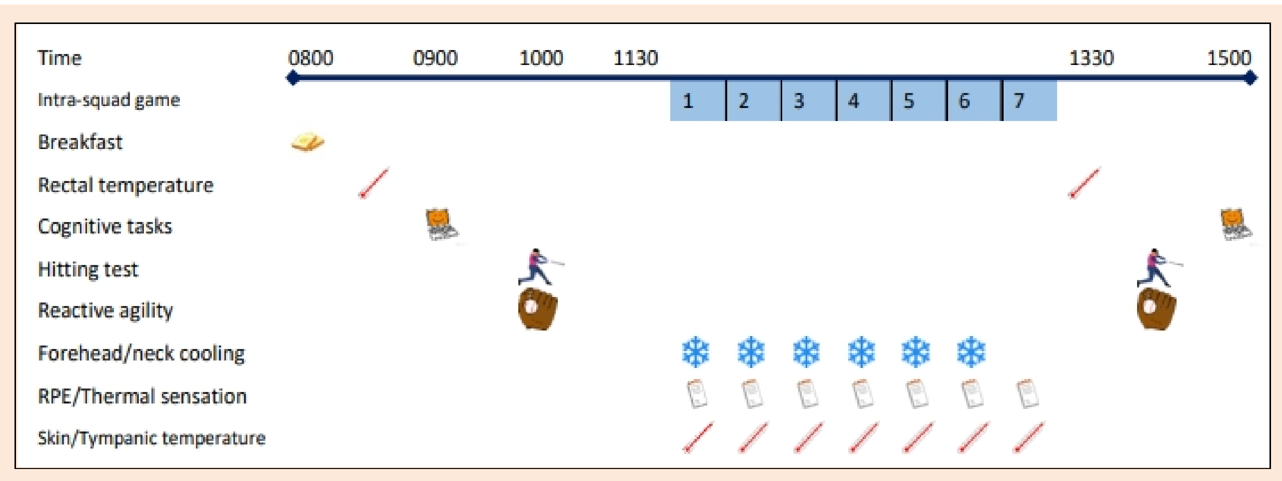

Figure 1. **Experimental procedure. No forehead/neck cooling in the control trial.**

Intrasquad game

One intrasquad game was played in mid-August while the other was played in early September. The 7-inning intrasquad games were played under the standard rules of baseball. Among the participants, two infielders and three outfielders were assigned to one team, and the remaining three infielders and two outfielders were assigned to the opposing team. The batting order of the participants in both games was identical and determined by the head coach. Pitchers in both games were the best available ones at that time. Pitchers was encouraged to perform with their best effort and replaced when their individual pitch count limits were reached. The games were played from approximately 11:30 to 13:30. Both games were played under similar environmental conditions (temperature 31.1°C - 33.4°C, humidity 63% - 67%).

Cooling intervention

The participants in the cooling trial put cold towels on their forehead and neck for 3 min in the shaded dugout during the offensive half innings in which they were not scheduled to make a plate appearance. Each participant received the cooling intervention three to four times during the game. After each use, the towels were completely immersed in a cooler containing water mixed with ice cubes and 1 kg table salt. There were ice cubes in the cooler at the end of the game. The participants in the control trial sat in the shaded dugout without any cooling intervention.

Temperature measurement

Rectal temperature was measured before breakfast and after each game with a digital thermometer (MT-B162, Geon Corp, Changhua, Taiwan) fitted with a disposable sheath for rectal use. Forehead skin and tympanic temperatures were measured with infrared thermometers (TD-1115 and TD-1118, respectively, FORA, New Taipei City, Taiwan) during the offensive half innings the participants spent in the dugout. In the cooling trial, forehead skin and tympanic temperatures were measured after the localized cooling interventions.

Hitting Test

The hitting test was administered before and after the intrasquad game. Participants used their own bats to hit balls launched from a pitching machine positioned 12 m from home plate. The ball speed was approximately 120 km/h. Participants were asked to try their hardest to hit the balls. Each test contained 15 batted balls. The participants could decide not to swing if they felt they could not make satisfactory contact. The exit velocity of each ball was measured immediately after contact with the bat by KarmaZone, an automated ball-tracking camera system installed in the stadium. The results from KarmaZone have been validated against the radar tracking system (Trackman, Vedbæk, Denmark) used by Major League Baseball (https://artomotion.tech/karmazone-electronic-strike-zone-for-baseball/). Swing power was measured with a sensor attached to the knob of the bat (Swingtracker, Diamond Kinetics, Pittsburgh, PA, USA).

