

Kinematics of Suryanamaskar Using Three-Dimensional Motion Capture

Abstract

Background: Suryanamaskar, a composite yogasana consisting of a sequence of 12-consecutive poses, producing a balance between flexion and extension is known to have positive health benefits for obesity and physical fitness management, upper limb muscle endurance, and body flexibility. However, limited information is available on biomechanical demands of Suryanamaskar, i.e., kinematic and kinetic. **Aims:** The present study aimed to explore the kinematics of spine, upper, and lower extremity during Suryanamaskar to enhance greater understanding of Suryanamaskar required for safe and precise prescription in the management of musculoskeletal disorders. **Methods:** Three-dimensional motion capture of Suryanamaskar was performed on 10 healthy trained yoga practitioners with 12-camera Vicon System (Oxford Metrics Group, UK) at a sampling frequency of 100 Hz using 39 retro-reflective markers. Data were processed using plug-in-gait model. Analog data were filtered at 10Hz. Joint angles of the spine, upper, and lower extremities during 12-subsequent poses were computed within Vicon Nexus. **Results:** Joint motion was largely symmetrical in all poses except pose 4 and 9. The spine moved through a range of 58° flexion to 44° extension. In the lower quadrant, hip moved from 134° flexion to 15° extension, knee flexed to a maximum of 140°, and 3° hyperextension. Ankle moved in a closed kinematic chain through 40° dorsiflexion to 10° plantarflexion. In the upper quadrant, maximum neck extension was 76°, shoulder moved through the overhead extension of 183°–56° flexion, elbow through 22°–116° flexion, and wrist from 85° to 3° wrist extension. **Conclusions:** Alternating wide range of transition between flexion and extension during Suryanamaskar holds potential to increase the mobility of almost all body joints, with stretch on anterior and posterior soft tissues and challenge postural balance mechanisms through a varying base of support.

Keywords: Kinematics, lower extremity, spine, Suryanamaskar

Introduction

Suryanamaskar referred as “sun salutation” is one of the ancient forms of Yogasanas practiced. It is a sequence of 12-consecutive poses, producing a balance between flexion and extension, performed with synchronized breathing.^[1] Performing asanas in continuous sequencing, such as sun salutation and performing asanas individually, may confer different benefits to the body. However, Suryanamaskar definitely helps in better calorie burn. Extensive information is available on physiological effects of Hatha Yoga and biomechanical demands of standing Hatha Yogasanas. Combination of series of Yogasanas performed with breathing control and mindfulness have demonstrated reduction in diastolic blood pressure, improved cardiorespiratory fitness, myocardial perfusion, serum cholesterol, upper limb muscle endurance, body flexibility, balance, bone density, and overall

positive benefits for weight and physical fitness management.^[1-9] However, the effect of individual asanas remains unexplored.

Physiological demands of Suryanamaskar too are reported previously.^[1,3,10] Improvements in pulmonary function, such as maximal inspiratory and expiratory pressures, forced expiratory volume in 1st s (FEV1), forced vital capacity, and peak expiratory flow rate, have been reported. Reduction in level of biomarkers indicative of oxidative stress have been observed along with enhanced glucose tolerance following regular practice of Suryanamaskar.^[3,10] Improvement in muscle mass and reduction in fat mass are some of the benefits attributed to Suryanamaskar intervention.^[1] Sinha *et al.*, in 2004, reported a 2.711 kcal/min increase in energy consumption from baseline to eighth posture concluding that Suryanamaskar is an ideal aerobic exercise utilizing slow stretches and placing optimal stress on the cardiorespiratory system.^[11]

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How to cite this article: Mullerpatan RP, Agarwal BM, Shetty T, Nehete GR, Narasipura OS. Kinematics of Suryanamaskar using three-dimensional motion capture. *Int J Yoga* 2019;12:124-31.

Received: May, 2018. **Accepted:** June, 2018.

