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Metabolic Responses to Exercise

PHYSIOLOGICAL RESPONSES TO IYENGAR YOGA PERFORMED BY TRAINED PRACTITIONERS

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ABSTRACT

Blank SE. Physiological Responses to Iyengar Yoga Performed by Trained Practitioners. ***JEP****online* 2006;9(1):7-23. The purpose of the study was to evaluate acute physiological responses to Hatha yoga asanas (poses) practiced in the Iyengar tradition. Preliminary data were collected on the impact of postural alignment on physiological responses. Intermediate/advanced level yoga practitioners (n=15 females) were monitored for heart rate (HR), oxygen uptake (VO_2), and brachial arterial blood pressure (n = 9) during a 90 min practice. The subjects, aged 43.5 ± 6.9 yr (average ± SD), had current weekly practice of 6.2 ± 2.4 hr/week and practice history 9.2 ± 7.2 yr. Physical characteristics of the subjects included: height (167.3 ± 4.1 cm), body mass (59.3 ± 7.2 kg), and percent body fat (23.1 ± 3.6 %). The practice included supine, seated, standing, inversions, and push up to back arch asanas maintained for 1-5 min. Physiological responses were significantly (p<0.05) greater in standing asanas, inversions, and push up to back arch versus supine and seated asanas. The average metabolic equivalent (MET) of each pose did not exceed 5 METs. The practice expended 149.4 ± 50.7 Kcal. The cumulative time spent within a HR zone of 55-85% HRmax was 29.7 ± 15.9 min (range = 10.8 – 59.9 min). Asana practice was classified as mild to moderate intensity exercise without evidence of a sustained cardiopulmonary stimulus. Intermediate and advanced practitioners maintained poses for up to 5 min without stimulating an undesirable pressor response. However, postural alignment significantly influenced blood pressure responses indicating that adherence to precise alignment has relevant physiological consequences for the yoga practitioner.

Key Words: Oxygen uptake, METs, Heart Rate, Pressor Response

INTRODUCTION

Yoga is an ancient Indian philosophy that encompasses eight limbs: 1) universal ethical principles, 2) rules of personal conduct, 3) the practice of yoga asanas, 4) the practice of yoga breathing techniques, 5) control of the senses, 6) concentration of the mind, 7) meditation, and 8) absorption of the infinite (1). The word Yoga, means “union”, “joining”, or “yoke” and yoga practice seeks to join the three components of each person: body, mind, and soul (1). There are various methods or systems of yoga. However, each system emphasizes a unique way to balance the physical need of body for health, the psychological need of the mind for knowledge, and the spiritual need of the soul for inner peace (2). The practice of Hatha yoga postures generally incorporates nine types of asanas: standing, sitting, twists, supine and prone poses, inversions, balancing poses, backbends, jumping, and relaxation.

Hatha yoga asanas taught according to the Iyengar tradition emphasize the balance of energy flows within the body and should be practiced with precise body alignment, muscular balance, and maximal spinal extension. This tradition differs from other popular types of yoga such as Ananda Yoga (gentle postures with focus on yogic breathing and use of silent affirmations), Astanga Yoga (Power Yoga is based on Astanga style, poses are sequenced in a series of flow and jumps), Bikram Yoga (26 beginning poses, taught at a recommended ambient temperature of 105º degrees and 60% humidity) and Sivananda Yoga (emphasizes five points of yoga: asanas, pranayama – yogic breathing, relaxation, lacto-vegetarian diet, and meditation). Iyengar yoga, developed by B.K.S. Iyengar, is unique in its inclusion of props to assist particularly the beginning practitioner in maintaining precise postural alignment in every pose. With this type of practice, self-discipline and self-awareness are developed through mindfulness of body alignment and balance (3).

A committed classical yoga asana practice can benefit cardiovascular health (4). However, few investigations have focused on quantification of the physical work of asanas and the work-related physiological adjustments during asana practice. The purposes of the study were to evaluate acute physiological responses to Hatha yoga practiced in the Iyengar tradition and to examine the impact of postural alignment on these physiological responses. Yoga asanas practiced according to the Iyengar tradition represent a classical system of Hatha yoga that is taught worldwide by trained and certified instructors. Because Iyengar yoga practice can incorporate physically demanding postures unattainable by most beginning students, physiological responses in this study were assessed on intermediate and advanced level Iyengar yoga practitioners.

The following hypotheses were tested. Physiological responses would not be altered by the: 1) type of asana, 2) duration of asana, or 3) postural alignment during practice.

METHODS

Subjects

Intermediate and advanced level yoga practitioners (n = 15 females) were monitored for heart rate (HR), oxygen uptake (VO_2) and brachial arterial blood pressure was monitored (n=9) during a 90-min asana practice. Blood pressure measures were not measured on all subjects due to unavailability of the equipment during testing of six of the subjects. The subjects were recruited from local yoga centers offering classes in the Iyengar tradition. Subjects were tested in the human exercise physiology laboratory in the morning or late afternoon. At least one day prior to testing, subjects arrived at the laboratory, gave written informed consent to participate in the study, and were acclimated to testing procedures. A yoga mat and props (e.g., blocks and blankets) were provided during the acclimation period and testing. Subjects were excluded from the study if any of the following applied: tobacco use, prescription drug use for metabolic conditions and/or myocardial function and/or blood pressure regulation, illegal drug use, food intake less than four hours prior to testing, caffeine and/or alcohol intake less than eight hours prior to testing, exercise less than twelve hours prior to testing, injury and/or illness. Washington State University's Institutional Review Board approved the study and written consent was obtained before data collection.

