Obesity, but not hypohydration, mediates changes in mental task load during passive heating in females

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Background. The independent effects of hypohydration and hyperthermia on cognition, and mood is unclear since the two stresses often confound each other. Further, it is unknown if obese individuals have the same impairments during hyperthermia and hypohydration that is often observed in non-obese individuals. **Methods:** The current study was designed to assess the independent and combined effects of mild hypohydration and hyperthermia on cognition, mood, and mental task load in obese and non-obese females. Twenty-one healthy females participated in two passive heating trials, wherein they were either euhydrated or hypohydrated prior to and throughout passive heating. Cognition (ImPACT), mental task load (NASA-TLX), and mood (Brunel Mood Scale; BRUMS) were measured before and after a 1.0ºC increase in core temperature (T_C). **Results.** After a 1.0ºC T_C elevation, hypohydration resulted in greater (p<0.05) body mass loss (-1.14±0.48 vs -0.58±0.48 kg versus; hypohydrated and euhydrated, respectively) and elevation in serum osmolality (292±4 vs 282±3 mOsm; p<0.05) versus euhydration. Hypohydration, independent of hyperthermia, did not affect mental task load or mood (p>0.05). Hyperthermia, regardless of hydration status, impaired (~ 5 A.U) measures of memory-based cognition (verbal and visual memory), and increased mental task load, while worsening mood (p<0.05). Interestingly, obese individuals had increased mental task load while hyperthermic compared to the non-obese individuals (p<0.05) even while euhydrated. Hypohydration did not exacerbate any heat-related effects on cognition between obese and non-obese females (p>0.05). **Conclusion.** These data indicate that hyperthermia independently impairs memory-based aspects of cognitive performance, mental task load, and leads to a negative mood state. hypohydration did not exacerbate the effects of hyperthermia. However, obese individuals had increased mental task load during hyperthermia.

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23 Running Head: Hyperthermia, Hypohydration, and Obesity

25

27   **Abstract**

28   **Background.** The independent effects of hypohydration and hyperthermia on cognition, and

29   mood is unclear since the two stresses often confound each other. Further, it is unknown if obese

30   individuals have the same impairments during hyperthermia and hypohydration that is often

31   observed in non-obese individuals. **Methods:** The current study was designed to assess the

32   independent and combined effects of mild hypohydration and hyperthermia on cognition, mood,

33   and mental task load in obese and non-obese females. Twenty-one healthy females participated

34   in two passive heating trials, wherein they were either euhydrated or hypohydrated prior to and

35   throughout passive heating. Cognition (ImPACT), mental task load (NASA-TLX), and mood

36   (Brunel Mood Scale; BRUMS) were measured before and after a 1.0ºC increase in core

37   temperature (T_C). **Results.** After a 1.0ºC T_C elevation, hypohydration resulted in greater ($p<0.05$)

38   body mass loss (-1.14±0.48 vs -0.58±0.48 kg versus; hypohydrated and euhydrated, respectively)

39   and elevation in serum osmolality (292±4 vs 282±3 mOsm; $p<0.05$) versus euhydration.

40   Hypohydration, independent of hyperthermia, did not affect mental task load or mood ($p>0.05$).

41   Hyperthermia, regardless of hydration status, impaired (~ 5 A.U) measures of memory-based

42   cognition (verbal and visual memory), and increased mental task load, while worsening mood

43   ($p<0.05$). Interestingly, obese individuals had increased mental task load while hyperthermic

44   compared to the non-obese individuals ($p<0.05$) even while euhydrated. Hypohydration did not

45   exacerbate any heat-related effects on cognition between obese and non-obese females

46   ($p>0.05$). **Conclusion.** These data indicate that hyperthermia independently impairs memory-

47   based aspects of cognitive performance, mental task load, and leads to a negative mood state.

48   hypohydration did not exacerbate the effects of hyperthermia. However, obese individuals had

49   increased mental task load during hyperthermia.

50   **INTRODUCTION**

51   Military personnel, construction workers, and firefighters, are often exposed to

52   occupational heat stress. These environments may cause hypohydration in addition to

53   hyperthermia, resulting in decrements to physical and cognitive performance (Adam et al. 2008).

54   The decrements in cognitive performance may not only affect job productivity but may have

55   serious implications for the safety of these workers. Therefore, understanding the independent and

56   combined effects of hyperthermia and hypohydration on cognitive performance and mood may

57   provide valuable information for those individuals who live and work in warm environments.

58   Hypohydration is commonly induced with heat stress and/or exercise because the elevation

59   in core temperature induces fluid loss secondary to sweating. However, both heat stress and

60   exercise can independently affect cognition and mood (Tomporowski et al. 2007; Racinais et al.

61   2008). Therefore, a preferred methodology to independently examine the effect of hypohydration

62   is fluid restriction. Some investigators have shown that mild hypohydration, with approximately

63   1-3% body mass loss by fluid restriction, causes slower psychomotor processing speed, impaired

64   visual and spatial working memory, increased errors and skill impairments (Wilson et al. 2003;

65   Petri et al. 2006; Patel et al. 2007; Suhr et al. 2010; Smith et al. 2012; Lindseth et al. 2013).

66   Additionally, mood ratings, such as feelings of tiredness and reduced vigor are observed with

67   hypohydration (Shirreffs 2003; Szinnai et al. 2005; Patel, Mihalik et al. 2007; Pross et al. 2013).

68   However, another study reported no cognitive differences with mild hypohydration (~2%) when

69   fluid is restricted for 36-h (Szinnai, Schachinger et al. 2005).

70   Heat stress alone, even when hydration is maintained, can lead to cognitive impairments in

71   more precise measures of cognitive function such as visual processing, pattern recognition

72   memory, and spatial memory (Wyon et al. 1979; Gaoua et al. 2011b). Simpler tasks like measures

73   of attention are preserved (Gaoua, Racinais et al. 2011b). Many studies fail to report hydration

74   status and/or maintain euhydration. Therefore, the independent effect of heat stress, and thus

75   hyperthermia, is sometimes difficult to discern.

76   Increased body mass index (BMI) in healthy young individuals is correlated with impaired

77   executive function, attention, problem solving, memory, and mental flexibility (Gunstad et al.