Reactive agility test

The reactive agility test was administered before and after the intrasquad game. The infielders fielded ground balls at the shortstop position, and the outfielders fielded fly balls in center field. The same coach hit balls to the participants' left or right side. The participants were asked to move toward the ball as soon as they had determined the trajectory and to make a maximal effort to catch it. Each test contained 15 batted balls. The entire testing procedure was recorded at 30 fps using a digital video camera (GZ-F170, JVC, Yokohama, Japan). An experienced coach calculated the reaction time, that is, the time from bat–ball contact to the participant's first definitive movement in the intended direction, post hoc through frame-by-frame analysis of the video footage (Hopwood et al., 2011) using Avidemus 2.7.6 (http://fixounet.free.fr/avidemux/). Reaction times longer than 1000 ms were excluded from analysis because the balls might have been hit too close to the participant so that only slow, slight movement was required.

Cognitive tests

The go/no-go task and SCWT were administered on a laptop computer in a quiet room. The room temperature was approximately 28°C. Reaction times shorter than 100 ms or longer than 1500 ms were excluded (Malcolm et al., 2018).

Go/no-go task

The go/no-go task consisted of 75 go stimuli and 25 no-go stimuli presented in a random order. The participants were instructed to press the space bar as fast as possible when they saw a red dot (go stimulus) appear inside a 7.6 × 7.6 cm^2 square in the center of the screen. Reaction times for only correct go stimuli were used for analysis.

SCWT

The SCWT comprised 25 congruent and 75 incongruent stimuli presented in a random order. The reaction time and error rate for the congruent and incongruent stimuli were calculated separately. Reaction times for only correct responses were used for analysis.

Perceived Exertion and Thermal Sensation

The participants reported their perceived exertion and thermal sensation during their offensive half innings. Perceived exertion was rated on the 10-point Borg scale, and thermal sensation was estimated with a 7-point ASHRAE scale from -3 (coolest) to 3 (hottest) (Ekici and Atilgan, 2013).

Statistical analyses

The data are presented as mean ± standard deviation. The normality of each variable was analyzed using the Shapiro–Wilk test. The variables before and after the intrasquad game in the same trial were compared using the paired-sample t test if the data were normally distributed or the Wilcoxon signed-rank test if they were not. Reactive agility in infielders and outfielders were analyzed separately as well as after pooling. Forehead skin temperature, tympanic temperature, ratings of perceived exertion (RPE), and thermal sensation between the same inning of the two trials were compared using the related-sample Wilcoxon signed-rank test. Statistical analyses were performed using SPSS version 20.0 (IBM, Armonk, NY, USA). A *p* value of

<0.05 was considered statistically significant. The effect size (ES) of paired-sample t test was calculated using Cohen's d, which was interpreted with values representing trivial, >0.20; small, 0.21 to 0.59; moderate, 0.60 to 1.19; large, 1.20 to 1.99; and very large, ≥2.0 (Cohen, 1992).

Results

The intrasquad game in the hot environment significantly increased rectal temperatures to approximately the same level in the control (38.15°C ± 0.31°C, $p < 0.001$, ES = 4.25) and cooling trials (38.08°C ± 0.24°C, $p < 0.001$, ES = 3.36; Table 1). Forehead and neck cooling significantly reduced forehead skin temperatures in the third, fourth, and sixth innings and tympanic temperatures in the third inning (Figure 2). The cooling intervention resulted in lower RPE in the third and sixth innings and lower thermal sensation in the fifth and sixth innings (Figure 2).

Swing power in the hitting test had significantly increased after the game in both trials (control trial: $p = 0.048$, ES = 1.28; cooling trial: $p = 0.016$, ES = 1.06), but no significant difference between trials was observed (Table 1). Despite the increases in swing power, the exit velocity of the batted balls did not change in either trial (Table 1).

Reactive agility in the infielders and all participants combined was significantly slower after the game in the control trial (infielders: $p = 0.043$; all participants: $p = 0.008$; Table 1). In the cooling trial, the participants showed an insignificant trend of deterioration after the game ($p = 0.066$, Table 1). No significant difference was observed between the two trials in reactive agility. Neither the game nor cooling intervention had a significant effect on reaction time or error rate in the go/no-go task or SCWT (Table 2).

Discussion

Intermittent cooling of the forehead and neck between the innings of a baseball game played in a hot environment resulted in significantly lower RPE and thermal sensation in collegiate players. However, the cooling intervention had a nonsignificant effect on hitting performance, reactive agility in defense, and cognitive function as measured by the go/no-go task and SCWT.

