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Pre-Exercise Ingestion of Pickle Juice, Hypertonic Saline, or Water and Aerobic Performance and Thermoregulation

Jarett Peikert, MS, ATC*; Kevin C. Miller, PhD, AT, ATC†; Jay Albrecht, PhD, LAT, ATC, HFS‡; Jared Tucker, PhD§; James Deal, PhD||

*Department of Health, Nutrition, and Exercise Science, North Dakota State University, Fargo; †School of Rehabilitation and Medical Sciences, Central Michigan University, Mount Pleasant; ‡Department of Health and Physical Education, Minnesota State University Moorhead; §Helen DeVos Children's Hospital, Grand Rapids, MI; ||Department of Human Development and Family Science, North Dakota State University, Fargo

Context: Ingesting high-sodium drinks pre-exercise can improve thermoregulation and performance. Athletic trainers (19%) give athletes pickle juice (PJ) prophylactically for cramping. No data exist on whether this practice affects aerobic performance or thermoregulation.

Objective: To determine if drinking 2 mL/kg body mass of PJ, hypertonic saline, or deionized water (DIW) pre-exercise affects aerobic performance or thermoregulation.

Design: Crossover study.

Setting: Controlled laboratory study.

Patients or Other Participants: Nine euhydrated men (age = 22 ± 3 years, height = 184.0 ± 8.2 cm, mass = 82.6 ± 16.0 kg) completed testing.

Intervention(s): Participants rested for 65 minutes. During this period, they ingested 2 mL/kg of PJ, hypertonic saline, or DIW. Next, they drank 5 mL/kg of DIW. Blood was collected before and after ingestion of all fluids. Participants were weighed and ran in the heat (temperature = 38.3°C ± 1°C, relative humidity = 21.1% ± 4.7%) at increasing increments of maximal heart rate (50%, 60%, 70%, 80%, 90%, 95%) until exhaustion or until rectal temperature exceeded 39.5°C. Participants were weighed postexercise so we could calculate sweat volume.

Main Outcome Measure(s): Time to exhaustion, rectal temperature, changes in plasma volume, and sweat volume.

Results: Time to exhaustion did not differ among drinks (PJ = 77.4 ± 5.9 minutes, hypertonic saline = 77.4 ± 4.0 minutes, DIW = 75.7 ± 3.2 minutes; $F_{2,16} = 1.1$, $P = .40$). Core temperature of participants was similar among drinks (PJ = 38.7°C ± 0.3°C, hypertonic saline = 38.7°C ± 0.4°C, DIW = 38.8°C ± 0.4°C; $P = .74$) but increased from pre-exercise (36.7°C ± 0.2°C) to postexercise (38.7°C ± 0.4°C) ($P < .05$). No differences were observed for changes in plasma volume or sweat volume among drinks ($P > .05$).

Conclusions: Ingesting small amounts of PJ or hypertonic saline with water did not affect performance or select thermoregulatory measures. Drinking larger volumes of PJ and water may be more effective at expanding the extracellular space.

Key Words: acetic acid, core temperature, exhaustion, sodium, vinegar

Key Points

- Ingesting 2 mL/kg body mass of pickle juice (PJ) or hypertonic saline with water pre-exercise did not affect performance.
- Ingesting PJ or hypertonic saline did not alter final core temperature or sweat volume.
- Ingesting PJ or hypertonic saline with modest volumes of water did not cause plasma volume expansion.
- Ingesting small volumes of PJ with water before exercise is unlikely to affect athletic performance or select thermoregulatory variables, such as rectal temperature or sweat loss.

Many athletes use strategies to improve performance that have little or no scientific support. Common performance aids include hyperhydrating,[1] carbohydrate loading,[2] taking drugs (eg, anabolic steroids and amphetamines)[3] or nutritional supplements (eg, caffeine, creatine, or whey protein),[4,5] and drinking sport drinks.[6,7] Another common anecdotal strategy is ingesting pickle juice (PJ), a salty brine, before competition.[8]