78   2006; Gunstad et al. 2007; Fedor et al. 2013). Although there is a paucity of data with obese

79   individuals, some studies suggest obesity is linked with poorer cognitive performance compared

80   to lean controls (Boeka et al. 2008; Lokken et al. 2009; Lokken et al. 2010). Poor cognitive

81   performance may be exacerbated in obese individuals when heat stressed because of impaired

82   thermoregulatory control (Bar-Or et al. 1969; Buskirk et al. 1969; Tucker et al. 2017). However,

83   the independent and combined effects of hyperthermia and hypohydration on cognition and mood

84   in obese individuals have not been investigated. Obese individuals also appear to have alterations

85   in brain structure (Stanek et al. 2011) and function (Wolf et al. 2007) which may affect changes in

86   cognitive performance or mental task following certain stressors (Mehta 2015). Further, given one-

87   third of Americans are reported to be overweight or obese (Ogden et al. 2015), it is important to

88   understand how cognition and mood are effected when obese individuals are heat stressed and/or

89   hypohydrated.

90   Therefore, the purpose of this study was to examine the independent and combined effects

91   of mild hypohydration (i.e., <2% body mass loss) and hyperthermia on cognition, mental task load,

92   and mood in obese and non-obese individuals. We chose rather mild levels of hypohydration and

93   hyperthermia because there is dearth of information in this area, but preliminary evidence suggests

94   that mild hypohydration and hyperthermia may have cognitive (Ganio et al. 2011; Armstrong et

95   al. 2012) and physiological (Moyen et al. 2016; Tucker et al. 2018) effects. Likewise, these mild

96   levels are more likely to occur in everyday living. We hypothesized that mild hypohydration,

97   induced by 24-h of fluid restriction, and hyperthermia would impair cognition and increase the

98   mental effort necessary to complete a task, defined as mental task load (Hart et al. 1988).

99   Furthermore, we hypothesized that hypohydration would exacerbate hyperthermic-related

100 impairments. We also hypothesized that impairments would coincide with a worsening in mood

101 state (i.e. increased fatigue, lowered vigor, etc). Finally, we hypothesized that obese individuals

102 would have greater decrements both cognition, mental task load, and mood compared to non-obese

103 participants.

MATERIALS AND METHODS

105   Ten obese and 11 non-obese female adults from 18 to 35 years old from the University of

106 Arkansas and surrounding community were recruited for this study. A priori power calculations

107 were not performed prior to data collection, but post-hoc power can be estimated from the statistics

108 provided in the results. The University of Arkansas Institutional Review Board granted Ethical

109 approval to carry out this study within its facilities (IRB# 14-05-719). Prior to participation all

110 participants signed a written informed consent. Participants were excluded if they had a history of

111 any diseases that could affect body fluid balance, or if they had a history of psychiatric disease,

112 concussion, dyslexia, or attention-deficit/hyperactivity disorder. This study focused on female

113 participants considering the paucity of data within this population. Furthermore, participants were

114 excluded if they took drugs influencing body fluid balance (e.g., diuretics) or regularly consumed

115 the caffeine equivalent of greater than six cups of coffee each day. Those who had an irregular

116 menstrual cycle, as well as those using an intrauterine device, or progesterone only form of birth

117 control were excluded due to different hormone concentrations of estrogen and progesterone from

118 normally menstruating females. Participant characteristics are in Table 1.

119 **Experimental Design**

120   A randomized, repeated-measures design was used to determine the independent and

121 combined effects of hypohydration and hyperthermia on cognitive performance, mental task load,

122 and mood. Each participant completed a familiarization and two trials: one euhydrated and one

123 hypohydrated. The familiarization visit occurred within two weeks prior to the first trial. Before

124 each trial, participants participated in a 24-h hydration intervention (described below) before

125 having their core temperature increased 1.0ºC via passive heating. Trials occurred during the

126 follicular phase of the menstrual cycle (days 1-7). Menstrual cycle status was based on self-

127 reported start of menses. A minimum of 48-h. separated trials. The layout of each trial is in Figure

128 1.

129   INSERT FIGURE 1 HERE

130 **Measures**

131   *Brunel Mood Scale (BRUMS).* BRUMS is validated instrument, derived from the Profile

132 of Mood States, with 24-item Likert measures evaluating feelings of tension, depression, anger,

133 vigor, fatigue, and confusion (Terry et al. 1999). The Likert type items ask respondents to indicate

134 the extent to which they are experiencing these feelings. Items are anchored by "0 = Not at all",

135 and "4 = Extremely". The reference timeframe utilized was "How you feel right now".

136   *Immediate Post-Concussion Assessment and Cognitive Testing (ImPACT).* ImPACT

137 computerized neurocognitive test evaluates performance by measuring six neurocognitive

138 modules that assess memory, attention learning, processing speed and reaction time. Scores are

139 created from the six neurocognitive modules that yield four composite scores; verbal memory,

140 visual memory, visual motor processing speed, and reaction time in seconds. The ImPACT

141 baseline test is a stable measure of neurocognitive performance and minimizes practice effects

142 through the use of multiple versions. ImPACT provides randomization of stimuli in alternate forms

143 at the initial test session and all subsequent test sessions included different forms to minimize

144 practice effects. Overall, current evidence would indicate that the ImPACT does adequately

145 control for practice effects (Schatz et al. 2006).

146 *Mental Task Load.* A visual analog scale (VAS) of concentration and the NASA Task Load

147 (NASA-TLX) were utilized to quantify mental task load (Hart and Staveland 1988; Bijur et al.

148 2001). The VAS is a continuous scale with two extreme statements used as anchors at opposite

149 ends of a 100 mm line. The anchors used were "not at all strong(ly)" and "very strong(ly)". This

150 scale was used to assess concentration using the statement "How hard did you have to concentrate

151 to accomplish the tasks successfully?". The NASA-TLX utilized in this study measured subjective

152 workload for mental demands, temporal demands, mental performance, effort, and frustration. The

153 participant marks on a line, which represents a continuous scale for each of the previously

154 mentioned sub-scales.

155 *Measures of Hydration Status.* Four measures of hydration status were utilized in each

156 experimental trial: body mass change, serum osmolality (S_{OSM}), urine osmolality (U_{OSM}), and urine

157 specific gravity (U_{SG}).

158 Change in body mass was calculated from the baseline weight recorded as the average of

159 the three or more weights obtained by the participant as follows. Participants were sent home with

160 a scale (Model: IP-TITN-ZJXR, BalanceFrom) to record nude body weight at the same time,

161 relative to the start time of their trials, each day for three consecutive days to establish a baseline

162 body weight (Cheuvront et al. 2004). From this baseline, body weight, the amount of body mass

163 lost, or gained, during the 24-h hydration intervention (see below) was calculated. The percentage

164 of body weight change from baseline was used to determine percent hypohydration at the

165   beginning of each trial (i.e., before heating but after the 24-h hydration intervention) and after each

166   trial (i.e., after heating).