Procedures

Subject height, body mass, and body composition were measured on the day of testing prior to asana practice. Body composition was determined by the bioelectrical impedance technique (Omron HBF-301 Body Fat Analyzer, Omron Healthcare, Inc., Schaumburg, IL). Subjects followed a video taped practice developed and narrated by a certified Iyengar yoga instructor. The practice (Table 1, Figure 1) consisted of a sequence of asanas in the following order: a) 5 min seated kneeling pose, b) "warm-up" asanas (~ 5 min seated and standing stretches), c) individual asanas (~65 min), d) releasing asanas (~10 min standing or seated twists), and e) corpse pose (5 min). Throughout the practice, subjects were given continual visual and auditory instructions via the video tape recording. All subjects were encouraged to remain in each pose for the entire pre-determined duration, which was established on the basis of traditional yogic philosophy and expected physical ability of the yoga practitioners. The subjects were also instructed not to "struggle" in the pose. If a subject was not capable of maintaining the pose for the desired duration, she was instructed to come out of the pose and assume a resting posture. The designated time for each asana, which varied from one to five min, and the actual time that subjects remained in the poses are shown in Table 1.

Table 1. Iyengar yoga asana sequence.

Asana (Sanskrit name)	Time[¥] (min)	Pose Time (min)
Seated kneeling pose (Virasana)	5	4.85 ± 0.25
Sitting twists[§]	5	~5
Downward facing dog (Adho Mukha Svanasana)	2	1.93 ±0.15
Standing forward bend (Utanasana II)	2	1.78 ± 0.18
Tree pose (Vrksasana)	2	1.71 ± 0.53
Handstand at wall (Adho Mukha Vrksasana)	2	1.20 ± 0.42
Headstand (Salamba Sirsasana I)	5	4.39 ± 0.86
Child's pose (Adho Mukha Virasana [§])	2	~ 2
Triangle (Utthita Trikonasana)	2	1.77 ± 0.15
Warrior II (Virabhadrasana II)	2	1.62 ± 0.32
Extended side angle pose (Utthita Parsvakonasana)	2	1.61 ± 0.25
Warrior I (Virabhadrasana I)	2	1.46 ± 0.33
Adho Mukha Virasana [§]	2	~2
Half-moon pose (Ardha Chandrasana)	1	1.42 ± 0.25
Side flank stretch (Parsvottanasana)	1	0.83 ± 0.17
Revolved Triangle (Parivrtta Trikonasana)	1	0.86 ± 0.17
Warrior III (Virabhadrasana III)	1	0.64 ± 0.20
Utanasana[§]	1	~1
Bridge pose (Setu-Bandha)	2	1.95 ± 0.25
Bridge on block under sacrum (Setu-Bandha)	2	1.81 ± 0.32
Back Arch (Urdhva Dhanurasana)	2	1.27 ± 0.43
Shoulderstand (Salamba Sarvangasana)	5	4.49 ± 0.55
Releasing poses and standing twists[§]	10	~10
Corpse pose (Savasana)	5	5.18 ± 0.38

Values are means ± SD. [¥]Time standing poses were held for twice the duration shown. [§]Not included in analyses.

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Figure 1. Asanas performed according to the Iygengar tradition. Photos represent: A) Seated kneeling pose (Virasana), B) Downward facing dog (Adho Mukha Svanasana), C) Standing forward bend (Utanasana II), D) Tree pose (Vrksasana), E) Handstand (Adho Mukha Vrksasana), F) Headstand (Salamba Sirsasana I), G) Child's pose (Adho Mukha Virasana), H) Triangle (Utthita Trikonasana), I) Warrior II (Virabhadrasana II), J) Extended side angle pose (Utthita Parsvakonasana), K) Warrior I (Virabhadrasana I), L) Half-moon pose (Ardha Chandrasana), M) Side flank stretch (Parsvottanasana), N) Revolved Triangle (Parivrtta Trikonasana), O) Warrior III (Virabhadrasana III, P) Bridge On Block (Setu-Bandha), Q) Bridge Under Sacrum (Setu-Bandha), R) Push up to back arch (Urdhva Dhanurasana), S) Shoulderstand (Salamba Sarvangasana), T) Corpse pose (Savasana).

Heart rate, VO_2, estimated metabolic equivalents (METs, 1 MET = 3.5 mL/kg/min), and O_2 pulse (an indirect measure of stroke volume of the heart, (5)) data were determined from an online breath-by-breath open circuitry gas analysis system (Viasys Health Care, Yorba Linda, CA) with 3-lead ECG using either the standard mouth breathing apparatus (n=6) or a two-way non-rebreathing nasal and mouth face mask (n = 9, Hans Rudolph, Inc, Kansas City, MO). The system was calibrated with standardized gases (26% oxygen, balance nitrogen; 16% oxygen, 4% carbon dioxide, balance nitrogen; Viasys Health Care). Measures of O_2 pulse were considered valid indirect estimates of stroke volume of the heart for asanas sustained for five min (i.e., seated kneeling pose, headstand, shoulderstand, and corpse pose). Subjects also wore a HR monitor (Polar Electro Inc., Woodbury, NY) to validate ECG data. HRmax was predicted as 220-age in years (6). HR data were averaged across each 10-s measurement.

Data from the standing poses were collected twice, first from postures with a lead right leg and then from a lead left leg. Data were collected throughout the duration of the asana and values were averaged across the last 30 s of the pose. Brachial blood pressure was determined using a Tango Stress Test BP Monitor (SunTech Medical Instruments, Inc., Raleigh, NC), which was calibrated by the manufacturer prior to use and validated on-site by comparison with manual auscultation using a calibrated aneroid sphymomanometer. Systolic blood pressure (SBP), diastolic blood pressure (DBP), mean arterial pressure (MAP) and the double product (HR x SBP, DP) measurements were taken within the last 30 s of each asana. Data from standing poses were combined and averaged. Steady state conditions occurred during the 5 min asanas; HR did not vary by more that 5 beats/min between the 4^{th} and 5^{th} min. Asanas lasting less than 5 min were considered non steady state conditions. An eight-year Iyengar yoga practitioner with teacher training experience subjectively evaluated each subject's postural alignment during the laboratory testing to provide preliminary data on the impact of postural alignment on physiological responses. Subjects were assessed for postural alignment in the frontal, transverse, and sagittal planes and the poses were scored from 1-4, where 4 = near ideal posture, 3 = moderate mal-alignment in no more than one plane, 2 = moderate mal-alignment in two or three planes, and 1 = severe mal-alignment in all planes.