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Access this article online

Website: www.ijoy.org.in

DOI: 10.4103/ijoy.IJOY_26_18

Quick Response Code:



Regarding biomechanical demands of yogasanas, previous researchers have reported kinetics, kinematics, and muscle activity during standing yogasanas in elderly individuals.^[12] Graded biomechanical stress placed by initiating training with supported and progressing to traditional unsupported tree pose, warrior pose, dog pose, and chair pose produced lower joint moment of force in the sagittal plane by 30%–268% during supported asanas. However, supported asanas generated lower muscle activity whereas traditionally performed asanas generated greater muscle activity and consequently greater joint moments which were however low moderate. Most standing asanas targeted quadriceps femoris, gluteus medius, erector spinae, and generated 70% greater activity in rectus abdominis than walking activity.^[6,12-14]

With respect to biomechanics of Suryanamaskar, the smooth rhythmic kinematic transition from one posture to another along with mathematical model to predict loads on the wrist, elbow, shoulder, hip, knee, and ankle joints are reported.^[15] Low loading stresses placed in unique distribution patterns are described suggesting that none of the joints are overloaded while performing Suryanamaskar.^[15,16] In addition, improvements in fatigue, balance, gait speed, and stride length are reported using clinical measures.^[17-20]

Thus in conclusion, there is still paucity of information on biomechanical demands of Suryanamaskar using robust biomechanical exploration regarding precise joint angles, range of motion, and center of mass (COM) trajectory offered during individual poses of Suryanamaskar is deemed necessary to inform clinicians and yoga practitioners to enable the inclusion of Suryanamaskar in routine healthcare. Therefore, the present study aimed to explore temporal variables, COM trajectory, and kinematics of Suryanamaskar.

Methods

Following approval from Ethical Committee for Research on Human Participants, MGM Institute of Health Sciences, Navi Mumbai, 10 healthy trained yoga practitioners (five males, five females) were recruited. All participants provided informed consent as per the Declaration of Helsinki guidelines. The participants were screened for known musculoskeletal, cardiovascular, respiratory, metabolic, and neurologic disorders. Following screening and informed consent, the participants were instructed to perform the described 12-pose sequence poses during motion capture.

The 12-pose sequences of Suryanamaskar were as follows: Pose 1–Salutation Pose (Pranamasana), Pose 2 – Raised Arm Pose (Hasta uttanasana), Pose 3 – Hand-to-Foot Pose (Hastapaadasana), Pose 4 – Equestrian Pose (Ashwa sanchalanasana), Pose 5 – Mountain Pose (Parvatasana), Pose 6 – Eight

Limb Pose (Ashtanganamaskara), Pose 7 – Cobra Pose (Bhujangasana), Pose 8 – Mountain Pose (Parvatasana), Pose 9 – Equestrian Pose (Ashwa sanchalanasana), Pose 10 – Hand-to-Foot Pose (Hastapaadasana), Pose 11 – Raised Arm Pose (Hasta uttanasana), and Pose 12 – Salutation Pose (Pranamasana) [Figure 1]. Consistency in the performance of sequence was maintained, as the participants belonged to and practiced different forms of Suryanamaskar. All participants were certified yoga practitioners, practicing Yoga for >5 years. In routine practice, seven followed traditional school of Yoga which practiced a sequence similar to the one described in our study whereas three followed nontraditional school of Yoga (where Pose 5 was plank pose in which trunk is maintained parallel to the ground instead of parvatasana (mountain pose) in which the hips remain flexed in inverted V position). However, in this study, all practitioners performed the poses as shown in Figure 1.

The participants performed two practice trials before testing. The participants were tested in suitable body suits to permit unobtrusive motion and prevent obstruction of markers. They were instructed to attain and hold each pose for 1 s.

Three-dimensional motion was captured with 12-camera Vicon system (Oxford Metrics Group, UK) at a sampling frequency of 100 Hz using 39 retro reflective markers [Figure 1]. Markers were secured with double-sided adhesive tape on predetermined anatomical landmarks defined by the plug-in-gait model. The markers were placed bilaterally on front forehead, back forehead, tip of shoulder, upper arm, lateral epicondyle of elbow, forearm, ulnar and radial styloid processes, anterior superior iliac spine, posterior superior iliac spine, lateral aspect of thigh, lateral condyle of femur, lateral aspect of tibia, lateral malleolus, posterior aspect of heel, second metatarsal head and at C7, sternal notch, xiphoid process of sternum, T10, and right scapula.^[21] The static trial was recorded while standing in anatomical position to enable calibration. Five dynamic trials of Suryanamaskar were captured, and data were processed using plug-in-gait model. Analog data were filtered at 10 Hz. Joint angles during 12 poses were computed within Vicon Nexus. Kinematics of the 12 poses is described further.

Results

Temporal variables and kinematics of spine (C7-L5), hip, knee, and ankle joints, and upper extremity in sagittal plane during all 12 poses of Suryanamaskar are [Table 1]. Total time taken to perform the entire 12-pose sequence was approximately 44.83 (7.27) s. The total time required to attain a pose including hold time was 2.5–5.5 s. COM of the body was observed to rise and fall with the poses with the highest position attained during raised arm pose 94.7 (4.6) cm whereas COM was the lowest during eight-limb pose 15.1 (2.5) cm.