167   U_{SG} was measured via a refractometer (clinical refractometer 30005, SPER Scientific,

168   Scottsdale, AZ, USA). U_{OSM} and S_{OSM} were measured by freezing point depression (3D3

169   Advanced Instruments Osmometer, Model 3250, Norwood, MA, USA).

170   Previously determined cutoffs for body mass change (<1%), S_{OSM} (<290mOsm), U_{OSM}

171   (<700mOsm), and U_{SG} (<1.020) were used to define participants as euhydrated and participants

172   were required to meet three of the four criteria prior to starting a trial (Sawka et al. 2007).

173   *Thermal Measurements.* Skin temperature (T_{sk}) was measured via skin thermocouples

174   (Omega Engineering, Stamford, CT, USA) placed on the right anterior thigh (midway between the

175   greater trochanter and lateral condyle), chest (midway between the axilla and areola), lateral calf

176   (midway between the tibial condyle and malleolus), and upper arm. Mean-weighted T_{sk} was

177   calculated according to Ramanathan (Ramanathan 1964): $T_{sk} = 0.3(chest + arm) + 0.2(thigh +$

178   calf). A rectal thermister (Physitemp Inc., Clifton, NJ, Ret-1) was used to measure core

179   temperature (T_C). Mean body temperature (T_b) was calculated using T_C and T_{sk} (19): $T_b = 0.2(T_{sk})$

180    $+ 0.8(T_C)$.

181   **Familiarization**

182   Prior to experimental trials, participants underwent a familiarization visit. At this visit we

183   recorded the participant's body mass via a scale (Health-o-Meter® digital scale, model: 349KLX,

184   IL, USA), height via a stadiometer (Seca, model: 7701321004, Vogel & Hamburg, Germany), and

185   body composition via dual x-ray absorptiometry (DXA, General Electric®, Lunar Prodigy Promo).

186   Participants were classified as lean if their body fat was <32% whereas a body fat of >39% was

187   classified as obese (Gallagher et al. 2000).

188   Participants were then familiarized with the BRUMS, ImPACT, the VAS for

189   concentration, and the NASA-TLX. Participants were sent home with a scale to establish a baseline

190   body weight as described above (Cheuvront, Carter et al. 2004).

191   **Experimental Trials**

192   For the 24-h prior to each experimental trial, participants underwent a hydration

193   intervention. For the first trial participants kept diet and fluid logs and replicated the diet portion

194   (i.e., calories) for the subsequent trial. During the euhydrated trial participants were encouraged to

195   consume adequate fluid, including an extra 950 ml the night prior to the trial and 475 ml ~2 hours

196   before the trial. Also, during passive heating for the euhydrated trial, participants consumed 37.5ºC

197   water to maintain euhydration. For the hypohydrated trial participants were given a 250 ml bottle

198   of water and asked to refrain from all other fluids and high moisture content foods (e.g., soup and

199   fruits) for the 24-h prior to laboratory arrival. Furthermore, no fluid was ingested throughout

200   passive heating.

201   Prior to each experimental trial participants refrained from alcohol and exercise for 24-h,

202   food for 4-h, and caffeine for 8-h. After the 24-h fluid intervention, and upon arrival to the

203   laboratory, pre-test compliance was verified with a 24-h history questionnaire. Participants then

204   used a private bathroom to obtain a nude weight (Health-o-Meter® digital scale, model: 349KLX,

205   IL, USA), insert a rectal thermistor, and provide a urine sample for measures of U_{SG} and $U_{OSM.}$

206   Participants were then fitted with a blood pressure cuff (Tango+; SunTech Medical, Inc.,

207   Morrisville, NC, USA) placed directly over the brachial artery to obtain blood pressure via

208   electrosphygmomanometry, and a monitor around the chest continuously recording heart rate (HR;

209   Polar Electro Inc., Lake Success, NY, USA). Skin thermocouples were then placed on the

210   appropriate locations (see above).

211   Participants were then dressed in a water-perfused, tube-lined suit that covers the entire

212 body, except the head, face, hands, and feet (Allen-Vanguard Technologies, Ottawa, Canada). The

213 suit permits the control of T_{SK} and T_C temperature by changing the temperature of the water

214 perfusing the suit. After instrumentation, and prior to heating, participants completed BRUMS

215 mood assessment, ImPACT and mental task load measures (VAS and NASA-TLX). Then an

216 intravenous catheter was inserted into the antecubital vein. After participants laid supine for ~30

217 minutes a blood draw was obtained. During the resting period water at 34°C was perfused through

218 the suit. After this resting period, participants were then exposed to passive heat stress by perfusing

219 45°C water through the suit and moved into an environmental chamber (34.5 ± 0.6°C, 30.8 ± 0.9%

220 relative humidity). HR, T_{SK}, T_B and T_C were continuously measured via computer software

221 (LabChart7, Colorado Springs, CO). Once a 1.0°C T_C increase was achieved, T_C was maintained

222 at this temperature by stabilizing the temperature of the water going through the suit. At the 1.0°C

223 increase in T_C, a blood draw was obtained. Participants then completed the BRUMS mood

224 assessment, ImPACT cognitive test and mental task load measures (VAS and NASA-TLX). All

225 ImPACT test sessions included different forms to minimize practice effects. Once testing was

226 completed, nude body mass, to calculate total body water loss, was obtained and participants

227 provided another urine sample.

228 **Statistical Analysis**

229   Statistical analyses were performed using IBM SPSS Statistics v23. In order to establish

230 evidence for the experimental design, a series of separate univariate ANOVAs were performed for

231 all physiological (T_C, T_B, T_{SK}, HR), hydration (U_{SG}, U_{OSM}, S_{OSM}, and body mass change) variables.

232   In order to test our hypotheses, three 2 (hypohydrated vs euhydrated) by 2 (baseline vs

233 hyperthermia) by 2 (obese vs non-obese) multivariate repeated measures analysis of variance

234 (MANOVAs) were performed on cognitive performance, mental task load, and mood outcome

235 variables. *Cognitive performance* outcome scores were derived from the ImPACT battery and

236 included verbal memory, visual memory, processing speed, and reaction time. *Mental task load*

237 scores were derived from the NASA-TLX and VAS and included mental demands, temporal

238 demands, mental performance, effort and frustration, and concentration. *Mood* scores were derived

239 from the BRUMS and included tension, depression, anger, vigor, fatigue, and confusion.

240 An alpha of less than 0.05 was deemed significant. In the case of a multivariate alpha of

241 less than 0.10 an exploratory analysis of the univariate effects were performed. If a statistically

242 significant multivariate effect was identified, then corresponding univariate ANOVAs were

243 examined.