Statistical Analyses

Data were tested for normality and equal variance. Differences were considered statistically significant at a two-tailed critical alpha of 0.05. Data were analyzed by General Linear Model multivariate analysis of variance (ANOVA) (SPSS, Inc., Chicago, IL). No significant interactions existed between any variables; therefore, post-hoc analyses on main effects were done using t-tests with a Bonferonni adjustment.

RESULTS

Subject Demographics

Fifteen women, aged 43.5 ± 6.9 yr (average ± SD), with current weekly practice 6.2 ± 2.4 hr/wk, and practice history 9.2 ± 7.2 yr participated in the study. Physical characteristics of the subjects included: height (167.3 ± 4.1 cm), body mass (59.3 ± 7.2 kg), and percent body fat (23.1 ± 3.6%).

Physiological Responses To Iyengar Yoga Asanas

Heart Rate and Blood Pressure Responses

The cumulative time spent within a HR zone of 55-85% HRmax was 29.7 ± 15.9 min (range = 10.8 – 59.9 min). Asanas were assigned to one of five pose categories: supine, seated, standing, back arch, and inversion poses. Significant main effects were observed for pose category on HR ($p < 0.001$), %HRmax, ($p < 0.001$, Figure 2), SBP ($p < 0.05$, Figure 3), DBP ($p < 0.001$, Figure 3), MAP ($p < 0.001$, Figure 3), DP ($p < 0.05$, Table 2) and for alignment on MAP ($p < 0.05$). None of the subjects exhibited postures that were classified as severe mal-alignment. Standing, back arch, and inversion poses produced significantly ($p < 0.05$) greater HR, SBP, DBP, MAP responses than occurred in the supine (corpse or bridge poses) or seated kneeling poses. Significant ($p < 0.05$) main effects were observed for changes in

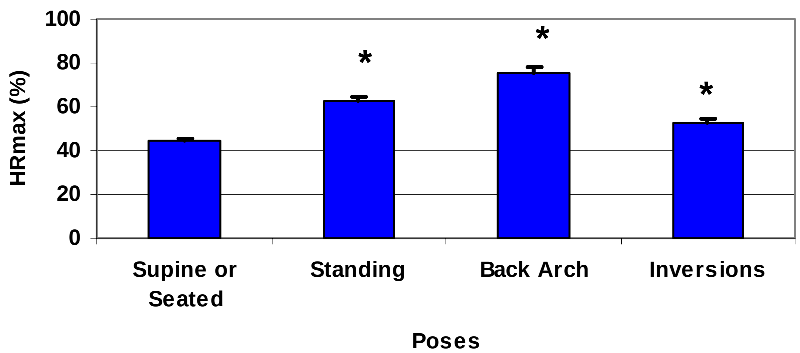

Figure 2. Heart rate response to asanas. Heart rate (HR) is expressed as %HRmax. Values are means + sem. Data for standing poses are the average of right and left lead legs. *Significant main effect of pose category versus supine or seated poses

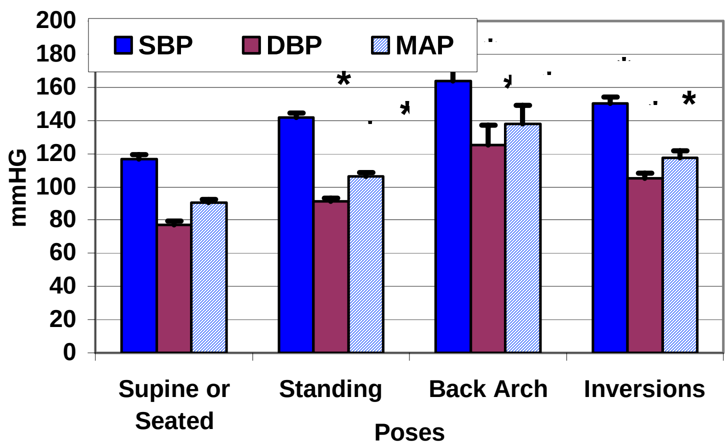

Figure 3. Blood pressure response to asanas. Values for Systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) are means + sem. Data for standing poses are the average of right and left lead legs. *Significant main effect of pose category versus supine or seated poses.

MAP (Figure 4) during standing, back arch, and inversion poses relative to seated kneeling pose, which was used as a meditative pose at the beginning of the practice.

Table 2. Ventilatory and Blood Pressure Responses to Asanas.