Of 337 athletic trainers polled, 63 (19%) have given PJ to athletes to prevent exercise-associated muscle cramps.[8] Most of these clinicians instruct athletes to ingest 70 to 200 mL of PJ, provide it 30 to 60 minutes before exercise, and give unknown volumes of water concurrently to prevent cramping.[8] Ingesting small volumes (1 mL/kg body mass) of PJ reduces the duration of electrically induced muscle cramps[9]; preventing muscle cramps may allow athletes to perform better. Some scientists have advised against drinking PJ because they are concerned that the high sodium content may negatively affect performance by accelerating dehydration, prolonging rehydration, or causing stomach upset and nausea.[10–12]

Consuming solutions that have high sodium content, such as PJ, could have many positive physiologic effects for an exercising person. Ingesting sodium can help maintain

plasma sodium concentration,[13] increase the osmotic drive to drink[14] and ad libitum water consumption, and decrease urine output.[15] All of these effects would help maintain or expand plasma volume. Some researchers[16] have observed plasma volume expansions up to 5% before exercise when participants ingested a large volume (10 mL/kg body weight) of a drink containing sodium (164 mmol/L). Plasma volume expansion may allow athletes to sweat at higher rates and exercise with greater skin blood flow, thereby improving thermoregulation[17] and possibly preventing the premature fatigue resulting from a critical core temperature.[18] This may explain why some participants can exercise longer when they ingest beverages containing sodium.[16,19,20]

No researchers have conducted experimental studies to investigate how consuming PJ and water affects performance or thermoregulation. Therefore, the purpose of our study was to test whether current PJ ingestion practices (ie, providing small volumes of PJ with additional water) affect performance and thermoregulation. Specifically, we wanted to determine if ingesting small volumes of PJ, hypertonic saline, or deionized water (DIW) before exercise delays time to exhaustion or affects rectal temperature, changes in plasma volume, or sweat volume. We hypothesized that PJ and hypertonic saline would delay time to exhaustion, increase plasma volume and sweat rate, and reduce final rectal temperature during exercise compared with DIW.

METHODS

Experimental Design

A crossover, factorial, repeated-measures design guided data collection. The independent variables were time (preingestion and 30 minutes postingestion) and drink (PJ [strained from whole dill pickles, Vlasic Pickles, Pinnacle Foods Group LLC, Cherry Hill, NJ], a hypertonic saline drink with sodium content similar to PJ, and DIW). Hypertonic saline was given as a treatment drink to determine if any ingredients in PJ besides the sodium affected the variables examined. The dependent variables were time to exhaustion (minutes), sweat volume (liters), change in plasma volume (percentage change compared with preingestion), and rectal temperature (centigrade). We measured urine specific gravity to ensure that participants were euhydrated when they began testing. Plasma potassium concentration, plasma sodium concentration, plasma osmolality, and plasma glucose concentration were measured and are reported descriptively to characterize the extracellular fluid space before and after drink ingestion.

Participants. Twelve healthy men volunteered for this study. Nine men (age = 22 ± 3 years, height = 184.0 ± 8.2 cm, mass = 82.6 ± 16.0 kg) completed testing. Two volunteers discontinued participation due to time conflicts and 1 because he was unable to perform the exercise testing protocol. Volunteers were excluded if they self-reported (1) any injury in the 3 months before data collection that would limit their abilities to exercise; (2) any surgery within the 6 months before data collection; (3) any neurologic, cardiovascular, or bloodborne diseases; (4) living a sedentary lifestyle (exercising less than 30 minutes 3 times per week)[21]; (5) a food allergy to pickles; or (6) a history of heat-related illness (eg, heat stroke, heat exhaustion, heat syncope). All participants provided written informed consent before participation, and the study was approved by the Institutional Review Board of North Dakota State University.

Testing Procedures. Participants completed 3 days of testing at least 48 hours apart. Twenty-four hours before testing, participants were instructed to drink water consistently and avoid exercise, high-sodium foods, alcohol, and caffeine. They were instructed to keep their diets consistent until they completed the experiment and to consume a similar meal the night before testing. Participants also fasted 12 hours and self-reported compliance before testing. During the 12-hour fast, they were encouraged to drink water.

Participants reported to a human performance laboratory, provided written consent, voided their bladders, and were weighed (model DA150 scale; Denver Instruments, Bohemia, NY) in shorts and socks to the nearest hundredth of a kilogram (body weight measurement 1). Urine specific gravity was assessed with a refractometer (model SUR-Ne; Atago USA Inc, Bellevue, WA) to determine if they were euhydrated (urine specific gravity $\leq$1.02).[22] If hypohydrated, participants were excused and instructed to return at least 24 hours later. If euhydrated, participants donned heart rate monitors (Polar Electric Inc, Lake Success, NY) and inserted rectal thermistors (Yellow Spring Instruments 4600, Advanced Industrial Systems Inc, Prospect, KY) at least 10 cm past the anal sphincter.

