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**Objective and subjective measures of exercise intensity during thermo-neutral and hot
yoga.**

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Abstract

While hot yoga has gained enormous popularity in recent years due in part to increased environmental challenge associated with exercise in the heat, it is not clear whether hot yoga is more vigorous than thermo-neutral yoga. Therefore, the aim of this study was to determine objective and subjective measures of exercise intensity during constant intensity yoga in a hot and thermo-neutral environment. Using a randomized, cross-over design, 14 participants completed two identical ~20-minute yoga sessions in a hot ($35.3 \pm 0.8^{\circ}\text{C}$; humidity: $20.5 \pm 1.4\%$) and thermo-neutral ($22.1 \pm 0.2^{\circ}\text{C}$; humidity: $27.8 \pm 1.6\%$) environment. Oxygen consumption (VO_2) and heart rate (HR) were recorded as objective measures ($\%\text{VO}_{2\text{max}}$ and $\%\text{HRmax}$) and rating of perceived exertion (RPE) was recorded as a subjective measure of exercise intensity. There was no difference in exercise intensity based on $\%\text{VO}_{2\text{max}}$ during hot vs. thermo-neutral yoga (30.9 ± 2.3 vs. $30.5 \pm 1.8\%$, $p=0.68$). However, exercise intensity was significantly higher during hot vs. thermo-neutral yoga based on $\%\text{HRmax}$ (67.0 ± 2.3 vs. $60.8 \pm 1.9\%$, $p=0.01$) and RPE (12 ± 1 vs. 11 ± 1 , $p=0.04$). According to established exercise intensities, hot yoga was classified as “light-intensity” based on $\%\text{VO}_{2\text{max}}$ but “moderate-intensity” exercise based on $\%\text{HRmax}$ and RPE while thermo-neutral yoga was classified as “light-intensity” exercise based on $\%\text{VO}_{2\text{max}}$, $\%\text{HRmax}$, and RPE. Despite the added hemodynamic stress and perception that yoga is more strenuous in a hot environment, we observed similar oxygen consumption during hot vs. thermo-neutral yoga classifying both exercise modalities as “light-intensity” exercise.

Keywords: low-intensity exercise, thermal stress, energy expenditure, rate of perceived exertion, balancing postures

Introduction

Yoga is a practice with origins in ancient India; it involves demanding balancing postures, voluntarily regulated breathing techniques, meditation and certain philosophical principles (Telles et al. 2014). A recent survey indicates that nearly 9% of U.S. adults (or 21 million people) have practiced yoga in the last year (Cramer et al. 2016). Hot yoga, a form of yoga exercise consisting of various strength poses performed in a warm environment, has gained enormous popularity in the U.S. in recent years. This increase in popularity has been attributed, at least in part, to the perceived health benefits of the increased environmental challenge associated with hot yoga compared to traditional (thermo-neutral). The noticeable thermoregulatory response of profuse sweating and increased heart rate leads practitioners to believe that hot yoga is more energy demanding than yoga performed in a thermo-neutral environment. However, it is not clear that the added hemodynamic stress and increased reliance on carbohydrate metabolism (less energy efficient) associated with exercising in the heat (Nielsen et al. 1990), is sufficient to increase exercise intensity, and consequently energy expenditure during hot yoga, when compared to thermo-neutral yoga.

Evaluating exercise intensity and energy expenditure during yoga is challenging. First, due to the dynamic nature of yoga practice, it is difficult to achieve a steady-state exercise intensity needed to appropriately evaluate exercise intensity and more importantly energy expenditure (Åstrand and Rodahl 1986). Therefore, identifying a set or series of yoga poses that elicit steady-state exercise conditions is an initial and vital step when evaluating and comparing exercise intensity and energy expenditure during hot vs. thermo-neutral yoga. Additionally, exercise intensity could be evaluated using objective parameters such as oxygen consumption (VO_2) and heart rate (HR) or subjective measures such as rate of perceived exertion (Hills et al.

2014). More conventionally, yoga patrons may sometimes rely on external devices like personal movement activity or heart rate monitors to track their exercise intensity. However, this may be particularly problematic during hot yoga since heart rate response during exercise may not be only influenced by exercise intensity but also by environmental temperature (Gonzalez-Alonso et al. 2000). More specifically, exercise in the heat can result in reduced stroke volume and a compensatory rise in heart rate to maintain cardiac output compared to exercise in a thermo-neutral environment (Rizzo and Thompson 2017). Collectively this suggests that hot and thermo-neutral yoga could be differential classified (e.g., light vs. moderate vs. vigorous intensity exercise) based on the measure of exercise intensity employed.