Asana	$\dot{V}_E$ (L/min)	Tidal Volume (L)	Breathing frequency (br/min)	SBP/DBP (mm Hg)	MAP (mmHg)	Double Product
Corpse pose	6.78 ± 2.03	0.84 ± 0.35	9.54 ± 5.68	112.55 ± 17.26 / 70.44 ± 11.40	84.48 ± 13.16	78 ± 17
Seated kneeling pose	7.25 ± 2.07	0.98 ± 0.23	8.08 ± 0.2.23	122.38 ± 14.88 / 83.0 ± 13.48	96.13 ± 13.59	97 ± 23
Bridge pose	12.90 ± 3.02	0.95 ±0.31	15.69±5.85	120.78 ± 17.58 / 76.89 ± 12.21	91.52 ± 13.66	94 ± 24
Bridge on block under sacrum	11.07 ± 4.07	0.90 ±0.29	13.92±6.75	111.44 ± 15.82 / 79.33 ± 11.44	90.04 ± 12.43	96 ± 20
Tree pose	13.73±3.90	0.93 ±0.32	16.40±5.24	115.00 ± 14.75 / 71.28 ± 11.86	85.85 ± 12.50	105 ±19
Triangle	16.47±5.55	0.94±0.29	19.48±7.04	134.67 ± 21.06 / 98.06 ± 12.40	110.26 ± 14.39	125 ±33
Half-moon pose	20.95±5.96	0.95±0.23	23.88±6.58	147.89 ± 19.64 / 102.78 ± 13.61	111.22 ± 24.65	158 ±45
Extended side angle pose	24.33±9.57*	1.11±0.31	23.21±6.82	156.94 ± 23.47 / 104.94 ± 13.70	122.28 ± 16.64	190 ±49*
Revolved Triangle	22.12±8.48*	1.00±0.38	24.08±6.06	144.72 ± 23.12 / 92.17 ± 12.84	109.69 ± 15.24	165 ±43*
Warrior I	25.42±7.78*	1.31±0.42	21.40±6.62	137.17 ± 15.39 / 79.00 ± 14.23	92.20 ± 18.51	173 ±47*
Warrior II	21.84±7.27*	1.22±0.48	20.21±6.25	151.89 ± 22.80 / 94.11 ± 13.75	113.37 ± 16.32	187 ±44*
Warrior III	28.69±7.73*	1.14±0.27	26.63±4.9 *	165.44 ± 21.93* / 104.72 ± 12.50	124.96 ±15.22*	219 ±48*
Side flank stretch	18.32±6.35	1.04±0.32	19.75±5.86	123.28 ± 12.90 / 74.39 ± 10.88	86.59 ± 21.88	117 ±40
Downward facing Dog	12.85±4.69	0.99±0.31	14.4±7.01	153.56 ± 22.70 / 100.67 ± 13.74	118.30 ± 15.11	130 ±30
Standing forward bend	11.38±3.51	1.10±0.27	11.19±5.49	131.33 ± 20.28 / 98.67 ± 11.64	109.56 ± 13.62	100 ± 26
Shoulder stand	15.83±4.60	0.84±0.26	21.08±7.51	152.00 ±28.72 / 94.75 ± 26.78	113.84 ± 25.82	134 ±34
Handstand	22.43±8.45*	1.26±0.53	19.96±5.76	165.88 ± 21.54* / 126.50 ± 17.47*	139.63 ±18.25*	200±56*
Headstand	13.30±3.17	1.05±0.51	15.40±6.20	151.38 ± 23.49 / 107.75 ± 14.95*	122.29 ± 16.94	151 ±46
Back arch	24.61±7.86*	1.08±0.39	24.73±7.65*	163.63± 30.99* / 125.25 ±33.64*	138.04±31.69*	226 ±48*

Values are means ± SD. *Significantly different from supine (corpse and bridge poses) or seated (seated kneeling) poses.

Comparisons made among standing, push up to back arch, and inversion postures, indicated a significant ($p < 0.05$) main effect of alignment on blood pressure responses. Moderate mal-alignment in two or three planes (alignment = 2 on 4 point scale) during standing and inverted poses produced significantly greater ($p < 0.05$) SBP, DBP, and MAP (Figure 5) during: half-moon pose, handstand, shoulderstand, and Warrior II and III than did near ideal alignment. Subjects with near ideal posture were capable of sustaining back arch for ~ 90-120 s whereas, subjects with mal-aligned poses maintained this pose for ~ 60 s. Practitioners (n = 3) with mal-alignment in one plane had significantly ($p < 0.05$) greater SBP, DBP, and MAP during push up to back arch than those (n = 2) with mal-alignment in two or three planes.

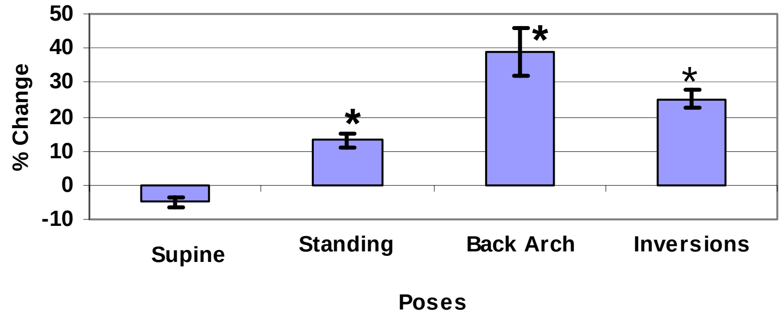

Figure 4. Comparison of Change in MAP during Asanas Relative to Seated Kneeling Pose. Mean arterial pressure (MAP) is expressed as percent change as compared with values for the five-min seated kneeling pose. Values are means ± sem. Data for standing poses are the average of right and left lead legs. *Significant main effect of pose category versus supine poses.

Comparisons were also made among all of the asanas, independent of pose category (Tables 2 and 3). Measures of HR ($p < 0.001$), age-predicted $\%HR_{max}$ ($p < 0.001$), SBP ($p < 0.05$), DBP ($p < 0.001$), and MAP ($p < 0.05$) significantly differed among the asanas. The duration of the pose also significantly altered HR ($p < 0.05$) and DP ($p < 0.05$) responses to asanas. Push up to back arch produced the greatest HR response during asana practice and corresponded with 75% HRmax. Warrior III, handstand, and push up to back arch produced the greatest SBP and MAP responses during the asana practice and these values were significantly different than blood pressure responses during supine and seated poses. Headstand, handstand, and push up to back arch significantly increased DBP as compared with supine or seated poses. The DP was significantly ($p < 0.05$) greater during extended side angle pose, revolved triangle, Warrior I, II, and III, handstand, and push up to back arch versus supine or seated poses.