RESULTS

245 **Confirmation of Experimental Design**

246 *Hydration.* Overall, there were no differences between hydration variables in the obese and

247 non-obese groups. In the euhydrated trial, subjects arrived with a body mass loss of only $0.02 \pm$

248 1.19% (relative to 3-day euhydrated baseline body mass), a S_{OSM} of 283 ± 2 mOsm, U_{OSM} of 331

249 ± 198 mOsm, and a U_{SG} of 1.011 ± 0.005. S_{OSM} did not increase in the euhydrated trial with

250 hyperthermia (mean change: -1.8 mOsm ± 3.5; $p=0.01$). There was a small change in body mass

251 (mean change: $-0.64 \pm 0.56\%$; $p = 0.05$). U_{OSM} and U_{SG} increased slightly after hyperthermia

252 during the euhydrated trial (mean change: 52 ± 199 mOsm and 0.003 ± 0.006, respectively;

253 $p>0.05$). However, participants were still considered euhydrated by current guidelines (Armstrong

254 2007).

255 In the hypohydrated trial, percent body mass loss ($-1.06 \pm 0.80\%$), S_{OSM} (287 ± 3 mOsm),

256 U_{OSM} (986 ± 118 mOsm), and U_{SG} (1.025 ± 0.004) were all elevated relative to the euhydrated trial

257   (all p<0.01). During the hypohydrated trial, body mass, U_{OSM}, U_{SG}, and S_{OSM} changed with passive

258   heating (-1.15± 0.45%, 53 ± 50 mOsm, 0.002 ± 0.003, and -4.8 ± 2.7 mOsm, respectively; all

259   p<0.05). When hyperthermic and hypohydrated, U_{OSM}, U_{SG}, S_{OSM}, and body mass loss were greater

260   compared to euhydrated and hyperthermic (all p<0.001). Detailed hydration data are available in

261   in Table 2.

262   *Physiological Responses.* As expected, T_C, T_{SK}, and T_B increased during hyperthermia

263   (mean change: 0.97 ± 0.05°C, 2.65 ± 1.00°C, and 1.14 ± 0.09°C, respectively; all p<0.001).

264   However, none of the other physiological variables (i.e., T_C, T_{SK}, and T_B) were significantly

265   different between non-obese and obese groups in the euhydrated trial (all p>0.05).

266   Hypohydration did not alter baseline T_C, T_B, or HR with the exception of T_{SK} being higher

267   (mean difference: 0.37 ± 0.54°C; p<0.01; independent effect of hydration). HR was significantly

268   higher in obese compared to non-obese at baseline in the hypohydrated trial (mean difference: 10

269   ± 18 bpm; p=0.02). Also, obese females had slightly higher HR after passive heating in the

270   hypohydrated trial (mean difference: 9 ± 19 bpm; p=0.04). There were no other differences in the

271   physiological variables (i.e., T_C, T_{SK}, and T_B) between non-obese and obese groups in the

272   hypohydrated trial (all p>0.10).

273   In the hypohydrated trial, passive heating increased T_C 0.99 ± 0.02°C, T_{SK} 2.69 ± 1.01°C,

274   T_B 1.16 ± 0.11°C, and HR 32 ± 8 bpm (all p<0.01). T_{SK} and T_B were greater at the end of the

275   hypohydrated trial compared to the euhydrated trial (mean difference: 0.40 ± 0.69 and 0.13 ±

276   0.23°C, respectively; p=0.01). T_C did not differ between trials at the end of heating (p>0.05).

277   Detailed physiological data are available in Table 3.

278   **Testing of Hypotheses**

279   *Cognitive Performance*. At a multivariate level, there was not a three-way interaction

280   between hyperthermia, hydration, group obesity on cognitive performance $F(4, 16) = 1.31$, p =

281   0.30, Wilks' $\Lambda = 0.25$ Also, there was not a two-way multivariate interaction between obesity and

282   hyperthermia, $F(4, 16) = 0.22$, p = 0.92, Wilks' $\Lambda = 0.95$, or obesity and hydration $F(4, 16) = 0.20$,

283   p = 0.92, Wilks' $\Lambda = 0.95$.

284   Further, there was no multivariate interactions between hydration and hyperthermia, $F(4,$

285    $16) = 1.53$, p = 0.24, Wilks' $\Lambda = 0.75$. However, there was an independent, multivariate effect of

286   hyperthermia indicating a decrease in cognitive performance, $F(4, 16) = 3.01$, p = 0.049, Wilks' Λ

287    $= 0.57$. Follow-up univariate analyses, presented in Figure 2, indicated that hyperthermia leads to

288   a reduction in verbal recognition memory, $F(1, 19) = 6.98$, p = 0.02, and trend towards reduction

289   in visual working memory $F(1, 19) = 3.58$, p = 0.07, but no change in visual processing speed or

290   reaction time. Further, there was trend towards an independent multivariate effect of hydration

291   status $F(4, 16) = 2.68$, p = 0.07, Wilks' $\Lambda = 0.59$. Follow-up univariate tests revealed that only

292   visual working memory was slightly reduced when hypohydrated (mean change: -4.9 ± 1.8 A.U.,

293   p = 0.01).

294   INSERT FIGURE 2 ABOUT HERE

295   *Mental Task Load.* There were no multivariate interactions between obesity, hydration and

296   hyperthermia on mental task load $F(6, 14) = 0.74$, p = 0.63, Wilks' $\Lambda = 0.24$. Further, there was

297   not a multivariate interaction between obesity and hydration status $F(6, 14) = 1.164$, p = 0.38,

298   Wilks' $\Lambda = 0.67$. However, there was an interaction between obesity and hyperthermia $F(6, 14) =$

299   2.93, p = 0.04, Wilks' $\Lambda = 0.44$. Interestingly, only in obese participants, hyperthermia increased

300   mental demand (p<0.04), decreased ratings of performance (p<0.01), and increased effort (p<0.01;

301   Figure 3). Pairwise comparisons indicate that temporal demand and frustration were unaffected by

302   hyperthermia in either group (Figure 3, Panel B and D; p>0.05). In both obese and non-obese

303   participants concentration increased (Figure 3, Panel F; p<0.05).

304   INSERT FIGURE 3 ABOUT HERE

305   There was trend for a multivariate interaction between hydration status and hyperthermia,

306   $F(6, 14) = 2.93$, p $= 0.06$, Wilks' $\Lambda = 0.46$. Exploratory analysis of the univariate tests only revealed

307   differences in temporal demand, which pairwise comparisons indicated a small but significant

308   increase in temporal demand when hypohydrated (mean change: 5.5 ± 9.1 A.U.; p<0.05), but not

309   when euhydrated (mean change: 1.3 ± 7.5 A.U.; p=0.42). Independent of hyperthermia, there was

310   no multivariate effect of hypohydration, $F(6, 14) = 2.93$, p $= 0.29$, Wilks' $\Lambda = 0.63$.