They were seated with their arms resting on a padded treatment table. The cubital fossa was cleaned with isopropyl alcohol, and a sterile catheter (BD, Franklin Lakes, NJ) was inserted into a superficial forearm vein. Participants remained seated for 30 minutes to allow fluid compartment equilibration. After this 30-minute equilibration period, a 5-mL baseline blood sample was collected. Participants then had 1 minute to ingest 2 mL/kg body weight of the treatment drinks: PJ, hypertonic saline, or DIW. Next, they had 4 minutes to ingest 5 mL/kg body weight of DIW. After they sat for 30 minutes, a second 5-mL blood sample was collected.

Participants voided their bladders completely, were weighed again (body weight measurement 2), entered an environmental chamber (temperature = 38.3°C ± 1°C, relative humidity = 21.1% ± 4.7%), and began performance testing by exercising for 30 minutes on a treadmill (model TMX425C; TrackMaster, Newton, KS) at 50% of their age-predicted maximal heart rates. After this 30-minute period, the treadmill's speed increased so that participants exercised at 10% more of their maximal heart rates. Thus, after the first 30 minutes, they exercised at 60% of their maximal heart rates. Exercise intensity increased every 10 minutes thereafter by 10% increments up to 90% of their maximal heart rates. If participants were able to run for more than 10 minutes at 90% of their maximal heart rates, treadmill speed was increased to 95% of their maximal heart rates, and no further adjustments were made. The exercise protocol was terminated when the participant was too fatigued to continue or rectal temperature exceeded 39.5°C. Rectal temperature was recorded every 10 minutes during exercise; however, only the final rectal temperatures were used for analysis. To ensure maximal effort, the primary investigator (J.P.) provided oral encouragement during testing.

After performance testing, participants exited the environmental chamber, towel dried, and were weighed (body weight measurement 3). Body weight measurement 3 was subtracted from body weight measurement 2 to calculate sweat volume lost, assuming that 1 kg of mass lost was equivalent to 1 L of fluid lost. Participants then removed the rectal thermistors and were excused. They were instructed to report for subsequent testing sessions at least 48 hours later. Testing occurred at the same time of day and only varied in the treatment fluid ingested. Treatment-fluid order was counterbalanced using half of the total possible combinations of fluid orders and was assigned randomly.

To minimize bias, several precautions were taken. Participants were not told what they would be drinking or any potential effects the drinks might have on performance. They were not told that the primary purpose of the study was to determine the effects of the fluids on performance. The primary investigator was blinded to the drink ingested each day. To prevent olfactory detection of the drinks, participants and investigators wore nose plugs before ingestion and then removed them after ingesting the fluid. Visual detection of the drinks was prevented by using opaque bottles and having a research assistant prepare the drinks. We attempted to blind participants to the exact time they spent running on the treadmill. Participants were instructed not to make any faces, gestures, or remarks regarding the contents of the water bottles.

Blood Analysis Procedures. We analyzed 1 mL of whole blood for hematocrit and hemoglobin concentration. Blood for hematocrit analysis was drawn into heparinized microcapillary tubes and centrifuged at 3000 rpm (model IEC Micro-MB; International Equipment Co, Needham Heights, MA) for 5 minutes and read using a microcapillary reader (model IEC 2201; Damon/IEC, Needham Heights, MA). Hemoglobin concentration was measured by mixing 20 μL of whole blood with 5 mL of cyanomethemoglobin reagent, and the absorbance was read at 540 nm on a standard spectrophotometer (iMark Spectrophotometer; Biorad, Hercules, CA). Hematocrit and hemoglobin concentrations were measured in triplicate immediately after sampling and were averaged for each blood sample so that statistical analyses and calculations could be performed. Changes in plasma volume were calculated by inserting hematocrit and hemoglobin data into the Dill and Costill[23] equation.