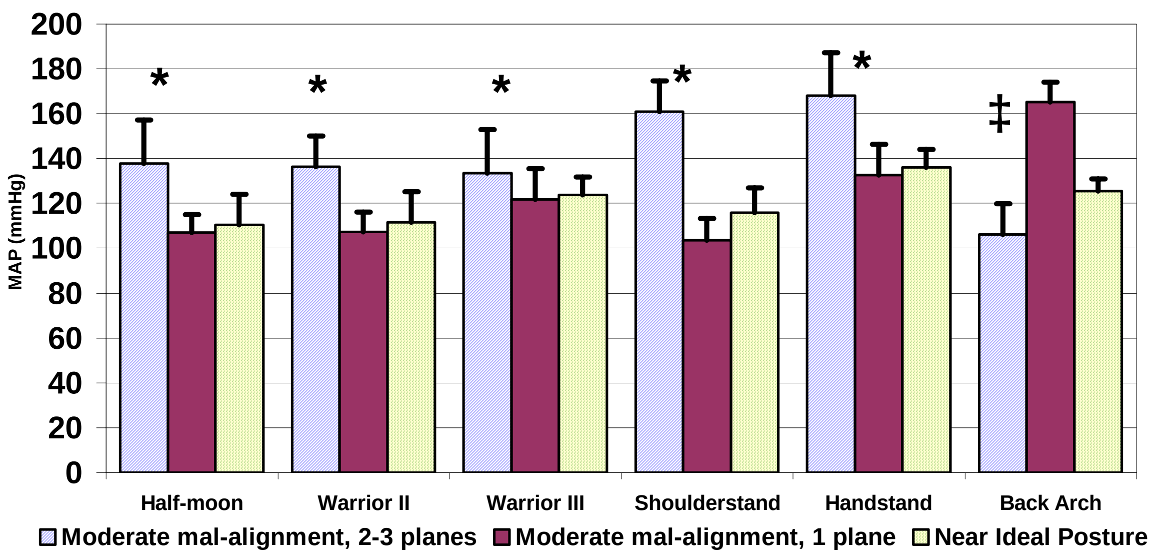

Figure 5. Influence of Postural Alignment on Mean Arterial Pressure. Values are means + sem for MAP. Data for standing poses are the average of right and left lead legs. Subjects were assessed for postural alignment in the frontal, transverse, and sagittal planes and the poses were scored from 1-4, where 4 = near ideal posture, 3 = moderate mal-alignment in no more than one plane, 2 = moderate mal-alignment in two or three planes, and 1 = severe mal-alignment in all planes. None of the subjects exhibited postures that were classified as severe mal-alignment. *Significantly different from near ideal posture. ‡Significantly different from moderate mal-alignment in one plane.

Table 3. Metabolic, HR, and Oxygen Pulse Responses to Asanas.

Asana	$\dot{V}O_2$ (mL/kg/min)	METs	HR (b/min)	%HRmax	O_2 Pulse (mL/b)
Corpse pose	3.64 ± 1.49	1.04 ± 0.43	70.20 ± 10.89	39.80 ± 6.08	3.13 ± 1.31
Seated kneeling pose	3.59 ± 1.46	1.03 ± 0.42	75.78 ± 9.52	43.09 ± 6.51	2.78 ± .96
Bridge pose	5.51 ± 1.97	1.57 ± 0.56	80.20 ±12.69	45.63 ± 7.98	
Bridge on block under sacrum	5.09 ± 2.04	1.45 ± 0.58	85.53 ± 12.08	48.60 ± 7.85	
Tree pose	7.13 ± 3.27	2.04 ± 0.93	92.23 ± 9.83	52.40 ± 6.59	
Triangle	8.30 ±4.04	2.37± 1.16	94.70 ± 14.49	53.84 ± 9.24	
Half-moon pose	9.89 ± 4.02	2.83 ± 1.15	110.60 ± 16.04	62.83 ± 10.00	
Extended side angle pose	11.04 ± 4.90	3.15 ±1.40	119.30 ± 19.33	67.70 ± 11.36	
Revolved Triangle	10.63 ± 5.04	3.04 ±1.44	111.40 ± 17.42	63.27 ± 10.63	
Warrior I	12.13 ± 3.91	3.47 ±1.12	127.57 ± 17.64	72.37 ± 10.22	
Warrior II	9.85 ± 3.82	2.81 ±1.09	121.00 ± 18.45	68.64 ± 10.70	
Warrior III	14.56 ± 5.39*	4.16 ±1.54*	126.71 ± 19.42	72.21 ± 11.85	
Side flank stretch	9.35 ± 4.36	2.64 ±1.25	97.57 ± 15.74	55.44 ± 9.77	
Downward facing Dog	7.01 ± 3.22	2.00 ± 0.92	86.67 ±10.45	49.26 ± 6.89	
Standing forward bend	5.69 ±2.14	1.62 ±0.61	81.00 ± 13.86	46.10 ± 8.90	
Shoulderstand	7.38 ±3.55	2.11 ±1.01	89.14 ± 11.86	50.60 ± 7.91	4.88 ± 2.05 *
Handstand	10.70 ± 4.57	3.06 ±1.31	111.80 ± 22.23	63.49 ± 13.02	
Headstand	6.33 ±2.32	1.81 ±0.66	96.15 ±27.84	54.12 ± 14.96	4.03 ± 1.42
Back arch	10.17 ± 4.13	2.91 ±1.18	132.94 ± 20.16*	75.42 ± 11.86*	

Values are means ± SD. *Significantly different from supine (corpse and bridge poses) and seated (seated kneeling) poses.