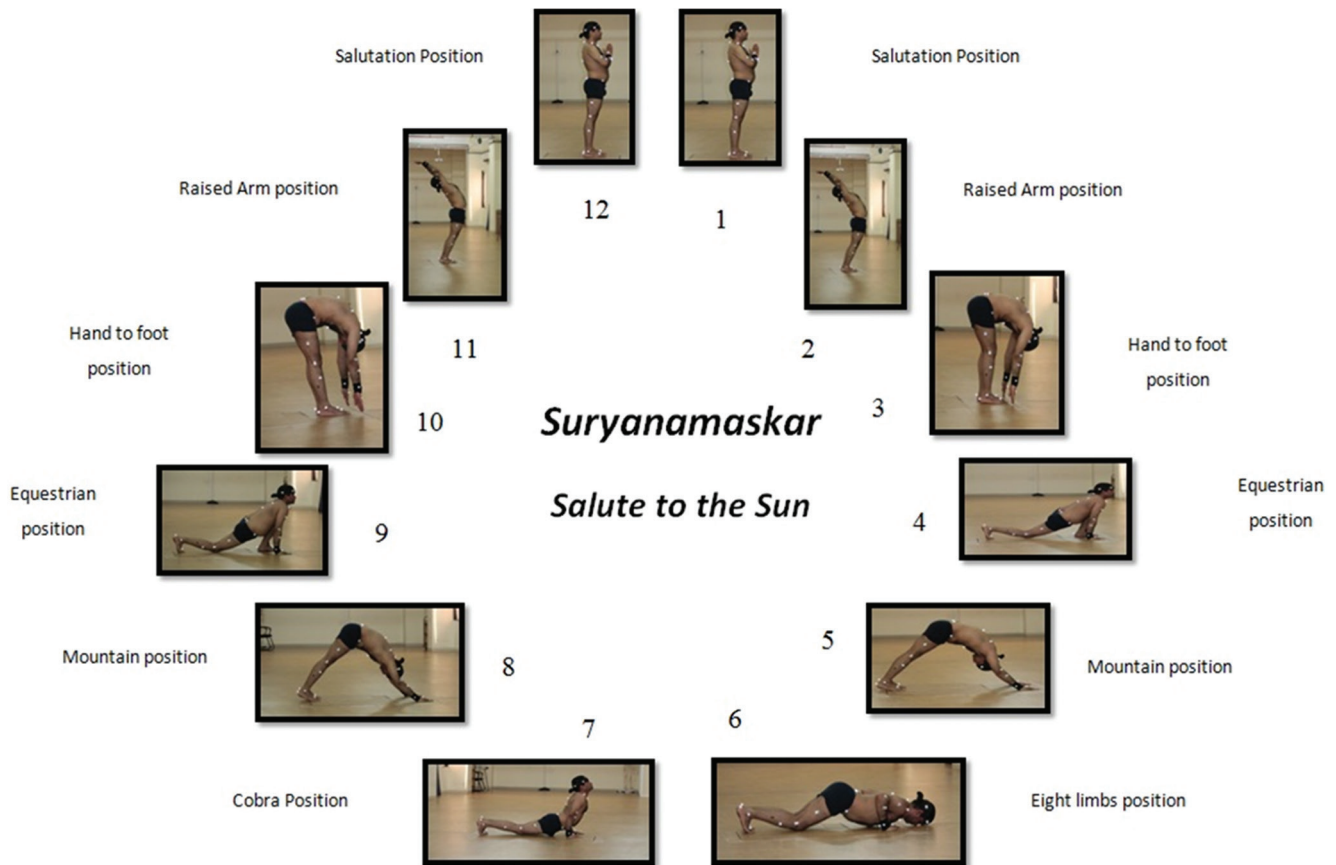


Figure 1: Twelve-pose cycle of Suryanamaskar

Movements were observed to be largely symmetrical in all poses except equestrian pose which was reciprocal. The spine moved through relative flexion and extension during the symmetrical poses. Overall, in the symmetrical poses of Suryanamaskar, the spine moved through a range from 58° flexion to 44° extension alternating between flexion and extension and remained in intermediate range of flexion while maintaining asymmetrical poses. Peak extension of $44.1^\circ \pm 8.8^\circ$ is attained during the raised arm pose whereas the peak flexion of $57.6^\circ \pm 16.3^\circ$ is attained during the hand-to-foot pose. The spine moves through intermediate flexion movement through Suryanamaskar. Extension of $12.9^\circ \pm 22.1^\circ$ is achieved in eight-limb pose and cobra pose $30.4^\circ \pm 40.5^\circ$. During the asymmetrical equestrian pose, the spine remains in 12° – 14° flexion [Figure 2].