The remaining blood was centrifuged at 3000 rpm for 15 minutes at 3°C. Plasma was removed, analyzed for plasma osmolality using freezing-point depression osmometry (model 3D3; Advanced Instruments Inc, Norwood, MA), and frozen (–80°C). Samples were later thawed and analyzed in duplicate for plasma sodium concentration, plasma potassium concentration, and plasma glucose concentration with an ion-selective electrode analyzer (model NOVA 16; Nova Biomedical, Waltham, MA).

Statistical Analysis

Differences in time to exhaustion, percentage change in plasma volume, rectal temperature, and sweat volume were analyzed among drinks over time using separate repeated-measures analyses of variance with NCSS (version 2007, NCSS, Kaysville, UT). Tukey-Kramer multiple comparison tests were used when we observed F values that were different for interactions or main level effects. Greenhouse-Geisser corrections were used when sphericity was violated. Data are reported as means ± standard deviations. The α level was set at .05.

RESULTS

Participants self-reported compliance with all pretesting instructions and were similarly euhydrated before testing (urine specific gravity: PJ = 1.006 ± 0.003, hypertonic saline = 1.007 ± 0.005, DIW = 1.006 ± 0.003; $F_{2,16} = 0.1$, $P = .83$).

The composition of each treatment drink is presented in Table 1. Participants ingested 166.0 ± 33.7 mL of PJ, 164.9 ± 33.4 mL of hypertonic saline, and 165.6 ± 33.0 mL of DIW. As a result, they ingested 1.5 ± 0.3 g, 1.5 ± 0.3 g, and 0 ± 0 g of sodium, respectively. Participants also ingested 415.0 ± 84.3 mL, 412.2 ± 83.4 mL, and 413.9 ± 82.6 mL of DIW after ingesting PJ, hypertonic saline, and DIW treatments, respectively, before exercise. Based on the sodium content ingested and the volume of DIW consumed after each treatment drink, the stomach contents had a sodium concentration of 112.6 ± 1.2 mmol/L for PJ, 113.6 ± 1.0 mmol/L for hypertonic saline, and 0 ± 0 mmol/L for DIW.

Participants lost similar volumes of sweat during exercise on each testing day (PJ = 1.1 ± 0.3 L, hypertonic saline = 1.1 ± 0.4 L, and DIW = 1.2 ± 0.3 L; $F_{2,16} = 0.6$, $P = .59$). Plasma variables pretreatment and posttreatment drink ingestion are presented in Table 2, where plasma sodium concentration, plasma potassium concentration, and plasma glucose concentration are reported descriptively. For percentage change in plasma volume, no interaction ($F_{2,16} = 1.3$, $P = .31$), main effect for treatment drink ($F_{2,16} = 1.3$, $P = .31$), or time effect ($F_{1,8} = 1.5$, $P = .27$) was observed.

Time to exhaustion did not differ among treatment drinks (PJ = 77.4 ± 5.9 minutes, hypertonic saline = 77.4 ± 4.0 minutes, DIW = 75.7 ± 3.2 minutes; $F_{2,16} = 1.1$, $P = .40$). We did not observe an interaction ($F_{2,16} = 0.7$, $P = .51$) or treatment drink effect ($F_{2,16} = 0.3$, $P = .74$) for final rectal temperature during exercise (PJ = 38.7°C ± 0.3°C, hypertonic saline = 38.7°C ± 0.4°C, DIW = 38.8°C ± 0.4°C). However, we observed a time effect ($F_{1,8} = 250.2$, $P < .001$). Rectal temperature was higher postexercise (38.7°C ± 0.4°C) than pre-exercise (36.7°C ± 0.2°C) ($P < .05$).

DISCUSSION

Three findings emerged from our investigation. First, ingesting 2 mL/kg body mass of PJ or hypertonic saline with water before exercise did not affect performance. Second, PJ or hypertonic saline ingestion did not alter final core temperature or sweat volume. Third, ingesting PJ or hypertonic saline with modest volumes of water did not cause plasma volume expansion. The clinical implications of these points are that ingesting small volumes of PJ with water before exercise is unlikely to affect athletic performance or select thermoregulatory variables, such as rectal temperature or sweat loss.