Ventilatory and Metabolic Responses

Significant ($p < 0.05$) main effects were observed for pose category (supine, seated, standing, back arch, and inversion poses) on minute ventilation (V_E, $p < 0.05$, Table 2), breathing frequency (f, $p< 0.001$, Table 2), VO_2 (L/min and mL/kg/min, $p< 0.001$, Table 3) and METs ($p < 0.05$, Figure 6).

Standing, back arch, and inversion poses produced significantly ($p < 0.05$) greater VO_2 and MET responses than occurred in the supine or seated postures. Oxygen uptake and oxygen pulse did not differ significantly between corpse pose and seated kneeling pose. Differences in the type of breathing apparatus used did not significantly affect minute ventilation ($p = 0.752$) or metabolic variables when postural alignment and time in the pose were statistically controlled. Oxygen pulse during shoulder stand was significantly ($p < 0.05$) greater than values obtained during seated kneeling pose. Differences in oxygen pulse during headstand versus seated kneeling pose were not statistically significant (Table 3).

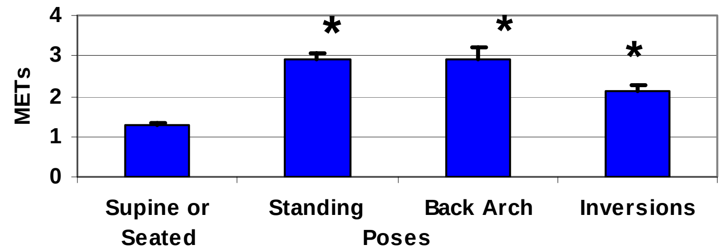

Figure 6. Metabolic responses to asanas. Values are means + sem for metabolic equivalents (METs). Data for standing poses are the average of right and left lead legs. *Significant main effect of pose category versus supine or seated poses.

Significant differences were observed when ventilatory and metabolic responses were compared among all of the asanas, independent of pose category (Tables 2 and 3). Minute ventilation, f, and VO_2 (L/min and mL/kg/min) significantly ($p < 0.001$) differed among the asanas. The most strenuous asanas in the practice, which elicited HR >60%HRmax and METs > 2.8, included: half-moon pose, extended side angle pose, revolved triangle, Warrior I, II, and III, handstand, and push up to back arch. Minute ventilation, f, and oxygen uptake were greatest during Warrior III pose. Warrior III sustained for one min required ~ 4.2 METs. The average cumulative metabolic expenditure for the 90-min practice was 149.4 ± 50.7 Kcal (range: 80.3 – 277.5).

DISCUSSION

Many of the early studies on physiological responses to yoga asana practice described the transcendental control of involuntary basal functions, such as regulation of heart rate (7,8), blood pressure (9), and other autonomic functions (10). Over the last thirty years, an increasing body of research as reviewed by Raub (4), supports the empirical evidence indicating that long-term yoga practice benefits health and well-being. Regular asana and pranayama (breath control) practice are known to influence cardiopulmonary and metabolic variables in resting and exercising subjects. For example, trained practitioners performing yoga asanas had lower heart rates and minute ventilation than did untrained subjects performing similar poses (11). Regular asana and pranayama practice reduced heart rate and blood pressure in resting young males (12). Six weeks of Hatha yoga practice reduced heart rate in resting elderly males and females (13). Yoga asanas, pranayama, and meditation training in conjunction with low fat lacto-vegetarian diet reduced blood pressure, heart rate, and other cardiovascular risk factors in resting males and females following a three-month residential program (14). Four to six weeks of intensive yoga training increased maximal aerobic power in young females (15), young males (16), and elderly subjects (13).

Yoga asanas require muscular strength and endurance, flexibility, and balance. The length of time that a given asana is performed can vary from several seconds to 5-10 min or longer, depending on the skill level and goals of the practitioner. Dynamic asana sequences (vinyasa) and jumpings that are incorporated into a yoga practice constitute rigorous whole body exercise. Moderate to strenuous yoga vinyasa and jumpings would be expected to promote cardiovascular endurance if the practice was sufficiently long. To achieve optimal cardiorespiratory benefits, the American College of Sports Medicine recommends that exercise include 20-60 min of large muscle rhythmic and dynamic activity with a minimum of 10 min of activity per session (17). During aerobic exercise, HR should be sustained between 55%-85% of HRmax. Dynamic asana sequences and jumpings are frequently included in asana practice performed according to the Iyengar tradition; however, these components were not included in this study because the primary focus was to evaluate acute physiological responses to individual asanas. The results of this study indicated that the yoga asanas required mild to moderate intensity energy expenditure.

Heart rate during the yoga practice was within a target HR zone (55-85% HR_{max}). Steady state heart rate was not sustained for a minimum of 10 minutes during the yoga practice. Yoga poses performed according to the Iyengar tradition are generally not sustained longer than several minutes. The exception would include certain inversions (headstand and shoulderstand) and corpse pose, which are typically performed for 5-10 minutes or longer. The range for cumulative time spent within this HR zone was 10.8 – 59.9 min. The range for cumulative energy expenditure during the yoga practice was 80.3 – 277.5 kcal. This volume of exercise meets the current public health recommendations for physical activity that provides substantial benefits for reduced risk of cardiovascular disease and improved cardiovascular fitness for sedentary adults (18).

The general cardiorespiratory responses to asanas were similar to changes observed in subjects who perform weight lifting circuit exercise. Metabolic cost during circuit exercise is usually less than that required during sustained strenuous whole body aerobic exercise (19). Circuit weight lifting also produces greater HR and reduced O_2 pulse values for a given VO_2 than does treadmill exercise (19). The isometric exercise component and low oxygen cost of each asana could induce an undesirable pressor response (disproportionate increase in HR with increased oxygen cost of exercise). Beginning students often perform breath holding during inversions, which would exacerbate the pressor response. In order to avoid such circumstances, yoga instructors frequently remind students to maintain appropriate breathing patterns. The results of this study indicate minute ventilation and breathing frequency increased with the metabolic demand of the asana. Tidal volume was not significantly altered among the poses. Intermediate and advanced practitioners were also capable of sustaining asanas for minutes without evidence of local muscle fatigue or a strong pressor response. The combination of muscular strength and endurance, flexibility, balance, and concentration enable the yoga practitioners to sustain challenging postures with limited evidence of a generalized disproportionate increase in HR relative to the change in oxygen uptake.