311   *Mood State.* There was no interaction between obesity, hydration, and hyperthermia, $F(6,$

312   $14) = 1.51$, p $= 0.25$, Wilks' $\Lambda = 0.61$. Also, there was no interaction between hydration status,

313   $F(6, 14) = 1.73$, p $= 0.19$, Wilks' $\Lambda = 0.57$, or hyperthermia, $F(6, 14) = 0.74$, p $= 0.63$, Wilks' $\Lambda =$

314   0.76 (i.e. non-significant interaction). Furthermore, there was no interaction between hydration

315   and hyperthermia on mood $F(6, 14) = 0.95$, p $= 0.49$, Wilks' $\Lambda = 0.711$. Mood state did not appear

316   to change when hydration status was altered, independent of hyperthermia, $F(6, 14) = 1.98$, p $=$

317   0.14, Wilks' $\Lambda = 0.54$.

318   However, there was trend for a main effect of hyperthermia $F(6, 14) = 2.79$, p $= 0.05$,

319   Wilks' $\Lambda = 0.46$. An exploratory univariate analysis, displayed in Figure 4, indicated increases in

320   anger (mean change: 0.4 ± 0.46 A.U.; p<0.01) and depression (mean change: -0.9 A.U. ± 1.1;

321   p<0.01), and decreased vigor (mean change: -1.1 ± 2.1 A.U.; p=0.03) during hyperthermia. There

322   were no changes in tension, fatigue, or confusion (all p > 0.10; Figure 4).

323   INSERT FIGURE 4 ABOUT HERE

324   **DISCUSSION**

325   In this study, we examined the independent and combined effects of mild hypohydration
326   and hyperthermia on cognition, mental task load, and mood between obese and non-obese females.
327   Mild hypohydration did not influence cognitive performance, mental task load, or mood state
328   regardless of hyperthermia or obesity. Hyperthermia, when observed separately from hydration
329   status (i.e. main effect of hyperthermia), decreased cognitive performance. In particular, measures
330   of verbal memory and visual memory were impaired, but reaction time and visual motor processing
331   were maintained. At the same time, most measures of mental task load (demand, performance,
332   effort, and concentration) were increased during hyperthermia. This analysis included obese and
333   non-obese individuals. Follow-up analysis revealed that much of the effect was driven by an
334   independent effect of the obese individuals having increased mental task load during hyperthermia;
335   for the most part, the non-obese individuals had no measurable change. Lastly, mood state, while
336   unaffected by obesity or hydration, was negatively affected by hyperthermia, which corresponded
337   to increased feelings of depression, anger, and reduced vigor. Overall, hyperthermia, but not
338   hypohydration, decreases cognitive performance, and worsens mood state in young females.
339   Mental task load specifically increased in obese females while hyperthermic; non-obese female's
340   mental task load was unaffected by hyperthermia.

341   The rationale for the current study stems Baar's global workspace theory of the conscious
342   mind which has a limited capacity (Baars 1993). Baar's suggests cognitive processes are working
343   in competition with each other rather than in parallel. Selected activities dominate cognitive
344   awareness by harnessing executive function. Stressors could increase the need for cognitive
345   function in one area of the brain, compromising other areas of the brain via cognitive load
346   competition (Cohen 1983; Baars 1993). In our study, hyperthermia impaired cognitive
347   performance while increasing perceived symptoms (thermal sensation) and impairing mood state.

348   Therefore, competition surfaced in executive function, and in order to preserve the cognitive skill

349   being used, the brain exerts more effort toward the skills, sparing cognitive performance

350   impairment in reaction time and visual processing. Thus, in order to meet the demands for stable

351   cognitive performance, mental task load increases.

352   **Effects of mild hypohydration**

353   In the current study, cognitive function, mood state, and mental task load were preserved

354   with 1.1% hypohydration in both obese and non-obese females. Like in previous studies (Amos et

355   al. 2000; Grego et al. 2005), the magnitude of hypohydration may not have been sufficient to

356   induce an observable impairment in cognitive function. Theoretically, there is a threshold at which

357   the mental task load becomes too great, leads to exhaustion, and cognitive function beings to

358   decline. Young healthy participants are able to adapt to progressive water deficit, even up to 2.6%

359   body mass loss, and maintain cognitive performance (Szinnai, Schachinger et al. 2005), which is

360   in agreement with the current study. Kempton et al, suggest this phenomenon is fueled by the

361   increase in the fronto-parietal brain activation resulting in unimpaired cognitive scores and a

362   deteriorated mental task load (Kempton et al. 2011). During fluid restriction there may be an initial

363   drop in short-term memory followed by a return to baseline 3.5 hours later, independent of

364   rehydration (Cian et al. 2000; Szinnai, Schachinger et al. 2005). In our study, no changes in

365   cognitive function during hypohydration, via ImPACT, were detected. Overall, cognitive function

366   appear to be well-preserved with mild hypohydration during fluid restriction.

367   **Effects of hyperthermia**

368   In two separate trials, we had subjects arrive either euhydrated or hypohydrated, and

369   subjects maintained this status throughout our heating protocol (Supplementary Table 1). Many

370   cognitive performance variables were stable when hyperthermic. However, verbal memory, and

371   to a lesser degree visual memory, were impaired (Figures 2 & 3). These visual and verbal memory

372   impairments are similar to those observed in previous studies (Gaoua, Racinais et al. 2011b;

373   Schlader et al. 2013). Cognitive function involving greater neuronal resources are impaired to a

374   greater extent during heat stress than less demanding tasks (Hocking et al. 2001; Simmons et al.

375   2008; Gaoua et al. 2011a; Gaoua, Racinais et al. 2011b; Schlader et al. 2015) and memory is a

376   more complex task than attention tasks. Baddedly's working memory theory states verbal memory

377   is controlled by the phonological loop, while the "visuospatial sketchpad" controls visual memory

378   (Baddeley et al. 1974). These functions are connected and controlled by central executive function.

379   In order to store memory as long-term memory, rehearsal is necessary, and visual memory is of

380   limited capacity. Therefore, if the brain is exerting effort toward storing verbal memory, which is

381   an easier task, competition occurs and the brain's ability to store visual memory, a more

382   complicated task, is limited.

383   Unlike memory, reaction time and attention were maintained during heat stress (Figure 2).

384   Other research suggests heating increases arousal, and thus maintains reaction time and attention,

385   until a critical T_C is reached where impairments occur, which our participants were well below

386   (Hancock et al. 2003). Participants in our study also reported difficulty concentrating (~33%

387   increase in concentration) during hyperthermia. However, attention, as measured by reaction time

388   and motor processing speed was not impaired. Difficulty concentrating could impair the ability to

389   form long-term memories and affect the learning ability of young females during heat stress.