Therefore, the aim of this study was to determine whether yoga exercise performed in a hot environment would elicit greater objective and subjective measures of exercise intensity and energy expenditure than yoga exercise performed in a thermo-neutral environment. Our hypotheses are: 1) there will be no difference in objective measures of exercise intensity during hot, compared to thermo-neutral yoga and 2) hot yoga will result in greater subjective measures of exercise intensity when compared to thermo-neutral yoga.

Methods

Subjects

A total of 14 adult (age: 22.1 ± 0.6 yrs) males ($n=7$) and females ($n=7$) completed this study (Table 1). Participants were healthy with no known cardiovascular disease or musculoskeletal injuries (e.g., anterior cruciate ligament tear, chronic use of lower extremity orthotics/prosthetics, broken limbs, etc.) that precluded them from performing common yoga poses. Participants were excluded from participation if they had a history of heat related illness (e.g., heat syncope, heat exhaustion, or heat stroke) within the last 6 months. In order to more generalize our findings, we

recruited participants with no yoga experience to those who regularly practice yoga. However, individuals who reported practicing hot-yoga in the last six months were excluded from participating. Six of our participants (43%) reported no yoga experience, five reported completing 1-10 yoga sessions (36%), and three (21%) reported completing 90-400 yoga sessions in their lifetime. Participants ranged in yoga experience from no yoga experience to participating in weekly yoga sessions. A written informed consent was obtained from all subjects prior to participation. All procedures were approved by the Central Michigan University Institutional Review Board.

Preliminary testing

A graded exercise treadmill test (GXT) was used to determine participants' maximal oxygen capacity (VO_2max) using indirect calorimetry (Vmax Encore Metabolic Cart; Carefusion Corporation, San Diego, CA) and maximal heart rate (HRmax). The GXT was performed on a treadmill and started with a 3-minute warm-up. After the warm-up participants self-selected a running speed on the treadmill they could maintain for ~30 minutes, each minute after that grade was increased by 1% until exhaustion. VO_2max was established as the average VO_2 in the last minute of exercise. All participants achieved VO_2max with a respiratory exchange ratio of ≥ 1.10 and within 10 bpm of participants' age predicted heart rate maximum (based on $220 - \text{age}$), a plateau in VO_2 ($< 150\text{mL}$ increase), and $\text{RPE} \geq 17$ (Balady et al. 2010). HRmax was established as the highest heart rate achieved during the VO_2max test using a Polar A300 downloadable heart rate monitor and chest strap (Polar Electro, Lake Success, NY).

Procedures

Using a randomized, cross-over design, all participants completed two identical yoga sessions on

131 separate days with approximately one week (± 2 days) in between (Figure 1). In a randomized
132 order, participants completed a ~20-minute yoga session, in a thermo-neutral environment (22.1
133 ± 0.2 °C) and hot environment (35.3 ± 0.8 °C). Yoga sessions included a 5-minute warm-up, 15
134 minutes of yoga postures, and a 2-5 minute cool down/relaxation period. Each yoga session was
135 scheduled at approximately the same time of day (± 1.5 hours) to avoid circadian rhythms effects.
136 Before each yoga session participants were instructed to drink plenty of fluids. Upon arrival to
137 the laboratory, hydration status was assessed by the specific gravity of participants' urine using a
138 refractometer. Participants were considered sufficiently hydrated if their urine specific gravity
139 (Usg) reading was <1.025 (Armstrong et al. 1998). Each yoga session was identical including
140 type and duration of each pose performed. These yoga sessions primarily focused mobility poses
141 and designed to engage the participants in a fluid and steady motion. Poses were somewhat
142 repetitious in nature to achieve this goal. Each yoga session was also led by the same trained
143 yoga instructor who was in person (no video recording) instructing each participant in a one-on-
144 one environment.