Brachial arterial blood pressure responses were influenced by changes in: a) arm position relative to the level of the heart, b) hydrostatic pressure as body position varied among supine, upright, and inverted poses, c) cardiac output, d) peripheral vascular resistance, and e) local arm muscle contraction. Given the above constraints, blood pressures recorded during each asana represented local brachial blood pressure and could not be used to assess systemic blood pressure. Yoga instructors consider inverted poses contraindicative for hypertensive persons because of increased upper body hydrostatic pressure and vascular resistance as compared with conditions in upright and supine postures. The inverted poses require a balance of upper and lower body muscular activity to maintain postural alignment. Muscular activity and energy demand are factors that contribute to the regulation of cardiac output and peripheral vascular resistance, and therefore, also influence blood pressure during inversions. Coulter (19) estimated brachial arterial blood pressure to approximate 140/100 mmHg when one performs headstand. The findings of this study indicate greater blood pressure responses than estimated by Coulter (20). Average SBP/DBP was 151.4 ± 23.5/108.8 ± 14.9 mmHg at five min of headstand.

Head stand and shoulder stand poses are considered the “king” and “queen” of yoga asanas, respectively (1). According to yogic philosophy, both of these poses offer numerous physical, emotional, and psychological benefits. Regular practice of these asanas is thought to enhance systemic function including specific benefits to the cardiovascular, lymphatic, nervous, and endocrine systems (1). Headstand is thought to rejuvenate the body and stimulate mental acuity; whereas, shoulderstand restores harmony and well being to the practitioner. In this study, headstand and shoulderstand did not elicit HR or oxygen uptake responses that significantly differed from the five-min upright-seated kneeling pose. Each of the poses required mild energy expenditure (< 3.1 METs). In addition, blood pressure responses were similar in shoulderstand and the upright-seated kneeling pose. These results indicate that the 5-min inversions did not induce a strong pressor response in intermediate and advanced yoga practitioners. Oxygen pulse, which is an estimate of stroke volume of the heart, was significantly greater in shouldstand than in headstand or the seated kneeling pose. Therefore, under conditions of correct anatomical alignment, shouldstand appears to promote enhanced stroke volume of the heart compared with an upright-seated kneeling pose.

The mild to moderate intensity energy requirements and corresponding HR of the Iyengar yoga practice in this study are consistent with the findings of Gopal et al. (11) who examined cardiorespiratory responses to several beginning-level sitting, lying, and inverted asanas in untrained and trained (at least six months of asana practice) male subjects (n = 14/group, ages 25-35). Steady state HR did not exceed 90 bpm when subjects performed various supine, seated, twists, and inversion asanas. HR during asanas was consistently lower in the trained versus untrained subjects leading the authors to conclude that a committed practice attenuates the cardiopulmonary requirements of asanas. Raub (4) reviewed the psychophysiologic effects of Hatha yoga and concluded that the overall cardiopulmonary endurance benefit from yoga practice is determined by the longevity of yoga practice.

This study was also designed to acquire preliminary data on the impact of postural alignment on physiological responses. Hatha yoga asanas taught according to the Iyengar tradition emphasize precise body alignment, muscular balance, and maximal spinal extension. Selection of intermediate and advance practitioners precluded from the study subjects with beginning level skills and thus reduced the diversity of postural alignment within the subject pool. The effect of postural alignment was most evident on blood pressure variables during inversions, push up to back arch, and the warrior standing poses. Compared with the near ideal posture, mal-alignment corresponded with increased brachial blood pressure during handstand, shoulderstand, half-moon pose and during the warrior II and III standing poses. These preliminary findings indicate that near ideal postural alignment may attenuate blood pressure responses during inversions and standing poses. However, practitioners with near ideal alignment in back arch did not have lower MAP than those with mal-aligned poses. The lack of difference in MAP can be explained by the observation that practitioners with near ideal alignment were capable of maintaining the pose for approximately 30s longer than the other subjects. Push up to back arch is a physically demanding asana that requires strong bilateral recruitment of arm, back, and leg musculature. Although these data are representative of a small sample size (n = 9 for blood pressure measurements), it is prudent to conclude from the results of this study that push up to a back arch, which is held for extended duration, may be contraindicative for individuals exhibiting mal-alignment in the pose and for hypertensive persons.

The Iyengar tradition emphasizes that certain yoga poses may be contraindicative for hypertensive persons. The results of the present study extend this knowledge by emphasizing the importance of postural alignment to blood pressure responses during asana practice. Awareness of blood pressure responses during asana practice is particularly relevant to the estimated 5.3 million yoga practitioners in the United States who are perimenopausal or post menopausal women (21) because ~30% of perimenopausal and 53% of post menopausal women are estimated to be hypertensive (22).

CONCLUSIONS

The Iyengar yoga practice was classified as mild to moderate intensity exercise for intermediate and advanced students. The cumulative energy expenditure of the practice met the current public health recommendations for physical activity that provides substantial benefits for reduced risk of cardiovascular disease and improved cardiovascular fitness for sedentary adults (18). The average energy expenditure of the yoga practice represented approximately 15% of the desired weekly exercise activity (~1000 kcal/wk of moderate intensity exercise) recommended by the Surgeon General for health promotion (23).