390   Therefore, cognitive impairments seen with hyperthermia in this study could be influenced by both

391   heat-associated physiological responses, and distractions formed from increased symptoms and a

392   negative mood state.

393   **Influence of hypohydration on responses to hyperthermia**

394   Although some cognitive performance variables were impaired during hyperthermia, they

395   were not impaired to a greater degree when mild hypohydration occurred. Given that our sample

396   was young and healthy, physiological mechanisms could compensate in order to stabilize variables

397   after a certain amount of stress. Previous research has suggested that a longer period of

398   hypohydration (60-h of fluid restriction) in young individuals did not exacerbate impairments seen

399   at lower levels of hypohydration, but instead young individuals were able to maintain cognitive

400   performance (Szinnai, Schachinger et al. 2005). Other models of inducing hypohydration, such as

401   diuretics or exercise, may be necessary to investigate if a greater degree of hypohydration affects

402   responses to hyperthermia.

403   **Influence of obesity**

404   Interestingly, there was no effect of body composition on cognitive performance, mood, or

405   presentation of any symptoms. However, mental task load, in many areas, was significantly

406   affected in the obese, but not the non-obese participants during hyperthermia. This indicates that

407   obese individuals had a perception that the heat was imposing a great demand upon them. There

408   is some evidence that autonomic dysfunction associated with obesity increases fatigue

409   development in obese adults during periods of high mental stress (Mehta 2015). In particular it is

410   concerning that decrements in physical performance occur much quicker in obese adults during

411   periods of high mental stress (Mehta 2015). The stress of hyperthermia was not sufficient to impair

412   cognitive performance, symptoms, or mood with moderate heating any more than it did for non-

413   obese participants. The obese individuals did experience increased cardiovascular strain (as

414   evidence by increased HR in this study), but the ability to maintain cerebral perfusion during

415   cognitive task between groups is probably unaffected (Bar-Or, Lundegren et al. 1969). In

416   summary, it is worth noting that performance is maintained in obese individuals, but they find it

417   harder to perform cognitive tasks while in the heat.

418   **Limitations**

419   Mood score only reflected negative feelings and did not give an overall mood state, which

420   may reduce our ability to fully interpret the overall mood state of the females. Also, mood

421   assessment occurred after instrumentation with the rectal probe which may negatively affect mood

422   state. Furthermore, the cognitive assessment (ImPACT) used was a series of five modules. The

423   modules are always administered in the same order for each test. Thus, the cognitive domains

424   measured were not counterbalanced. The lack of counterbalancing could indicate impairment to

425   one domain might affect a later module and the corresponding domain. However, given the

426   conditions of the experiment were counterbalanced, we are confident in our ability to examine the

427   effect of hydration and hyperthermia status on the measured variables. Additionally, we recognize

428   impairment to attention might impair latter modules. Although, most studies using heat stress

429   indicate attention is preserved, studies using hypohydration suggest attention might deteriorate.

430   Furthermore, since we were using a controlled passive heating protocol involving a water-

431   perfusion suit, heat was administered to the skin first and subsequently caused an increase in T_C.

432   The extension that this form of hyperthermia results in changes in cognition relies on the

433   assumption that changes in T_C (in this case rectal) reflect changes in brain temperature (Covaciu

434   et al. 2011). The water-perfusion suits in this study do create an unnatural hyperthermic

435   environment surrounding the skin with 49°C water. This allows for rapid increases in T_{SK} and T_C,

436   but limits external validity because such an extreme environment is unlikely to exist in an

437   occupational setting. Also, a number of other factors occur during exercise or physical labor, such

438   as blood flow demands and heat production at the muscle that may influence the cognitive response

439 to exertional heat stress. Therefore, these results may not be generalized to exertional

440 hyperthermia.

441 **Conclusions**

442 In this study, we demonstrated that apparently healthy adult females experience mild

443 cognitive impairments, specific to memory, during moderate hyperthermia (+1.0 °C increase inT_C

444). These impairments are not worse in obese individuals nor were cognitive impairments worsened

445 when hypohydrated. Hypohydration did not affect any variable related to cognitive function, with

446 the exception of a trend in visual memory. Impairments in mood, evidenced by increased fatigue

447 and depression, and mental task load accompanied cognitive impairments during hyperthermia.

448 Obese individuals experienced a greater demand of the mental activities during hyperthermia, but

449 did not experience greater cognitive impairments. Overall, obese individuals may not experience

450 greater cognitive impairments during hyperthermia, but they likely have to put forth a greater effort

451 to maintain their cognitive abilities. Therefore, during periods of high heat stress, obese individuals

452 are unlikely to experience cognitive performance decrements despite exerting greater effort in

453 comparison to their lean peers. Future studies should seek to determine if physical tasks are equally

454 affected by hyperthermia and hypohydration in obese and non-obese adults.

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461
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606
607

Demographic data from both the obese and non-obese groups.

Table 1. M±SD demographic data for non-obese and obese		
	Non-Obese	**Obese**
N	11	10
Age (y)	22 ± 2	22 ± 2
Height (cm)	165 ± 5.8	161.3 ± 4.9
Mass (kg)	60.56 ± 5.76	79.79 ± 17.69*
Body Fat (%)	25.13 ± 3.93	44.24 ± 5.08*

*Significantly different between groups (p<0.05)

Hydration data collected pre- and post-heating while euhydrated and dehydrated in obese and non-obese individuals.

Table 2. Hydration Markers

		Non-Obese			Obese		
Body Mass Loss (kg) from 3-day Euhydrated Baseline							
Pre-heating	Euhydrated	0.62	±	1.08	-0.44	±	1.39
	Hypohydrated	-0.97	±	0.74[b]	-0.91	±	0.90[b]
Body Mass Loss (kg) after passive heating							
Post-heating	Euhydrated	-0.89	±	0.43	-0.23	±	0.24
	Hypohydrated	-1.46	±	0.29[b]	-0.78	±	0.37[b]
Urine Specific Gravity							
Pre-heating	Euhydrated	1.008	±	0.005	1.009	±	0.006
	Hypohydrated	1.024	±	0.004[b]	1.026	±	0.004[b]
Post-heating	Euhydrated	1.009	±	0.003	1.011	±	0.007
	Hypohydrated	1.026	±	1.004[a,b]	1.029	±	0.004[a,b]
Urine Osmolality (mOsm)							
Pre-heating	Euhydrated	347	±	195	377	±	226
	Hypohydrated	961	±	105[b]	1051	±	116[b]
Post-heating	Euhydrated	401	±	104	454	±	271
	Hypohydrated	992	±	89[a,b]	1126	±	114[a,b]
Serum Osmolality (mOsm)							
Pre-heating	Euhydrated	285	±	2	283	±	3
	Hypohydrated	289	±	4[b]	287	±	3[b]
Post-heating	Euhydrated	284	±	3	281	±	2
	Hypohydrated	294	±	4[a,b]	291	±	3[a,b]

[a]Significant difference from corresponding pre-heating value [b]Significant difference from corresponding euhydration value

Physiological data collected pre- and post-heating while euhydrated and dehydrated in obese and non-obese individuals.