Reducing regional skin temperature can lower heart rate, RPE, and thermal discomfort during exercise in hot environments, despite high core temperatures (Armada-da-Silva et al., 2004; Mundel et al., 2007). Additionally, face cooling resulted in significantly greater self-paced cycling power output than did no cooling or heating of the face, indicating that thermal sensation and thermal discomfort are major determinants of exercise intensity (Schlader et al., 2011a). Short periods of intermittent cooling during baseball competitions have been employed to alleviate thermal strain and improve performance. Collegiate baseball catchers who wore a cooling vest between innings during simulated games in a heat chamber exhibited significantly fewer elevations in core temperature, heart rate, and RPE (Bishop et al., 2017). Moreover, cooling the shoulders and arms between innings has attenuated the decline in pitchers' pitch velocity, improved perceived recovery, and increased the number of total pitches thrown before fatigue onset (Bishop et al., 2016; Verducci, 2001). Our results also demonstrated that intermittent cooling of the forehead and neck significantly alleviated thermal sensation and RPE in baseball players. It has been shown that lower thermal sensation resulted in higher self-selected exercise intensity in hot environments (Schlader et al., 2011b). It is possible that intermittent cooling will allow baseball players to execute higher exercise intensity in critical situations during the game. In addition, lower RPE may help to alleviate the psychological stress in professional baseball players who played multiple games in summer months.

Intermittent cooling has also been applied to other sports. Cooling the head and neck during 90 - 120-s breaks reduced increases in core and skin temperature, RPE, and heart rate in tennis players during high-intensity intermittent running in a hot and humid environment (Schranner et al., 2017). Cooling the neck for 1 min between table tennis

Table 1. Rectal temperature, exit velocity, swing power in the hitting test and reaction time in the reactive defense test before and after the intrasquad game in the control and cooling trials.

	Control		Cooling	
	Before	After	Before	After
Rectal temperature (°C)	36.61 ± 0.17	38.15 ± 0.31*	36.62 ± 0.28	38.08 ± 0.24*
Swing power (W)	56.42 ± 3.93	58.48 ± 3.20*	56.36 ± 4.40	58.01 ± 3.68*
Exit velocity (km/h)	131.76 ± 5.93	133.31 ± 7.59	130.11 ± 7.20	131.96 ± 6.59
Reactive agility (s)				
Infielders	0.286 ± 0.052	0.325 ± 0.061*	0.278 ± 0.037	0.290 ± 0.029
Outfielders	0.449 ± 0.086	0.657 ± 0.170	0.503 ± 0.206	0.748 ± 0.217
All	0.367 ± 0.109	0.491 ± 0.212*	0.390 ± 0.183	0.518 ± 0.282

*$p < 0.05$, significantly different from before the game in the same trial.

Table 2. Results of go/no-go task and Stroop Color and Word Test before and after the intrasquad game in the control and cooling trials.

			Control		Cooling	
			Before	After	Before	After
Go/no-go task		Reaction time (s)	0.343 ± 0.038	0.330 ± 0.018	0.344 ± 0.022	0.327 ± 0.019
		Error rate (%)	1.20 ± 1.32	2.10 ± 1.52	1.70 ± 1.57	1.50 ± 1.58
Stroop test	Congruent	Reaction time (s)	0.720 ± 0.101	0.719 ± 0.100	0.729 ± 0.106	0.740 ± 0.088
		Error rate (%)	0.90 ± 1.10	0.90 ± 1.52	0.70 ± 0.82	1.20 ± 0.92
	Incongruent	Reaction time (s)	0.765 ± 0.129	0.751 ± 0.114	0.793 ± 0.090	0.763 ± 0.099
		Error rate (%)	2.40 ± 2.41	2.20 ± 2.04	2.20 ± 2.35	4.00 ± 3.09