During the symmetrical poses, hip joint was observed to move from 130° flexion to 15° extension, achieving maximum flexion of $82.8^\circ \pm 9.5^\circ$ during hand-to-foot pose and maximum extension of $15.2^\circ \pm 7.8^\circ$ during cobra pose. However, peak hip flexion was attained while maintaining the asymmetrical equestrian pose $134.4^\circ \pm 23.0^\circ$ on one side with slight hip flexion of $15.6^\circ \pm 0.31^\circ$ on the opposite side. Some of the participants (50%) were observed to achieve hip extension during this pose on the opposite side hip extension [Figure 2].

During the symmetrical poses, maximum flexion of $29.9^\circ \pm 13^\circ$ at the knee was achieved during eight-limb pose whereas slight hyperextension $3.9^\circ \pm 5.2^\circ$ was seen during salutation pose. Peak knee joint flexion of $109.8^\circ \pm 27.3^\circ$ was observed during the asymmetrical equestrian pose in combination with peak hip flexion [Figure 2].

Ankle was observed to move in a closed kinematic chain through a maximum of $30.5^\circ \pm 11.4^\circ$ dorsiflexion during mountain pose to $5.7^\circ \pm 3.4^\circ$ relative plantar flexion during hand-to-foot pose [Figure 2].

The neck was observed to remain in extension through most of the poses except for those which demanded greater flexion at the lumbar spine – hand-to-foot pose and mountain pose. Peak neck extension of $76.9^\circ \pm 17.0^\circ$ was achieved during cobra pose whereas the least amount of extension of $1.9^\circ \pm 17.8^\circ$ was observed during mountain pose. About 60% of participants achieved neck flexion during this pose. The asymmetrical equestrian pose demanded 60° of neck extension.

Shoulder joint achieved a peak flexion of $54.6^\circ \pm 1.7^\circ$ during the hand-to-foot pose. While full overhead extension beyond 180° was achieved during raised arm pose. Elbow was observed to flex maximally to $113.2^\circ \pm 7.58^\circ$ during namaskar pose and eight-limb pose ($116.3^\circ \pm 17.0^\circ$) while

Table 1: Temporal variables and kinematics of spine, hip, knee, ankle, neck, shoulder, elbow and wrist during 12 poses of Suryanamaskar