Table 3. Physiological Markers			Non-Obese			Obese		
Rectal Temperature (°C)								
	Pre-heating	Euhydrated	36.77	±	0.28	36.78	±	0.41
		Hypohydrated	36.83	±	0.24	36.87	±	0.43
	Post-heating	Euhydrated	37.72	±	0.26[a]	37.76	±	0.39[a]
		Hypohydrated	37.82	±	0.24[a]	37.85	±	0.44[a]
Skin Temperature (°C)								
	Pre-heating	Euhydrated	35.10	±	0.51	34.97	±	0.45
		Hypohydrated	35.37	±	0.33	35.43	±	0.58
	Post-heating	Euhydrated	37.62	±	0.68[a]	37.75	±	0.77[a]
		Hypohydrated	37.90	±	0.62[a,b]	38.27	±	0.80[a,b]
Mean Body Temperature (°C)								
	Pre-heating	Euhydrated	36.60	±	0.26	36.60	±	0.39
		Hypohydrated	36.80	±	0.23	36.72	±	0.42
	Post-heating	Euhydrated	37.71	±	0.27[a]	37.76	±	0.41[a]
		Hypohydrated	37.83	±	0.24[a,b]	37.90	±	0.44[a,b]
Heart Rate (bpm)								
	Pre-heating	Euhydrated	64	±	5	70	±	11[c]
		Hypohydrated	65	±	8	75	±	10[c]
	Post-heating	Euhydrated	94	±	8[a]	104	±	14[a,c]
		Hypohydrated	98	±	8[a]	106	±	11[a,c]

1 [a]Significant difference from corresponding pre-heating value [b]Significant difference from corresponding
2 euhydration value. [c]Significant difference from corresponding non-obese value

Figure 1

Schematic of experimental design.

Data collection began with 3 days of euhydrated body weights (blue box, far left) collected every morning upon waking. In the 24-h prior to each trial participants either were assigned a fluid prescription protocol or withheld from fluid intake (black boxes, middle left). Upon arriving to the lab on testing day, participants underwent baseline testing (Black stars within experimental trial box, far left). Passive heating immediately began upon completion of baseline testing. Once a 1.0°C increase in rectal temperature was reached post testing began (Black stars within experimental trial box, far right). Participants were removed from the environmental chamber after post testing was completed. The black stars represent when measures for perception mood (Brunel Mood Scale; BRUMS), mental task load (NASA-TLX), and cognitive performance (ImPACT) occurred.
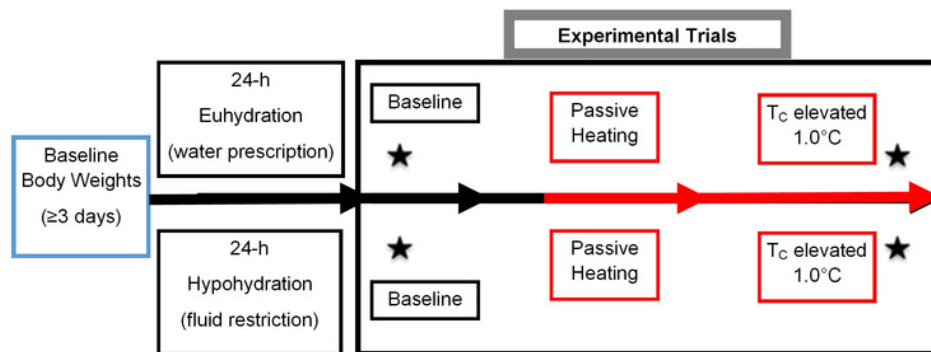
Figure 2

Cognitive Performance

(A) Cognitive performance variables (y-axis) from the ImPACT at baseline and during hyperthermia. Below are (B) reaction time (C) visual motor performance, (D) visual memory, and (E) verbal memory from the ImPACT for each group (obese and non-obese) at baseline and during hyperthermia. *Indicates significant difference from baseline (p<0.05), # Indicates a trend for a difference between baseline (p<0.10). Symbols are vertically offset for clarity.
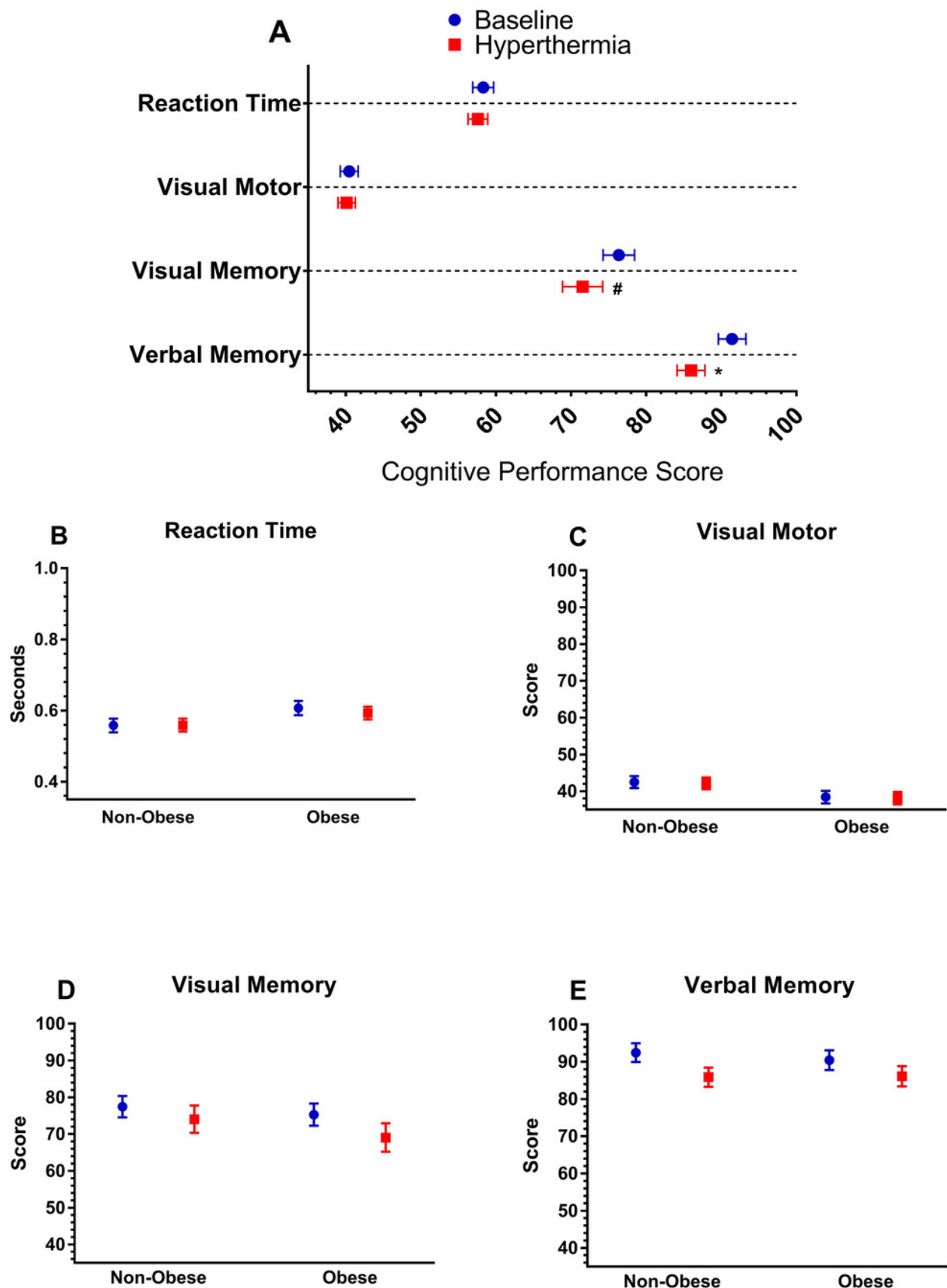
Figure 3