145 ***Measurements***

146 After emptying their bladder, participants' body weight was recorded wearing comfortable, loose
147 clothing (also worn during the subsequent yoga session). Then participants were fitted with a
148 facemask covering their nose and mouth connected to a Vmax Encore 29 Metabolic Cart
149 (Carefusion 211 Inc., Yorba Linda, CA) to determine oxygen consumption (VO_2) and carbon
150 dioxide production (VCO_2). Prior to the onset of each yoga session, the metabolic cart was
151 calibrated in the room where the yoga session was going to be completed. Conversely,
152 participants were fitted with this facemask in a thermo-neutral environment regardless of the trial
153 they were scheduled for. Therefore, participants were not exposed to a hyper-thermic

environment until the exercise session started (similar to real-world conditions). All of the yoga sessions were performed in the same ~10 x 10 foot room in our laboratory heated with a space heater set to 35°C. The space heater would turn on below a room temperature of 35°C and off above that temperature. Expired air was collected continuously throughout the 20-minute yoga session. Expired air volumes of subjects were converted to standard temperature, and pressure, dry (STPD) to correct for the effects of the different ambient temperatures in air volume. Participants were also fitted with a heart rate monitor (Polar A300, Polar Electro, Lake Success, NY) to measure heart rate response during each yoga session. Rate of perceived exertion (RPE; 6-20 Borg Scale) was also recorded every 5-minutes throughout the ~20-minute yoga session as a third index of exercise intensity. Ambient temperature was recorded immediately prior to each yoga session (“Pre”). At the completion of each yoga session (“Post”), participants’ weight and ambient temperature were re-recorded.

Dietary considerations

Participants were asked to complete a dietary log of everything they ate and drank 24 hours prior to their first yoga session and then instructed to repeat this exactly prior to their second yoga session.

Data Analysis

VO₂ was used to determine constant intensity exercise, defined as a 5 minute period of yoga in which average VO₂ changed by <10% (Δ VO₂) (Thomas et al. 2009). This occurred during minutes 12-17 of our yoga session. Therefore, all of our major outcome measures (with the exception of RPE) average values from this time period only during our yoga exercise session.

Objective measures of exercise intensity including percent VO_2max ($\%\text{VO}_2\text{max}$) and metabolic equivalents (METs) as well as HRmax ($\%\text{HRmax}$) were determined based on average VO_2 and HR, respectively during steady-state exercise. Respiratory exchange ratio (RER) was also calculated during steady-state exercise to determine substrate utilization using the non-protein RER data (Frayn 1983; Kravitz et al. 1997) (i.e., carbohydrate vs. fat). Average RER and VO_2 during steady-state exercise were also used to calculate energy expenditure (kcal/min) as previously described (Brouwer 1957).

Statistical analysis

A two-way ANOVA with one factor repeating (condition x time) with Tukey post-hoc analysis was used to assess potential significant differences in body weight and ambient conditions. Assumptions for use of ANOVA were met. Students paired t-test were used to assess potential differences in exercise intensity (i.e., $\%\text{VO}_2\text{max}$, $\%\text{HRmax}$, METs, RPE), substrate utilization (RER), and energy expenditure (kcal/min) between the two conditions (i.e., thermo-neutral vs. hot). All statistical analyses were performed using SigmaPlot 12.5 (Systat Software, Inc., San Jose, CA). All data is presented as mean $\pm$ SE and statistical significance was set at $p < 0.05$.

Results

Participant characteristics

All participants were sufficiently hydrated prior to participation in thermo-neutral ($U_{\text{sg}}=1.012\pm0.002$) and hot ($U_{\text{sg}}=1.020\pm0.006$) yoga sessions. Additionally, there was no difference in body weight between trials further suggesting adequate hydration (74.9 ± 4.5 vs. 75.1 ± 4.6 , $p=0.98$) (Steiner et al. 2007).

Ambient conditions and body mass

By design, compared to the thermo-neutral yoga session, room temperature was significantly higher during the hot yoga session at Pre (22.1 ± 0.2 vs. $35.3 \pm 0.8^\circ\text{C}$, $p < 0.01$) and this was maintained Post (22.3 ± 0.2 vs. $35.3 \pm 0.8^\circ\text{C}$, $p < 0.01$). Compared to the thermo-neutral yoga session, relative humidity was also lower during the hot yoga session (27.8 ± 1.4 vs. $20.5 \pm 1.4\%$, $p < 0.01$). During this brief yoga exercise session (~20 minutes) we observed a modest yet significant reduction in body mass from Pre to Post during thermos-neutral (74.9 ± 4.5 vs. 74.8 ± 4.5 , $p = 0.01$) and hot (75.1 ± 4.6 vs. 74.9 ± 4.5 , $p < 0.01$) yoga. However, body mass was not significantly different at any time point between the two yoga sessions.

