

A meta-analysis of yoga studies in the field of biomechanics

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Abstract

The purpose of this study was to perform a “Meta-analysis on the Biomechanical Studies on Yoga”. The studies used in this study were collected from online databases such as Science Direct, PubMed, and Google Scholar. The articles published from 2000 to 2020 were considered. The keywords used were “yoga,” “biomechanics” and “athletes” Total studies, identified were N=4960 and the studies included for this study were sixteen (N=16). Results revealed that yogic practices can be used to improve the static and dynamic balance, muscle torque, joint moment of force, muscle activation, stabilizer of muscle, angular and linear kinematic, centre of pressure and range of motion of healthy individuals. It can be concluded that there is a strong body of knowledge of yoga studies in the field of biomechanics.

Keywords: yoga, biomechanics, kinematics, kinetics, muscle force

Introduction

Biomechanics has been defined as the study of the structure, function, and motion of the mechanical aspects of biological systems (Bista, 2020) [1]. In this way knowledge of biomechanics guides the way we handle our posture and therefore helps us evade musculoskeletal injuries (Nara *et al.* 2016) [7, 10].

The pose formation and posture are deeply ingrained in yoga. Yoga, an ancient art of pose formation which is synchronized with breathing techniques and meditation has been making waves around the globe. The populace of yoga has increased due to its effectiveness in increasing fitness and healing properties for many non-communicable diseases such as arthritis, diabetes, etc (Campos *et al.*, 2016).

In the last two decades a significant amount of research studies has been conducted in yoga which come under the domain of biomechanics. This body of knowledge in

biomechanics tries to understand the relationship of body movements with the performance in a yoga asana, demands of various yogic poses, elucidates the muscles involved and their degree of contraction in any given yogic pose (Campos *et al.*, 2016; Chen *et al.*, 2017; Yadav *et al.*, 2018) [5, 17], balance (Hasan *et al.*, 2020; Silver *et al.*, 2005) [15, 16].

This study had threefold objectives. (1) To provide summary on the studies (from 2000 to 2020) done on yoga in the domain of biomechanics and kinesiology. (2) To identify the research gaps in the contemporary biomechanical and kinesiology literature in regard to yoga. (3) To provide recommendations on the future biomechanical studies on yoga.

Methods

The procedure of studies included in the meta-analysis is shown with the help of following flowcharts

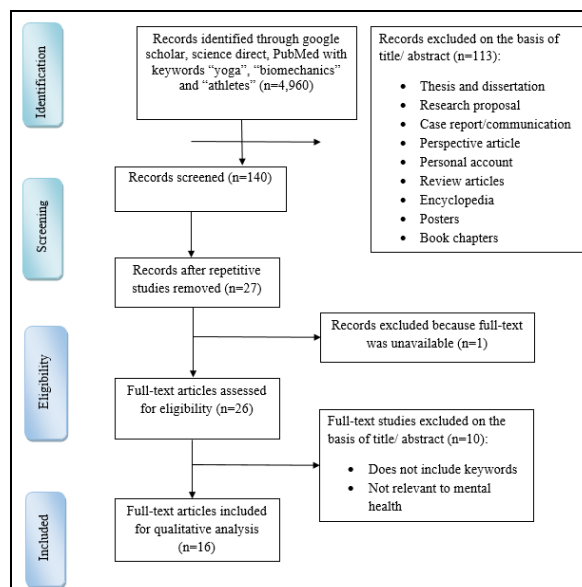


Fig 1: Flow Chart Depicting the Selection of Studies for Meta-Analysis on Biomechanics and Yoga

Search Strategy

This study sought to perform a meta-analysis on biomechanical studies on yoga. The databases including Science Direct, PubMed, and Google Scholar were searched with the relevant keywords. The keyword used were “yoga”, “biomechanics” and “athletes”. The research article published from 2000 to 2020 were considered. The studies were excluded if the retrieved document was a Thesis and dissertation, short communications, encyclopedia, discussions, editorials, Personal account, review articles, conference abstracts, posters, book chapters. Another exclusion criteria was if the participants were unhealthy subjects.

Results

A total number of 16 studies were included for this meta-analysis. In the process of tabulation, the major subheadings were aim of the study, sample size, gender, age, intervention, experimental duration (Acute/Chronic), results of the study and conclusion. For furthering the meta-analysis in regards to sample size, gender, age, intervention, treatment protocol (Acute/Chronic) were analyzed using the statistics namely average, frequency, percentage (%) and ranking, analysis pertaining to the same have been documented in the tables 1

Table 1: Summary of the Studies Depicting the Meta -Analysis on Biomechanics and Yoga