	Salutation pose 1		Raised arm pose 2		Hand to foot pose 3		Equestrian pose 4		Mountain pose 5		Eight limb pose 6	
	Mean (SD)	(minimum-maximum)	Mean (SD)	(minimum-maximum)	Mean (SD)	(minimum-maximum)	Mean (SD)	(minimum-maximum)	Mean (SD)	(minimum-maximum)	Mean (SD)	(minimum-maximum)
Time taken for asana (s)	2.5 (0.7)	3.0 (0.6)	3.0 (0.6)	4.6 (1.2)	3.7 (0.3)	3.2 (1.5)	3.2 (1.5)	5.2 (1.1)				
COM (cm)	2.0/4.0 92.0 (3.9)	2.5/4.5 93.8 (3.6)	3.00/6.50 68.8 (5.2)	3.00/4.0 41.9 (4.4)	3.0/4.0 41.9 (4.4)	1.5/6.5 53.0 (4.4)	1.5/6.5 53.0 (4.4)	4.0/7.5 15.1 (2.5)				
Spine°	85.8/97.8 -19.9 (3.0)	86.3/98.0 -44.1 (8.8)	61.4/76.9 57.3 (23.8)	36.9/52.7 12.8 (27.0)	36.9/52.7 12.8 (27.0)	46.7/59.9 36.7 (10.6)	46.7/59.9 36.7 (10.6)	12.4/20.3 -12.9 (22.1)				
Hip°	-26.8/-15.5 3.5 (6.0)	-62.7/-33.0 -10.1 (4.98)	0.9/81.6 82.6 (16.1)	-36.7/36.7 139.9 (19.7)	-36.7/36.7 139.9 (19.7)	20.8/53.0 49.2 (26.2)	20.8/53.0 49.2 (26.2)	32.3/25.2 46.5 (21.2)				
Knee°	-6.7/15.5 -3.9 (5.2)	-17.0/-2.5 5.8 (19.5)	43.5/1 8.3 (6.0)	-1.6 (15.5) 113.9 (26.5)	-1.6 (15.5) 113.9 (26.5)	12.1/94.6 57.2 (28.0)	12.1/94.6 57.2 (28.0)	14.5/71.90 29.9 (13.1)				
Ankle°	-11.9/4.4 1.3 (3.5)	-8.5/59.2 13.8 (5.3)	-1.7/1.3 -1.1 (5.7)	32.1 (17.5) 26.2 (8.6)	32.1 (17.5) 26.2 (8.6)	-14.2/58.6 5.9 (19.5)	-14.2/58.6 5.9 (19.5)	4.2/46.1 23.3 (13.6)				
Neck°	-5.0/5.7 -10.5 (14.1)	4.4/21.0 -60.1 (19.8)	-7.1/8.1 -5.1 (29.4)	11.2 (9.3) -63.95 (21.98)	11.2 (9.3) -63.95 (21.98)	-2.2/4 -1.9 (17.8)	-2.2/4 -1.9 (17.8)	-2.0/39.9 -40.4 (41.9)				
Shoulder°	-41.5/8.6 23.4 (12.4)	-94.5/-25.0 7.8 (17.2)	-60.1/28.0 54.6 (1.70)	-94.00/-18.9 41.6 (11.2)	-94.00/-18.9 41.6 (11.2)	-25.5/22.7 21.2 (32.2)	-25.5/22.7 21.2 (32.2)	-93.2/19.8 -25.8 (12.4)				
Elbow°	1.3/40.9 112.5 (7.0)	-35.0/30.7 32.5 (7.7)	44.90/60.20 23.4 (3.7)	21.1/60.6 30.3 (4.5)	21.1/60.6 30.3 (4.5)	-27.5/80.6 27.1 (7.2)	-27.5/80.6 27.1 (7.2)	-44.3/0.7 116.3 (17.0)				
Wrist°	102.5/125.3 66.4 (22.2)	22.7/41.3 33.4 (30.3)	15.9/27.60 39.8 (14.86)	19.9/37.3 32.8 (48.4)	19.9/37.3 32.8 (48.4)	17.6/41.3 31.1 (48.5)	17.6/41.3 31.1 (48.5)	87.9/145.5 85.4 (13.4)				
	14.8/90.3	-12/66.6	-13.80/98.3	-37.7/93.9	-37.7/93.9	-59.0/108.6	-59.0/108.6	61.6/105.0				
	Cobra pose 7											
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)
Time taken for asana (s)	3.2 (0.87)	4.3 (1.2)	3.5 (0.5)	3.00 (0.7)	3.00 (0.7)	3.0 (0.3)	3.0 (0.3)	2.5 (0.7)				
COM (cm)	2.0/5.0 29.1 (7.4)	3.0/6.0 52.6 (6.7)	3.0/4.5 39.0 (2.6)	2.0/4.0 70.0 (5.0)	2.0/4.0 70.0 (5.0)	2.5/3.5 94.7 (4.6)	2.5/3.5 94.7 (4.6)	2.0/4.0 92.2 (4.0)				
Spine°	24.0/48.5 -30.4 (40.5)	35.7/59.8 40.0 (12.3)	35.4/43.0 14.0 (12.0)	60.9/77.7 57.6 (16.3)	60.9/77.7 57.6 (16.3)	87.2/98.8 -48.2 (8.3)	87.2/98.8 -48.2 (8.3)	86.0/98.3 -15.7 (12.7)				
Hip°	-67.6/52.9 -15.2 (7.8)	24.4/64.6 66.8 (12.6)	-6.4/32.4 140.2 (13.0)	19.2/75.6 82.8 (9.5)	19.2/75.6 82.8 (9.5)	-63.0/-40.5 -2.9 (7.3)	-63.0/-40.5 -2.9 (7.3)	-30.5/7.9 8.3 (8.6)				
Knee°	-25.5/-3.7 19.5 (5.8)	52.3/92.2 2.5 (5.7)	-9.8 (20.4) 126.2 (12.8)	70.2/96.7 4.8 (5.5)	70.2/96.7 4.8 (5.5)	-9.8/10.4 1.6 (11.6)	-9.8/10.4 1.6 (11.6)	-5.9/21.2 -2.7 (2.1)				
	12.2/30.0	-4.1/14.5	38.7 (11.9)	-7.0/13.0	-7.0/13.0	-13.8/18.6	-13.8/18.6	-13.2/4.1				
	Salutation pose 12											
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)
Time taken for asana (s)	3.2 (0.87)	4.3 (1.2)	3.5 (0.5)	3.00 (0.7)	3.00 (0.7)	3.0 (0.3)	3.0 (0.3)	2.5 (0.7)				
COM (cm)	2.0/5.0 29.1 (7.4)	3.0/6.0 52.6 (6.7)	3.0/4.5 39.0 (2.6)	2.0/4.0 70.0 (5.0)	2.0/4.0 70.0 (5.0)	2.5/3.5 94.7 (4.6)	2.5/3.5 94.7 (4.6)	2.0/4.0 92.2 (4.0)				
Spine°	24.0/48.5 -30.4 (40.5)	35.7/59.8 40.0 (12.3)	35.4/43.0 14.0 (12.0)	60.9/77.7 57.6 (16.3)	60.9/77.7 57.6 (16.3)	87.2/98.8 -48.2 (8.3)	87.2/98.8 -48.2 (8.3)	86.0/98.3 -15.7 (12.7)				
Hip°	-67.6/52.9 -15.2 (7.8)	24.4/64.6 66.8 (12.6)	-6.4/32.4 140.2 (13.0)	19.2/75.6 82.8 (9.5)	19.2/75.6 82.8 (9.5)	-63.0/-40.5 -2.9 (7.3)	-63.0/-40.5 -2.9 (7.3)	-30.5/7.9 8.3 (8.6)				
Knee°	-25.5/-3.7 19.5 (5.8)	52.3/92.2 2.5 (5.7)	-9.8 (20.4) 126.2 (12.8)	70.2/96.7 4.8 (5.5)	70.2/96.7 4.8 (5.5)	-9.8/10.4 1.6 (11.6)	-9.8/10.4 1.6 (11.6)	-5.9/21.2 -2.7 (2.1)				
	12.2/30.0	-4.1/14.5	38.7 (11.9)	-7.0/13.0	-7.0/13.0	-13.8/18.6	-13.8/18.6	-13.2/4.1				