Exercise trial

Steady-state was achieved between minute 12-17 where the average ΔVO_2 was $3.0 \pm 1.2\%$ and $3.6 \pm 0.6\%$ for thermo-neutral and hot yoga session respectively (Figure 2). Therefore, exercise intensity ($\%\text{VO}_{2\text{max}}$, METs, $\%\text{HRmax}$), substrate utilization (RER), and energy expenditure (kcal/min), were reported for minutes 12-17 of each yoga session. We did not detect a significant difference in exercise intensity during the thermo-neutral and hot yoga sessions as a function of $\%\text{VO}_{2\text{max}}$ or METs (Table 2). However, exercise intensity was significantly higher during hot yoga than thermo-neutral yoga as a function of $\%\text{HRmax}$ (Table 2). RER was also higher during hot yoga (Table 2) indicating greater reliance on carbohydrate metabolism for energy production during the hot yoga session (84.0% vs. 67.5% , based on non-protein RER). Despite the added thermal stress placed on the cardiovascular system during hot yoga, energy expenditure was also similar between the two yoga sessions (Table 2). Based on RPE,

participants also perceived the hot yoga session to be more difficult at all time points throughout the yoga session when compared to an identical yoga session in a thermo-neutral environment (Figure 3).

Discussion

The overall aim of this study was to determine objective and subjective measures of exercise intensity during constant intensity yoga in a hot and thermo-neutral environment. In order to do that we first identified a 5-minute period between minutes 12-17 of the yoga session where VO_2 changed by $<10\%$ (ΔVO_2) (Thomas et al. 2009). We found that in regards to objective measures of exercise intensity, VO_2 response was similar, while HR markedly higher during identical yoga sessions performed in a hot and thermo-neutral environment. RPE as a subjective measure of exercise intensity, was reportedly higher during the hot yoga session compared to the thermo-neutral session. Additionally, according to established criteria for classifying exercise intensities (Garber et al. 2011), our hot yoga session would be classified as “light-intensity” based on $\%\text{VO}_2$ but “moderate-intensity” exercise based on $\%\text{HR}_{\text{max}}$ and RPE while the identical yoga session performed in a thermo-neutral environment would be classified as “light-intensity” exercise based on $\%\text{VO}_{2\text{max}}$, $\%\text{HR}_{\text{max}}$, and RPE.

Patrons of hot yoga cite the increased environmental challenge associated with hot yoga compared to thermo-neutral as part of the appeal. This perception may also give patrons of hot yoga the impression that they are working harder and expending more calories during a session of hot yoga than they would have if that yoga session was performed in a thermo-neutral environment. Our findings indicate that identical yoga sessions performed in a thermo-neutral and hot environment result in similar energy expenditure due to similar rates of VO_2 . To our

knowledge this is the first study to compare energy expenditure during yoga in a thermo-neutral and hot environment. However, Savard et al. (1988) reported similar results during one-leg cycling exercise at a similar workload (20-25% VO_2max) where skin temperature was kept neutral (35°C) or heated (38°C) (Savard et al. 1988), while at higher exercise intensities (>60% VO_2max) there is greater oxygen consumption and thus energy expenditure when exercising in a hot compared to thermo-neutral/cool environment (Fink et al. 1975; Nielsen et al. 1990). This is most likely due to increased respiratory and hemodynamic stress (i.e., circulatory) demands associated with heat dissipation via skin blood flow and concurrent maintenance of cardiac output. Collectively, the available data suggest that the added thermoregulatory and hemodynamic stress during light-intensity (<40% VO_2max)/short duration (20 minutes) exercise in a hot environment is not enough to result in a detectable increase in oxygen consumption and thus energy expenditure during an acute and brief yoga session.

Consistent with previous findings, we also observed significantly higher heart rate response during yoga performed in a hot environment compared to a thermo-neutral environment (Savard et al. 1988; Febbraio et al. 1994). This has a number of important practical implications for yoga patrons who may monitor exercise intensity/energy expenditure with consumer physical activity monitors that report heart rate for users. First, yoga participants may view yoga performed in the heat as “moderate-intensity” and expect to gain the health and fitness benefits associated with engaging in regular moderate-intensity physical activity. Additionally, there are number of consumer physical activity monitors available that report energy expenditure in addition to heart rate for users (Shcherbina et al. 2017). Although the calculations used to determine energy expenditure by these devices are proprietary, they most likely take into consideration variables

including: height, weight, exercise modality and heart rate. Consequently, during yoga/exercise performed in hot environment, when heart rate is artificially higher due to the added circulatory demands, energy expenditure may also be artificially inflated giving users a false sense of energy (calorie) expenditure. Keeping in mind that exercise is often used to help individuals maintain/lose weight, this may be important information to disseminate to consumer physical activity monitor users as well as an important area of consideration for consumer physical activity monitor developers.