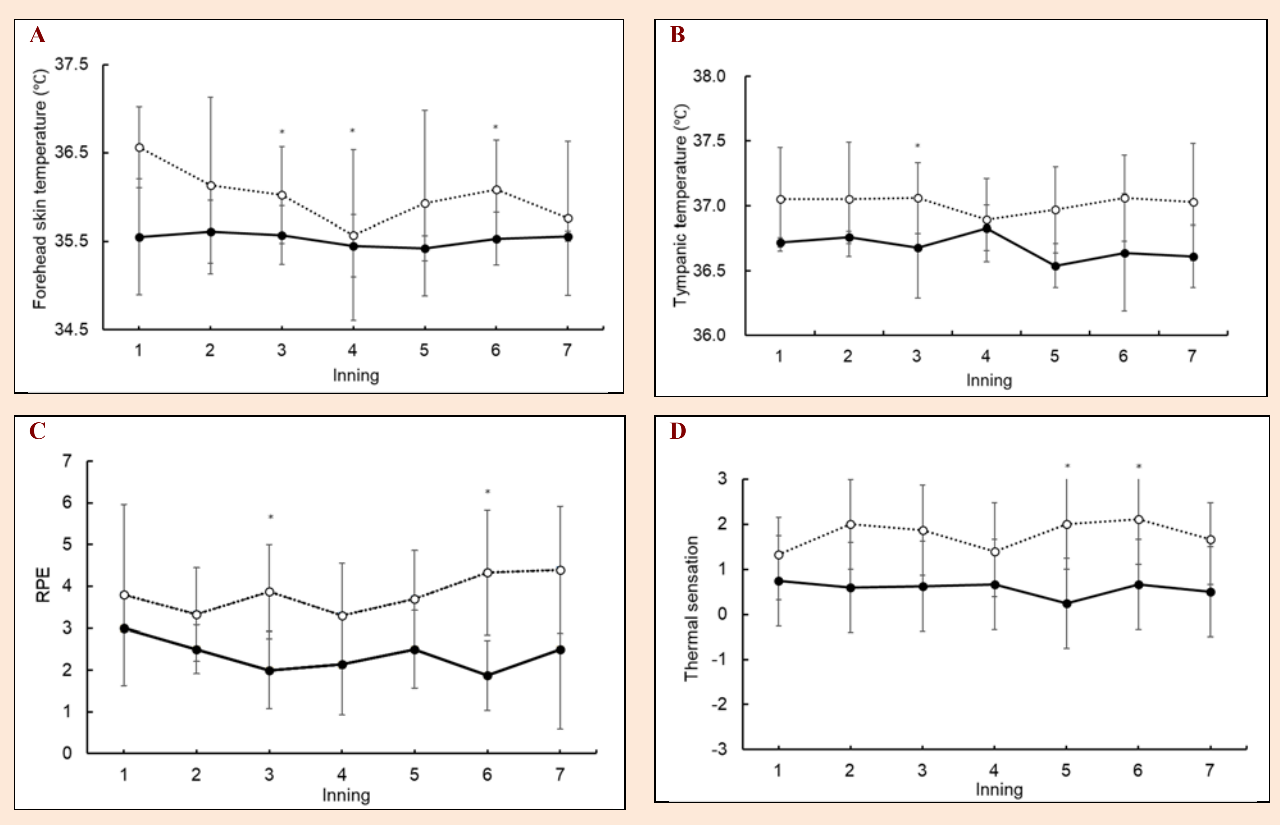

Figure 2. (A) Forehead skin temperature, (B) tympanic temperature, (C) rating of perceived exertion, (D) and thermal sensation during the intrasquad baseball game in the control (○) and cooling (●) trials. * $p < 0.05$, significant difference between the control and cooling trials in the same inning.

games also lowered thermal sensation and increased sport-specific skill performance, as indicated by the number of balls hit to predetermined targets, even in a mild environment (average temperature 21.3°C) (Desai and Bottoms, 2017).

This study revealed that swing power was significantly higher after the game in both trials. The muscles that contribute to swinging the bat are possibly further activated when the muscle temperature increases after exposure to heat (Mallette et al., 2021). However, the increases in swing power did not result in a higher exit velocity of batted balls, possibly because the participants made less optimal bat–ball contact. The less optimal contact may result from impaired trajectory prediction and swing execution process after exposure to heat. However, these baseball-specific cognitive functions cannot be measured with computer-based tests such as go/no-go task and SCWT.