Plasma Volume and Time to Exhaustion

Previous investigators[16,20,24] examining performance after salt ingestion have attributed athletes' ability to exercise longer to plasma volume expansion before

Table 1. Treatment Drink Composition (Mean ± SD)

	Drink[a]		
	Pickle Juice	Hypertonic Saline	Deionized Water
Osmolality, mOsmol/kg H_2O	853 ± 2.8	726.5 ± 2.1	0 ± 0
Specific gravity	1.020 ± 0	1.012 ± 0	1.000 ± 0
pH	3.82 ± 0.01	5.89 ± 0.04	5.86 ± 0.11
Sodium concentration, mmol/L	395 ± 0	402.5 ± 3.5	Nondetectable
Potassium concentration, mmol/L	29.5 ± 0.7	0 ± 0	Nondetectable
Chloride concentration, mmol/L	317.5 ± 17.7	390.0 ± 0	Nondetectable
Glucose concentration, mmol/L	26.6 ± 2.3	Nondetectable	Nondetectable

[a] Pickle juice, hypertonic saline, and deionized water characteristics were measured in duplicate.

exercise. Scientists[24,25] have observed rapid plasma volume expansions when euhydrated participants ingested large volumes of hypertonic sodium solutions before exercise. Greanleaf et al[24] and Sims et al[16] noted similar plasma volume expansions (approximately 5%) when participants ingested 10 mL/kg body weight (approximately 757 mL) of a sodium (164 mmol/L) drink 105 minutes before exercise. After the high sodium ingestion, Greenleaf et al[24] noted that participants were able to exercise 6 minutes longer at 87% to 91% of peak oxygen consumption. Sims et al[16] reported that participants were able to exercise 11.5 minutes longer before core temperature reached 39.5°C and 20.8 minutes longer to complete exhaustion when exercise intensity was 70% maximal oxygen consumption.

We did not observe a plasma volume expansion before exercise or delayed time to exhaustion. Most likely, this observation is because the sodium content ingested in the PJ and hypertonic saline trials was not great enough to increase extracellular sodium concentration and, thus, the osmotic fluid pressure. Our participants ingested approximately 1.5 g of sodium and approximately 415 mL of water in the PJ and hypertonic saline trials. Thus, the sodium concentration of the fluid in the stomach was less than that of the plasma (112 mmol/L versus 141 mmol/L, respectively). Our plasma sodium concentration data confirmed that negligible changes occurred by the end of exercise in each fluid condition. Our data also suggested that the additional metabolites (eg, acetate, glucose, chloride) ingested in the PJ condition did not contribute to the development of an osmotic gradient that favored fluid movement into the vasculature. These observations confirm those of other authors who have shown that ingesting small volumes of PJ without water before[26] or after[27] exercise does not increase plasma osmolality or plasma sodium concentration.

Some authors[11,12] have speculated that ingesting PJ would exacerbate dehydration, delay rehydration, or result in nausea and abdominal cramps. As such, performance may be affected if athletes do not feel well at the onset of exercise. To date, researchers[9,26–28] have not observed nausea or abdominal cramps after the ingestion of small amounts of PJ (eg, 1 mL/kg body mass). These symptoms have been observed after ingestion of salt tablets and large volumes of water,[29,30] large volumes of isotonic and hypertonic sodium drinks,[31] or large volumes of PJ (ie, 7 mL/kg body mass).[32] None of our participants experienced upset stomach or abdominal cramping after PJ ingestion, and finishing times were similar between trials.

Plasma Volume and Core Temperature

Hypohydration reduces the body's ability to dissipate heat storage by decreasing sweat rate and skin blood-flow response.[17] Some authors have theorized that ingesting

Table 2. Plasma Variables Preingestion and Postingestion (Mean ± SD) (n = 9)