Contd...

Table 1: Contd...

	Cobra pose 7	Mountain pose 8	Equestrian pose 9	Hand to foot pose 10	Raised arm pose 11	Salutation pose 12
	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)	Mean (SD)
	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)	(minimum-maximum)
Ankle°	18.5 (11.6) -0.0/31.6	29.1 (12.9) -3.5/41.6	30.5 (11.0) 18.62 (7.1)	-5.7 (3.4) -10.3/0.3	11.8 (10.2) -4.7/23.2	0.8 (5.8) -10.2/8.8
Neck°	-76.9 (17.0) -106.2/-54.1	2.8 (16.4) -23.9/30.4	-72.4 (14.8) -102.6/-48.3	1.3 (26.5) -49.8/23.2	-34.9 (54.4) -75.3/67.8	-5.3 (16.1) -24./23.0
Shoulder°	3.8 (17.4) -15.7/41.7	11.9 (22.9) -33.6/47.0	38.6 (14.4) 5.2/59	54.5 (5.8) 39.8/59.5	-3.4 (22.2) -35.6/20.7	24.3 (7.0) 17.0/35.8
Elbow°	27.3 (8.1) 15.5/41.5	22.3 (5.0) 15.1/30.4	26.2 (5.4) 19.5/32.6	24.2 (4.5) 17.8/33.2	36.8 (6.6) 29.9/44.7	113.2 (7.5) 105.9/129.8
Wrist°	66.5 (44.2) -52.9/104.9	31.7 (34.3) -25.0/97.0	27.9 (62.4) -79.5/119.3	3.1 (69.2) -146.0/95.5	6.1 (33.2) -29.1/59.9	48.98 (66.4) -110.8/92.7

SD=Standard deviation, COM=Center of mass

least flexion was observed during the mountain pose ($22.3^\circ \pm 5.0^\circ$) and hand-to-foot pose ($23.4^\circ \pm 3.7^\circ$). The highest wrist extension of $85.4^\circ \pm 13.4^\circ$ was observed during eight-limb pose whereas the least extension was observed during hand-to-foot pose ($3.1^\circ \pm 69.2^\circ$). However, it was observed that the wrist showed greatest variability in motion with wide standard deviations.

Discussion

This is the first study to report precise joint angles at the spine, hip, knee, and ankle in the sagittal plane. Temporal variables and kinematics of poses attained during Suryanamaskar and factors which might influence kinematics are discussed below.