Reactive agility tests using sport-specific stimuli have acceptable reliability in team sports such as softball and rugby (Gabbett et al., 2007; Morral-Yepes et al., 2021; Oorschot et al., 2017). Reactive agility tests have high validity because they can distinguish players of varying skill levels and preplanned change of direction tests cannot (Gabbett et al., 2008; Scanlan et al., 2015). Cognitive function plays a crucial role in the reaction time and response accuracy in reactive agility tests (Naylor and Greig, 2015). The present study measured players' reaction times between the bat's contact with the ball and the first identifiable movement toward the trajectory of the batted ball. This reactive agility test simulates infielders' and outfielders' defensive movements in real games. Reaction time was significantly slower after the game in the hot environment, and cooling had no significant effect. Delayed defender reactions may affect the outcome of the game, especially in a hot environment. However, the SCWT results did not differ significantly after the game in either trial. Cognitive tasks in nonsport situations, therefore, may not reflect the cognitive requirements of real baseball games. Our results are consistent with those obtained from softball tests: infielders display superior reactive agility to that of outfielders (Gabbett et al., 2007). Infielders require a faster response to field groundballs hit in various directions; therefore, our results are sensible. Our infielders had similar reaction times to cricketers in a fielding test (average 0.221–0.270 s) (Hopwood et al., 2011). To our best knowledge, this is the first study that investigated the effect of hot environments in reactive agility. The impaired reactive agility after the game in both trials suggested that more aggressive cooling interventions, such as increasing the frequency of cooling or combing with ingesting cold drinks, might be required in hot environments.

The local connectivity of functional brain networks decreases in hyperthermia, which can lead to cognitive impairment (Tan et al., 2018). However, studies have obtained mixed results regarding the effect of hyperthermia in go/no-go tasks, reporting that reaction times and error rates worsened (Ando et al., 2015) or were unaffected (Shibasaki et al., 2019) after strenuous exercise in a hot environment. Exercising to exhaustion in a hot environment reduced accuracy on incongruent SCWT trials (Watson et al., 2012). Another study, however, revealed that accuracy on incongruent SCWT trials declined over time during intermittent exercise at similar magnitudes in hot and cold environments in team sports athletes, but congruent SCWT reaction time and accuracy were not affected in either environment (Donnan et al., 2021). Intermittent cooling also exerted mixed effects on cognitive function in hot environments. Neck cooling reduced the decline in spatial span memory but had no effect on the impairment of pattern recognition memory (Racinais et al., 2008). Another study suggested that neck cooling was ineffective in attenuating impairment in working memory and declines in go/no-go results after strenuous exercise in warm and humid environments (Ando et al., 2015). Neck cooling may only enhance performance in complex cognitive tasks after exercise in a hot environment (Lee et al., 2014). The inconsistency in the effects of temperature on cognitive function may result from differences in exercise type and the timing of the cognitive tests (Lambourne and Tomporowski, 2010).

All of our participants had become acclimatized to hot environments throughout their years of baseball training. The average high temperature ranges between 30.1°C and 33.4°C while average humidity is 70.8%-77.4% from May to October in Taichung, Taiwan, where the experiment was carried out (Central Weather Bureau, 2022). The average core temperature after the games was approximately 38.1°C, a significant increase of approximately 1.5°C from the baseline. The magnitude of this increase was higher than that of baseball catchers who completed a 99-min simulated game in a heat chamber (Bishop et al., 2017). Participants' core temperature after the game was lower than the hypothesized threshold (approximate 38.5°C) for hyperthermia-induced impairment of cognitive function (Schmit et al., 2017). The acclimatization may be one reason that the performance in the go/no-go task and SCWT was unaffected. However, we did observe a decline in reactive agility, indicating a negative effect of heat or game-related stress on sport-specific cognitive function.

This study has several limitations. First, we attempted to simulate a real game as accurately as possible. Therefore, not all participants received the same number of cooling interventions because some were on base more often and spent less time in the dugout. This approach reflected the real baseball game situation, although it led to individual differences in total cooling time. Second, the stimuli we used in the hitting and agility tests were more difficult to control than those of standardized laboratory-based tests were. However, because these field-based tests simulated real game situations, the results of this study are probably more applicable to real competitions. Third, the participants took turns undertaking hitting, reactive agility, and cognitive tests after the intrasquad game. The delay between the end of game and the start of the hitting, reactive agility, and cognitive tests was different among the participants. Whether the additional recovery time after the game affected the outcomes in these tests is uncertain.

Conclusion

The results suggest that intermittent cooling of the forehead and neck during a baseball game reduces RPE and thermal sensation but does not affect hitting or defense performance or cognitive function in a hot environment. The decline in reactive agility after an intrasquad game in a hot environment warrants further investigation. Future studies may use baseball-specific tasks or data from real games to examine the effect of heat exposure and cooling.

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Key points

- Hot environments can impair the complex cognitive functions that are crucial to baseball hitting and defense.
- Intermittent cooling on forehead and neck using ice-cold towels during a baseball game in a hot environment significantly reduced forehead and tympanic temperatures, perceived exertion, and thermal sensation.
- Intermittent cooling had no effect on hitting performance, reactive agility in defense, and cognitive functions measured with go/no-go task and SCWT.

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