Similar to previous reports, we observed greater RPE during yoga performed in the heat compared to thermo-neutral conditions (Kuoppasalmi 1986; Armada-da-Silva et al. 2004). RPE rating has been suggested to be a combination of psychological and physiologic cues from contracting skeletal muscle as well as the respiratory and cardiovascular responses to that exercise session (Maw et al. 1993). Although workload was equal between our two yoga sessions, yoga performed in a hot compared to thermo-neutral environment resulted in a higher heart rate response. This suggests that elevated heart rate may have been the impetus for participants rating greater RPE values since both are intimately bonded (Gonzalez-Alonso et al. 1995). Conversely previous reports indicate that when RPE is held constant and used by participants to control workload, workload drops but heart rate still remains elevated during exercise in the heat compared to both thermo-neutral and cool conditions (Kuoppasalmi 1986; Maw et al. 1993). Therefore, the difference in cardiovascular responses we observed during the two yoga sessions cannot solely explain the elevated RPE values reported during hot yoga. In regards to application, neither RPE nor heart rate appear to be the most appropriate tools for participants to gauge exercise intensity during yoga performed in a hot environment. Also,

because participants feel as though they are working harder during hot yoga, they may likely overestimate their energy expenditure (as previously discussed), which may be problematic from a weight maintenance/loss perspective. Moreover, participants of hot yoga may be inclined to reduce their effort during hot yoga, whether intentionally or unintentionally, as they perceive it to be harder than it actually is resulting in reduced exercise intensity and consequently minimizing potential health and fitness adaptations from their yoga training.

We also found that RER values were higher during yoga performed in a hot compared to thermoneutral environment, indicating a greater reliance on carbohydrate metabolism. This is consistent with previous findings that have consistently indicated that exercise in a hot environment increases reliance on carbohydrate metabolism (Febbraio et al. 1994; O'Hearn et al. 2016). The increased reliance on carbohydrate metabolism during exercise in the heat appears to be the result of humoral factors. More specifically, Hargreaves et al., (1996) detected a greater counterregulatory hormone response (i.e., glucagon, catecholamines, cortisol, and growth hormone) during 40 minutes of exercise in hot (40°C) compared to control conditions (20°C) contributing to greater whole body carbohydrate oxidation (Hargreaves et al. 1996). At the high workloads in the experiments of Febbraio and Hargreaves (i.e., 70% VO_2max during 40 min) muscle glycogen use was elevated when exercising in a hot environment. Importantly some athletes/exercisers may engage in a hot yoga during their “off” or recovery days. Although light-intensity exercise may be ideal for a recovery day activity, because of the increased reliance on carbohydrate when exercising in the heat, hot yoga may actually inhibit the recovery process (e.g., glycogen repletion) in these athletes.

Our study has certain limitations. It is possible that there are differences in energy expenditure during light-intensity yoga exercise performed in a thermo-neutral and hot environment but they are below detectable limits with current technology. For example, we observed a non-significant difference in VO_2 between the two yoga sessions equal to $\sim 3\%$ which is well within the 5% detectable limits of indirect calorimetry (Frankenfield et al. 2016). Another limitation of our analysis is that we did not control for menstrual cycle and as previous reports indicate, menstrual cycle phase can influence body temperature and energy expenditure (Buskirk and Puhl 1996; McNeil and Doucet 2012). Another potential limitation of our study was that participants could have been slightly dehydrated during exercise. While because similar body weights between trials indicate consistency in hydration status, this could also mean participants were equally dehydrated prior to each trial. Yet it is reasonable to assume that consistency in hydration/dehydration status would impact results similarly in each trial. Additionally, we did not measure body temperature during either yoga session. However, previous reports indicate that core temperature remains relatively stable for at least the first 20 minutes of exercise performed in a hyper-thermic environment during moderate and high intensity exercise (Nybo et al. 2002; Mora-Rodriguez et al. 2010; Zuhl et al. 2014). Importantly our participants performed low-intensity exercise. Therefore, we would anticipate that our participants' core temperature would have also remained stable in the current analysis. This may also explain why the added physiologic stress of low-intensity exercise performed in a hyper-thermic environment was not enough to detect differences in metabolic cost (i.e., energy expenditure). Additionally, the yoga session performed in this analysis was only 20 minutes. Therefore, it is possible that a longer yoga session performed at a higher intensity could result in greater energy expenditure, but this remains to be determined.