	Drink[a]		
	Pickle Juice	Hypertonic Saline	Deionized Water
Plasma volume, % change from preingestion			
Preingestion	0 ± 0	0 ± 0	0 ± 0
Postingestion	−0.9 ± 4.1	1.9 ± 3.1	1.0 ± 3.3
Plasma osmolality, mOsmol/kg H_2O			
Preingestion	284 ± 4	283 ± 2	284 ± 4
Postingestion	285 ± 3	284 ± 2	282 ± 4
Plasma sodium concentration, mEq/L (mmol/L)			
Preingestion	141.5 ± 1.2 (141.5 ± 1.2)	140.7 ± 1.5 (140.7 ± 1.5)	141.6 ± 1.4 (141.6 ± 1.4)
Postingestion	141.6 ± 1.2 (141.6 ± 1.2)	141 ± 0.5 (141 ± 0.5)	140.4 ± 1.5 (140.4 ± 1.5)
Plasma potassium concentration, mEq/L (mmol/L)			
Preingestion	4.0 ± 0.2 (4.0 ± 0.2)	3.9 ± 0.2 (3.9 ± 0.2)	4.0 ± 0.2 (4.0 ± 0.2)
Postingestion	4.0 ± 0.2 (4.0 ± 0.2)	4.0 ± 0.3 (4.0 ± 0.3)	4.0 ± 0.1 (4.0 ± 0.1)
Plasma glucose concentration, mg/dL (mmol/L)			
Preingestion	99.10 ± 7.21 (5.5 ± 0.4)	93.69 ± 5.41 (5.2 ± 0.3)	97.30 ± 5.41 (5.4 ± 0.3)
Postingestion	97.30 ± 7.21 (5.4 ± 0.4)	93.69 ± 5.41 (5.2 ± 0.3)	95.50 ± 3.60 (5.3 ± 0.2)

[a] Plasma osmolality, plasma sodium concentration, plasma potassium concentration, and plasma glucose concentration are reported descriptively for each drink.

hypertonic solutions, such as PJ, may accelerate dehydration[11] or may cause overheating due to the lack of hypotonic fluid needed to restore plasma volume.[10] We observed no differences in plasma volume changes when PJ, hypertonic saline, or DIW was given as a treatment before ingesting 5 mL/kg body weight of DIW.

Plasma volume expansion may delay the rise in temperature that occurs during exercise. In another study,[16] participants were able to exercise longer and at core temperatures that were 0.4°C lower when they ingested a high-sodium (164 mmol/L) drink versus a low-sodium drink (10 mmol/L). Given that sweat rates and volumes were similar between sodium trials, the core temperatures of participants may have been lower due to the 4.5% increase in plasma volume before exercise.[16] The authors speculated that an expansion of the extracellular space may have reduced cardiac stress and total work during exercise, thereby decreasing the amount of heat produced.[16] Given that plasma volume changes and sweat volumes were similar between treatment drinks in our study, it is not surprising that rectal temperatures remained consistent between trials.

Limitations

Four limitations must be addressed. First, our participants were instructed to come to each session well hydrated. It is possible that participants overhydrated before reporting to the laboratory and the effects of the treatment drinks were masked by the hyperhydration before testing. The National Athletic Trainers' Association[33] has recommended that athletes consume moderate to large volumes (500 to 600 mL) of fluids 2 to 3 hours before exercise and an additional 200 to 300 mL 10 to 20 minutes before exercise. Second, participants did not ingest enough sodium in the PJ and hypertonic saline trials to create a favorable osmotic gradient to encourage water to shift into the vascular space. The volume of PJ consumed in our study was chosen because 87% (80 of 92) of athletic trainers polled give their athletes $<$200 mL of PJ to prevent muscle cramps[8]; our main purpose was to test the effect of this practice on performance and thermoregulation. Third, our method of testing may have incorporated more anaerobic fatigue than other protocols assessing the effects of drinks on exercise performance.[16,20,24] With our protocol slowly accelerating to 95% of participants' maximal heart rates, anaerobic failure may have caused them to terminate exercise earlier. This protocol was chosen to replicate a short-distance race or sports in which athletes appear to use PJ most frequently to prevent cramping (eg, American football and basketball).[34,35] Fourth, given our blinding and termination protocol, we were unable to measure distance run for this study.

CONCLUSIONS

Our data indicated that drinking small volumes of PJ or hypertonic saline before ingesting modest amounts of water had no effect on aerobic performance, rectal temperature, sweat volume, or plasma volume. The inability of PJ or hypertonic saline to expand plasma volume is most likely due to the dilution of these drinks in the stomach and the inability to create an osmotic gradient that favored fluid movement into the vascular space. Consuming more PJ with water may increase plasma volume and enhance performance and core temperature maintenance. Future researchers may want to evaluate this possibility.

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Address correspondence to Kevin C. Miller, PhD, AT, ATC, School of Rehabilitation and Medical Sciences, Central Michigan University, 1208 Health Professions Building, Mount Pleasant, MI 48859. Address e-mail to mille5k@cmich.edu.