The type of asana and the duration of each asana significantly determined physiological responses. Preliminary evidence indicates that postural alignment has relevant physiological consequences for the yoga practitioner. The ability to achieve near ideal postural alignment in standing and inversion asanas enabled the experienced practitioner to hold postures for extended periods without an apparent generalized pressor response. Push up to back arch was among the physically demanding asanas that elicited the greatest blood pressure responses when this pose was maintained for an extended duration.

A wide variety of yoga practices currently exist, reflecting the evolution of ancient yogic traditions and the increasing popularity of yoga in western cultures. At least 16.5 million people in the United States practice yoga; 77.1% are women (21). Few investigations have focused on quantification of the physical work of asanas and the work-related physiological adjustments during asana practice. Standardized testing protocols and methodology are warranted so that the quantity and quality of yoga practice can be described in terms of work physiology. Under controlled laboratory conditions, the physiological responses to yoga asanas can be quantified and critically evaluated. Based on this evidence, yoga asanas can be fully integrated into western approaches to exercise prescription for healthy, rehabilitating, and diseased populations.

Yoga is an ancient Indic system. Approaching the study of yoga asanas through the discipline of work physiology seeks, in part, to explain the biological phenomena of this system. Objective analyses of the research findings will lend credibility to the integration of yoga practice into clinical treatment within western cultures and to the value of a committed yoga practice for health and well-being.

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REFERENCES

1. Iyengar BKS. ***Light on Yoga***. New York: Schocken Books, 1979:19-53.
2. Bender Birch B. ***Power Yoga: The Total Strength and Flexibility Workout***. New York: Simon & Schuster, 1995:17-34.
3. Mehta S, Mehta M, Mehta S. ***Yoga the Iyengar Way***. New York: Alfred A. Knopf, 1997:8.
4. Raub JA. Psychophysiologic effects of Hatha yoga on musculoskeletal and cardiopulmonary function: A literature review. ***J Altern Complement Med*** 2002;8:797-812.
5. Whipp BJ, Higgenbotham MB, Cobb FC. Estimating exercise stroke volume from asymptotic oxygen pulse in humans. ***J Appl Physiol*** 1996;81:2674-9.
6. Franklin BA. ***ACSM's guidelines for exercise testing and prescription***. Philadelphia: Lippincott, Williams, and Wilkins, 2000:145-7, 50.
7. Anand BK, Chinna GS. Investigations on yogic claiming to stop their heart beats. ***Indian J Med Res*** 1961;49:90-4.
8. Wenger MA, Bagchi BK, Anand BK. Experiments in India on voluntary control of the heart and pulse. ***Circulation*** 1961; 24:1319-24.
9. Gopal KS, Bhatnagar OP, Subramanian N, Nishith SD. Effect of yogasanas and pranayamas on blood pressure, pulse rate and some respiratory functions. ***Indian J Physiol Pharmacol*** 1973;17:273-6.
10. Wenger MA, Bagchi BK. Studies of autonomic functions in practitioners of yoga in India. ***Behav Sci*** 1961;6:312-23.
11. Gopal KS, Anantharamn V, Nishith SD, Bhatnagar OP. The effect of yogasanas on muscular tone and cardio-respiratory adjustments. ***Indian J Med Sci*** 1974;28:438-43.
12. Joseph S, Sridharan K, Patil SKB, Kumaria ML, Selvamurthy W, Joseph NT et al. Study of some physiological and biochemical parameters in subjects undergoing yogic training. ***Indian Journal of Medical Research*** 1981;74:120-4.
13. Bowman AJ, Clayton RN, Murray A, Reed JW, Subhan MMF, Ford GA. Effects of aerobic exercise training and yoga on the baroreflex in healthy elderly persons. ***Eur J Clin Invest*** 1997;27:443-9.
14. Schmidt T, Wijga A, Von Zur Mühlen A, Brabant G, Wagner TOF. Changes in cardiovascular risk factors and hormones during a comprehensive residential three month kriya yoga training and vegetarian nutrition. ***Acta Physiol Scand Suppl*** 1997;640:158-62.
15. Raju PS, Prasad KVV, Venkata RY, Murthy KJR, Reddy MV. Influence of intensive yoga training on physiological changes in 6 adult women: A case report. ***J Altern Complement Med*** 1997;3:291-5.
16. Raju PS, Madhavi S, Prasad KVV, Venkatreddy M, Eswarreddy M, Sahay BK. Comparison of effects of yoga & physical exercise in athletes. ***Indian J Med Res*** 1994;100:81-7.
17. Pollock ML, Gaesser GA, Butcher J, Després J-P, Dishman RK, Franklin BA et al. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in health adults. ***Med Sci Sports Exerc*** 1998;30:975-91.
18. Blair SN, LaMonte MJ, Nickaman MZ. The evolution of physical activity recommendations: how much is enough? ***Am J Clin Nutr*** 2004;79(suppl):913S–20S.
19. Hurley BF, Seals DR, Ehsani AA, Cartier L-J, Dalsky GP. Effects of high-intensity strength training on cardiovascular function. ***Med Sci Sports Exerc*** 1984;16:483-8.
20. Coulter HD. ***Anatomy of Hatha Yoga: A manual for students, teachers, and practitioners***. Honesdale, PA: Body and Breath, Inc., 2001:437-73.
21. Yoga Journal: The Voice of Yoga Online. ***Yoga Journal***, February 7, 2005, <http://www.yogajournal.com/about_press020705.cfm> (Accessed 07.18.2005).
22. Fields LE, Burt VL, Cutler JA, Hughes J, Roccella EJ, Sorlie P. The Burden of Adult Hypertension in the United States: A Rising Tide. ***Hypertension*** 2004: 44:398-404.

23. U.S. Department of Health and Human Services, Centers for Disease control and Prevention, National Center for Chronic Disease Prevention and Health Promotion. ***Physical activity and Health: A report of the Surgeon General*.** Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease control and Prevention, National Center for Chronic Disease Prevention and Health Promotion, 1996.