Conclusions

In summary, despite the impression that hot yoga is more intense than yoga performed in a thermo-neutral environment, this direct comparison has never been made. Here we found that while hot yoga elicited a higher %HRmax and higher RPE values when compared to thermo-neutral yoga, VO₂ and energy (caloric) expenditure were similar between environmental conditions. Consistent with previous reports (Clay et al. 2005; Hagins et al. 2007; Larson-Meyer 2016), we found that yoga performed in a thermo-neutral environment would be classified as “light-intensity” exercise regardless of measurement tool utilized (i.e., %VO₂max, %HRmax or RPE). However, while hot yoga would still be classified as “light-intensity” based on VO₂ values, more mainstream markers of exercise intensity including perceived exertion and HR response would suggest to yoga patrons that they are working harder during hot vs. thermo-neutral yoga. Unfortunately, this may lead them to believe they are exercising more vigorously and expending more calories than they actually are which could have long-term implications for their health and fitness (Zuhl et al. 2014).

Conflict of Interest

The authors report no conflicts of interest associated with this manuscript.

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361 **Reference**

- 362 Armada-da-Silva, P.A., Woods, J., and Jones, D.A. 2004. The effect of passive heating and face
363 cooling on perceived exertion during exercise in the heat. *Eur. J. Appl. Physiol.* **91**: 563-
364 71. doi:10.1007/s00421-003-1006-0.
- 365 Armstrong, L.E., Soto, J.A., Hacker, F.T., Jr., Casa, D.J., Kavouras, S.A., and Maresh, C.M.
366 1998. Urinary indices during dehydration, exercise, and rehydration. *Int. J. Sport Nutr.* **8**:
367 345-55.
- 368 Åstrand, P.-O. and Rodahl, K.r. 1986. **Textbook of work physiology : physiological bases of**
369 **exercise**. New York: McGraw Hill.
- 370 Balady, G.J., Arena, R., Sietsema, K., Myers, J., Coke, L., Fletcher, G.F., et al. 2010. Clinician's
371 Guide to cardiopulmonary exercise testing in adults: a scientific statement from the
372 American Heart Association. *Circulation*, **122**: 191-225.
373 doi:10.1161/CIR.0b013e3181e52e69.
- 374 Brouwer, E. 1957. On simple formulae for calculating the heat expenditure and the quantities of
375 carbohydrate and fat oxidized in metabolism of men and animals, from gaseous exchange
376 (Oxygen intake and carbonic acid output) and urine-N. *Acta. Physiol. Pharmacol. Neerl.*
377 **6**: 795-802.
- 378 Buskirk, E.R. and Puhl, S.M. 1996. **Body fluid balance : exercise and sport**. Boca Raton: CRC
379 Press.
- 380 Clay, C.C., Lloyd, L.K., Walker, J.L., Sharp, K.R., and Pankey, R.B. 2005. The metabolic cost
381 of hatha yoga. *J. Strength Cond. Res.* **19**: 604-10. doi:10.1519/15144.1.

- 382 Cramer, H., Ward, L., Steel, A., Lauche, R., Dobos, G., and Zhang, Y. 2016. Prevalence,
383 Patterns, and Predictors of Yoga Use: Results of a U.S. Nationally Representative
384 Survey. *Am. J. Prev. Med.* **50**: 230-5. doi:10.1016/j.amepre.2015.07.037.
- 385 Febbraio, M.A., Snow, R.J., Stathis, C.G., Hargreaves, M., and Carey, M.F. 1994. Effect of heat
386 stress on muscle energy metabolism during exercise. *J. Appl. Physiol.* (1985) **77**: 2827-
387 31.
- 388 Fink, W.J., Costill, D.L., and Van Handel, P.J. 1975. Leg muscle metabolism during exercise in
389 the heat and cold. *Eur J. Appl. Physiol. Occup. Physiol.* **34**: 183-90.
- 390 Frankenfield, D.C., Ashcraft, C.M., Wood, C., and Chinchilli, V.M. 2016. Validation of an
391 indirect calorimeter using n-of-1 methodology. *Clin. Nutr.* **35**: 163-8.
392 doi:10.1016/j.clnu.2015.01.017.
- 393 Frayn, K.N. 1983. Calculation of substrate oxidation rates in vivo from gaseous exchange. *J.*
394 *Appl. Physiol. Respir. Environ. Exerc. Physiol.* **55**: 628-34.
- 395 Garber, C.E., Blissmer, B., Deschenes, M.R., Franklin, B.A., Lamonte, M.J., Lee, I.M., et al.
396 2011. American College of Sports Medicine position stand. Quantity and quality of
397 exercise for developing and maintaining cardiorespiratory, musculoskeletal, and
398 neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med.*
399 *Sci. Sports. Exerc.* **43**: 1334-59. doi:10.1249/MSS.0b013e318213febf.
- 400 Gonzalez-Alonso, J., Mora-Rodriguez, R., Below, P.R., and Coyle, E.F. 1995. Dehydration
401 reduces cardiac output and increases systemic and cutaneous vascular resistance during
402 exercise. *J. Appl. Physiol.* (1985) **79**: 1487-96.