Suryanamaskar involves movements of all body segments and is a promising model of whole-body exercise. Each sequence of Suryanamaskar was accomplished in a range of 37–51 s, with an average of 44.8 s/sequence. One sequence of gentle exercise which mobilizes almost all body joints in <1 min holds huge potential for prescription as mobility exercise for people with time and space constraints typical to the hectic urban lifestyle globally. Moreover, the time taken for achieving each pose along with transition to the next pose was fairly well distributed ensuring that loads were not sustained on one joint for prolonged duration of time.

In addition, COM travels through a wide range vertical trajectory of 79.3 cm from the lowest position of 15.1 cm from ground to a highest position of 94.7 cm during the complete sequence of Suryanamaskar. In comparison, walking on a level surface produces an average vertical displacement of 4.4 ± 1.2 cm of COM, which is 18 times smaller displacement. Yet, walking is known to demonstrate improvement in postural sway.^[17,18] Moderate walking activity three times/week for 2 km regularly has demonstrated improved postural sway in elderly people.^[19] Therefore, we speculate that Suryanamaskar which produces 18 times greater vertical displacement of COM than walking, can challenge postural control mechanisms to a greater extent than walking. Therefore, Suryanamaskar holds potential for application of training stimulus for postural control in people with impaired balance.

Kinematically, Suryanamaskar was observed to be largely symmetrical following a graceful sequence of poses that moved the spine and lower extremity joints through a near complete range of motion. Predominant motion in the sagittal plane, alternated between flexion and extension. All involved joints were observed to move through a large range of motion which would be effective in stretching muscles and soft tissue. Flexion of the spine during pose 3 would exert a stretch on posterior structures such as dorsolumbar fascia, hamstrings, and tendoachilles whereas the extension of