Mental Task Load

Perceived mental task load (NASA-TLX, visual analog score in arbitrary units) for (A) mental demand, (B) temporal demand (C) performance, (D) frustration, (E) effort, and (F) concentration for each group (obese and non-obese) at baseline and during hyperthermia *Indicates significant difference from baseline within group (p<0.05).
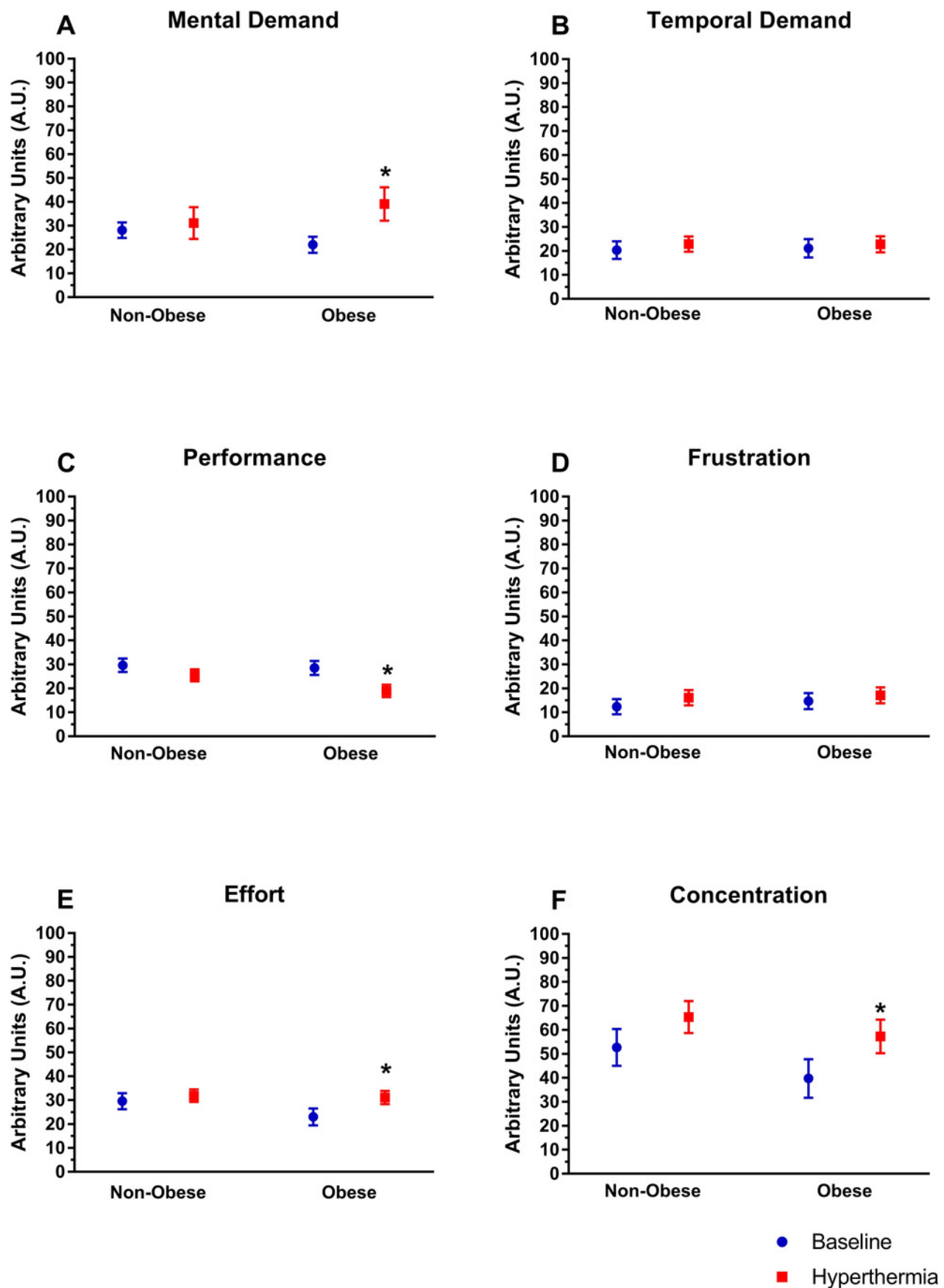
Figure 4

Mood state scores from the Brunel Mood Scale

(A) Perceived mood state scores (in arbitrary units) from the Brunel Mood Scale (BRUMS) compared at baseline and during hyperthermia. To the right are the mood responses split by group (obese versus non-obese) including (B) tension, (C) depression, (D) anger, (E) vigor, (F) fatigue, and (G) confusion.*Indicates significant difference from baseline (p<0.05), # Indicates a trend for a difference between baseline (p<0.10).