- 403 Gonzalez-Alonso, J., Mora-Rodriguez, R., and Coyle, E.F. 2000. Stroke volume during exercise:
404 interaction of environment and hydration. *Am. J. Physiol. Heart Circ. Physiol.* **278**:
405 H321-30.
- 406 Hagins, M., Moore, W., and Rundle, A. 2007. Does practicing hatha yoga satisfy
407 recommendations for intensity of physical activity which improves and maintains health
408 and cardiovascular fitness? *BMC Complement Altern. Med.* **7**: 40. doi:10.1186/1472-
409 6882-7-40.
- 410 Hargreaves, M., Angus, D., Howlett, K., Conus, N.M., and Febbraio, M. 1996. Effect of heat
411 stress on glucose kinetics during exercise. *J. Appl. Physiol.* (1985) **81**: 1594-7.
- 412 Hills, A.P., Mokhtar, N., and Byrne, N.M. 2014. Assessment of physical activity and energy
413 expenditure: an overview of objective measures. *Front. Nutr.* **1**: 5.
414 doi:10.3389/fnut.2014.00005.
- 415 Kravitz, L., Robergs, R.A., Heyward, V.H., Wagner, D.R., and Powers, K. 1997. Exercise mode
416 and gender comparisons of energy expenditure at self-selected intensities. *Med. Sci.*
417 *Sports Exerc.* **29**: 1028-35.
- 418 Kuoppasalmi, K., Ilmarinen, R., Smolander, J., Harkonen, M., Korhonen, O. 1986. Relationship
419 between physiological responses and perceived exertion of muscular exercise under
420 various environmental conditions. *Psychiatry Fenn*: 69-77.
- 421 Larson-Meyer, D.E. 2016. A Systematic Review of the Energy Cost and Metabolic Intensity of
422 Yoga. *Med. Sci. Sports Exerc.* **48**: 1558-69. doi:10.1249/MSS.0000000000000922.
- 423 Maw, G.J., Boutcher, S.H., and Taylor, N.A. 1993. Ratings of perceived exertion and affect in
424 hot and cool environments. *Eur. J. Appl. Physiol. Occup. Physiol.* **67**: 174-9.

- 425 McNeil, J. and Doucet, E. 2012. Possible factors for altered energy balance across the menstrual
426 cycle: a closer look at the severity of PMS, reward driven behaviors and leptin variations.
427 Eur. J. Obstet. Gynecol. Reprod. Biol. **163**: 5-10. doi:10.1016/j.ejogrb.2012.03.008.
- 428 Mora-Rodriguez, R., Del Coso, J., Hamouti, N., Estevez, E., and Ortega, J.F. 2010. Aerobically
429 trained individuals have greater increases in rectal temperature than untrained ones
430 during exercise in the heat at similar relative intensities. Eur. J. Appl. Physiol. **109**: 973-
431 81. doi:10.1007/s00421-010-1436-4.
- 432 Nielsen, B., Savard, G., Richter, E.A., Hargreaves, M., and Saltin, B. 1990. Muscle blood flow
433 and muscle metabolism during exercise and heat stress. J. Appl. Physiol. (1985) **69**:
434 1040-6.
- 435 Nybo, L., Moller, K., Volianitis, S., Nielsen, B., and Secher, N.H. 2002. Effects of hyperthermia
436 on cerebral blood flow and metabolism during prolonged exercise in humans. J. Appl.
437 Physiol. (1985) **93**: 58-64. doi:10.1152/japplphysiol.00049.2002.
- 438 O'Hearn, K., Tingelstad, H.C., Blondin, D., Tang, V., Filion, L.G., and Haman, F. 2016. Heat
439 exposure increases circulating fatty acids but not lipid oxidation at rest and during
440 exercise. J. Therm. Biol. **55**: 39-46. doi:10.1016/j.jtherbio.2015.11.002.
- 441 Rizzo, L. and Thompson, M.W. 2017. Cardiovascular adjustments to heat stress during
442 prolonged exercise. J. Sports Med. Phys. Fitness. doi:10.23736/S0022-4707.17.06831-1.
- 443 Savard, G.K., Nielsen, B., Laszczynska, J., Larsen, B.E., and Saltin, B. 1988. Muscle blood flow
444 is not reduced in humans during moderate exercise and heat stress. J. Appl. Physiol.
445 (1985) **64**: 649-57.