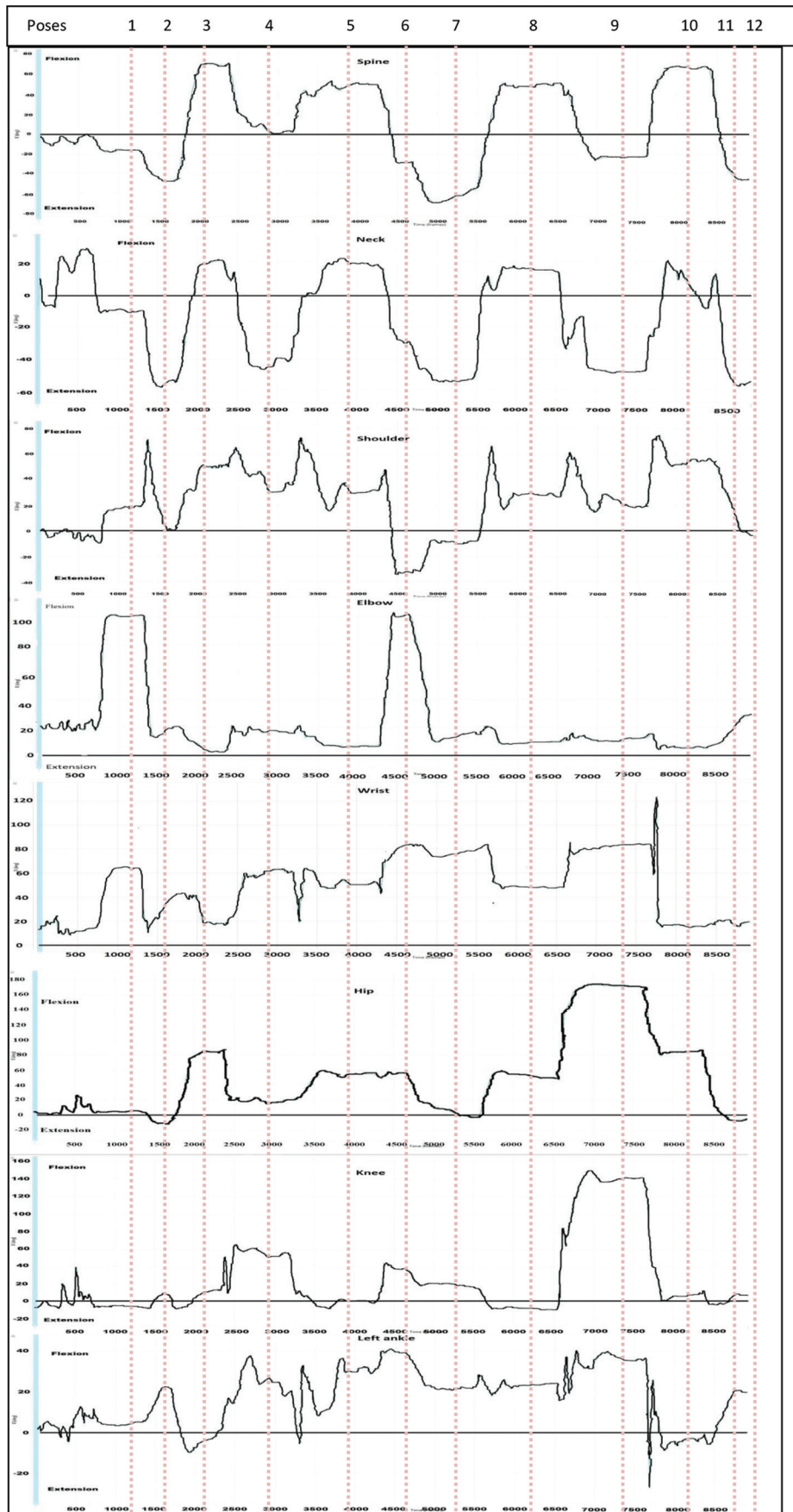


Figure 2: Spine, hip, knee, ankle, neck, shoulder, elbow, and wrist motion during Suryanamaskar

the spine and hip would stretch iliopsoas. In addition, alternating flexion-extension movements would ensure alternate distribution of compressive forces at the spine, which could be beneficial contrary to certain exercises, which have either a flexion or an extension bias and are likely to produce compressive forces on anterior or posterior structures of the spine, respectively.

Complete knee flexion up to 132° ensures stretching of the quadriceps muscle while movement of ankle in a closed kinematic chain through 32° dorsiflexion effectively stretches the gastrocnemius and soleus. These findings substantiate the reports of increase in muscle flexibility following the Suryanamaskar intervention.^[1,22,23] In addition, alternating flexion-extension movements may ensure even distribution of compressive loads on spine and lower extremity. Thus, Suryanamaskar holds potential to increase the mobility of almost all body joints, with a stretch on anterior and posterior soft tissues. Joint moments encountered by various joints during Suryanamaskar are reported to be highest at the hips.^[11,16] It is speculated that submaximal loading of joints compared to other high-impact activities such as running, along with comparable energy expenditure make Suryanamaskar a suitable exercise option for improving strength and mobility in people with degenerative musculoskeletal disorders, as none of the joints seem to be overstressed.

Similarly, the upper body quadrant also demonstrated a wide range of movement. Neck extension during most poses with a maximum of 76° could be beneficially used in people involved in desk jobs demanding continuous flexion activity and subsequent development of neck pain. Shoulder moved through overhead extension of 183°–56° flexion, elbow from 22° to 116° flexion, and wrist from 85° to 3° wrist extension; demonstrating that alternating wide-range transition between flexion and extension during Suryanamaskar has the potential to increase mobility of all joints throughout the body, stretch anterior and posterior soft tissues, and challenge the postural balance mechanisms through a varying base of support. Given, wide and large range of motion offered, Suryanamaskar holds huge potential as a single complete exercise to enhance flexibility and postural control of the body in a closed kinematic chain to impart benefits of weight bearing.

The wide range of motion observed during Suryanamaskar may be influenced by inherent joint laxity or greater soft-tissue length which may explain knee extension range beyond neutral. Wide standard deviation in angles in some of the poses may be due to inherent variation in technique and greater awareness of joint position sense in some people compared to others. Studies report improvement in balance performance following Suryanamaskar intervention in healthy as well as people with neurological disorders which may be due to enhanced joint position sense following training.^[1,20]

The present findings inform the principal motion in sagittal plane. There is further scope to discuss coupled motion in coronal and transverse planes.

Findings from the present study offer robust insight in kinematics of Suryanamaskar, providing precise information on joint motion occurring at spine, upper extremity, and lower extremity joints to enable clinicians to offer evidence-based prescription of Suryanamaskar.

Conclusion

It is concluded that alternating wide range of transition between flexion and extension during Suryanamaskar holds potential to increase mobility of almost all body joints by stretching anterior-posterior soft tissues and challenge postural balance mechanisms through a varying base of support.

Financial support and sponsorship

Intramural support from MGM School of Physiotherapy, MGM Institute of Health Sciences, Navi Mumbai, India.

Conflicts of interest

There are no conflicts of interest.

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