- 446 Shcherbina, A., Mattsson, C.M., Waggott, D., Salisbury, H., Christle, J.W., Hastie, T., et al.
447 2017. Accuracy in Wrist-Worn, Sensor-Based Measurements of Heart Rate and Energy
448 Expenditure in a Diverse Cohort. *J. Pers. Med.* **7**. doi:10.3390/jpm7020003.
- 449 Steiner, M.J., Nager, A.L., and Wang, V.J. 2007. Urine specific gravity and other urinary
450 indices: inaccurate tests for dehydration. *Pediatr. Emerg. Care*, **23**: 298-303.
451 doi:10.1097/01.pec.0000270162.76453.fa.
- 452 Telles, S., Sharma, S.K., Yadav, A., Singh, N., and Balkrishna, A. 2014. A comparative
453 controlled trial comparing the effects of yoga and walking for overweight and obese
454 adults. *Med. Sci. Monit.* **20**: 894-904. doi:10.12659/MSM.889805.
- 455 Thomas, S.S., Buckon, C.E., Schwartz, M.H., Russman, B.S., Sussman, M.D., and Aiona, M.D.
456 2009. Variability and minimum detectable change for walking energy efficiency
457 variables in children with cerebral palsy. *Dev. Med. Child. Neurol.* **51**: 615-21.
458 doi:10.1111/j.1469-8749.2008.03214.x.
- 459 Zuhl, M.N., Lanphere, K.R., Kravitz, L., Mermier, C.M., Schneider, S., Dokladny, K., et al.
460 2014. Effects of oral glutamine supplementation on exercise-induced gastrointestinal
461 permeability and tight junction protein expression. *J. Appl. Physiol.* (1985) **116**: 183-91.
462 doi:10.1152/japplphysiol.00646.2013.

463

Table 1. Participant characteristics

	Male	Female
	(n=7)	(n=7)
Age (y)	23.3 ± 0.7	20.9 ± 0.6
Height (cm)	182.8 ± 2.1	166.8 ± 2.2
Body weight (kg)	86.5 ± 5.1	63.2 ± 4.3
BMI (kg/m ²)	26.0 ± 1.2	22.9 ± 1.5
VO ₂ max (ml/kg/min)	47.7 ± 2.7	42.4 ± 2.6
HRmax (bpm)	191 ± 2	188 ± 5

Data expressed as mean ± SE.

Table 2. Exercise intensity and substrate metabolism during steady-state yoga exercise.

	Thermo-neutral	Hot	P-value
%VO ₂ max (%)	30.5 ± 1.8%	30.9 ± 2.3%	0.68
METs	3.8 ± 0.1	3.9 ± 0.2	0.65
%HRmax (%)	60.8 ± 1.9%	67.0 ± 2.3%*	0.01
RER (VCO ₂ /VO ₂)	0.91 ± 0.08	0.95 ± 0.02*	0.01
Energy Expenditure (kcal/min)	4.93±0.02	5.12 ± 0.50	0.42

Data expressed as mean ± SE. *Significantly different than thermo-neutral yoga.

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Figure 1. Timeline of experimental events.

Figure 2. Oxygen consumption during two-identical yoga sessions performed during thermo-neutral (open circles) and hot (closed circles) ambient conditions.

Figure 3. Rate of perceived exertion during two-identical yoga sessions performed during thermo-neutral (open circles) and hot (closed circles) ambient conditions. *Significantly different than thermo-neutral at the same time point, $p < 0.05$.

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198x64mm (300 x 300 DPI)

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Figure 2. Oxygen consumption during two-identical yoga sessions performed during thermo-neutral (open circles) and hot (closed circles) ambient conditions.

215x279mm (300 x 300 DPI)

279x362mm (300 x 300 DPI)