S.no	Study	Aim	Sample size	Age (in years)	Intervention	Intervention duration	Result
1.	Silver <i>et al.</i> , (2005)	To measure the effect of six weeks of yoga training on selected measures of static and dynamic balance	15 M 15 F	26.3 ± 8.3 years of men 28.7 ± 6.34 years of females	<ul style="list-style-type: none"> Yoga training Hatha yoga 	six weeks yoga training hatha yoga performed 50 minutes twice a week	<ul style="list-style-type: none"> Significant difference was found for main effect for time on A/P leg swing (dynamic balance). Mean differences were observed for the yoga group in both dynamic balance tests.
2.	Busko <i>et al.</i> , (2006)	To examine the changes of the maximal muscle torque in female during 6- months power yoga training.	12F	24 ± 6.1 years	<ul style="list-style-type: none"> Ashtanga yoga 	Twice a week for 6 months	<ul style="list-style-type: none"> No correlation between the body mass and muscle torque in static conditions in the six-month training, with the exception of the right knee extensors and trunk extensors.
3.	Yu <i>et al.</i> , (2012)	The objective of the study was to characterize the physical demands that are associated with two yoga asanas namely Vrikshasana and Utthita Hasta Padangustasana	6 M 14 F	70.1 ± 3.8 years	<ul style="list-style-type: none"> Vrikshasana Utthita Hasta Padangustasana 	32 eeks	<ul style="list-style-type: none"> No difference between the intermediate and advanced Tree variations regarding hip and knee JMOFs in both the sagittal and frontal planes Utthita Hasta Padangustasana introductory and intermediate variations induced sagittal JMOFs that were in the opposite direction of the classic advanced pose version at the hip and knee
4.	Meng <i>et al.</i> , (2014)	To assess the potential use of 11 yoga poses in specific training and rehabilitation program via examination of the muscle activation patterns in selected trunk and hip muscles.	8M 22F	32 ± 12.3 years	Yogasanas (halfway lift, forward fold, downward facing dog, upward facing dog, high plank, low plank, Chair, Mountain arms up, mountain arms down, dominant side warrior 1, non-dominant side warrior 1)	Each pose maintains in 15s.	<ul style="list-style-type: none"> Significant of pose and muscle and the significant pose x muscle interaction. Longissimus thoracis (LT) and external oblique abdominis (EOA) muscle produced significantly higher EMG levels than the lower fibers of rectus abdominis (RAL). External oblique

							abdominis (EOA) generated significantly greater muscle activity than the upper fibers of rectus abdominis (RAU).
5.	Meng Ni <i>et al.</i> , (2014)	To compare the muscle activation patterns in 14 dominant side muscles during different yoga poses across three skill level.	9M 27F	31.6 ± 12.6 years	11 yoga poses sequence (chair, downward facing dog, halfway lift, forward fold, high plank, low plank, mountain pose with arms up, mountains pose with arms down, upward facing dog, non- dominant side warrior 1 pose, dominant side warrior 1 pose)	Each pose holds for 15s.	<ul style="list-style-type: none"> Significant main effects of pose for all 14 muscles. Upper body muscle shows higher significant Core muscles shows higher significant
6.	Flao <i>et al.</i> , (2015)	To compare the perceived grip, balance, comfort of yoga and gym mats correlate with biomechanical and mechanical assessment.	2M 12F	36 ± 6.9 years	<ul style="list-style-type: none"> Downward facing dog pose Tree pose Gym pose 	Downward facing dog pose for 3 times. Tree poses for five times for 20s to evaluate the balance. Gym pose measure the knee pressure in 60s	<ul style="list-style-type: none"> Significant but low correlation with the grip. Balance shows the deviation and the range of motion of the cop on the anteroposterior axis are relevant. Assessment of comfort the contact area is most correlated with sensory data.
7.	Nara <i>et al.</i> , (2016)	To investigate the co-contraction of selected knee stabilizer muscles as a measure of neuromuscular fatigue in relation to gender, performance and side (left and right) of male and female during sustained squat posture.	32 M 18 F	19.8 ± 2.2 years of men 19.3 ± 1.8 years for females	Squat performing as a chair pose	Squat for 30s, 60s,90s and 120s	<ul style="list-style-type: none"> FHP has higher co-activation than that of MHP Female high performance (FHP) having higher chances of picking up injuries Female high performance reflects higher muscular development
8.	Campos <i>et al.</i> , (2016)	The aim of the study was to examine the curvature of the spine while performing Sirshasana	6M 5F	29.4 ± 8.8 years	<ul style="list-style-type: none"> Sirsasana Walked on the treadmill 	5sec hold asana 5min walk on treadmill	<ul style="list-style-type: none"> Significantly different of the spine analysed region. In sagittal plane, inferior lumbar lordosis was significantly lower during than during neutral curve and orthostatic position. In frontal plane, in the middle thoracis region, the spinal positions than for the neutral curve and orthostatic posture.
9.	Chen <i>et al.</i> , (2017)	To understand the process of headstand and	6M 6F	34 ± 4 years	Handstand	3 times Holding the position in 5s.	<ul style="list-style-type: none"> No significant difference was found in joint angles.

		difference between gender.					<ul style="list-style-type: none"> No significant difference was found in overall pressure distribution between genders.
10.	Pereira <i>et al.</i> , (2017)	To compare healthy people and people with back pain on the electromyographic pattern of core muscles	19 M 13 F	28 ± 9 years	<ul style="list-style-type: none"> Only given instruction Instruction with video Video shown by the instructor with instructions One subject is taken by the instructor for demonstration 	12 weeks	<ul style="list-style-type: none"> No significant difference between the health group and group with lower back pain in the selected muscles. Significant difference in the external oblique muscle between group and between muscles.
11.	Ratthore <i>et al.</i> , (2018)	To determine the effects of yoga posture on the trunk muscle activities by examining the muscle activation patterns in erector spine and rectus abdominis muscles.	10M	19 ± 3 years	<ul style="list-style-type: none"> Cobra poses Boat poses 	8seconds hold for first pose 5 seconds hold for second pose	<ul style="list-style-type: none"> Significant effects of cobra pose on trunk muscle activities. Significant changes in trunk muscle activation during cobra pose as compared to boat pose.
12.	Yadav <i>et al.</i> , (2018)	To find the correlation of selected angular and linear kinematic variable and performance of chakrasana.	10M	20 ± 2 years	<ul style="list-style-type: none"> Chakrasana 	Execution of the skill and three judges were evaluated the final phase.	<ul style="list-style-type: none"> Significant correlation in the angular kinematics variables
13.	Patil <i>et al.</i> , (2018)	To measure the effect of yoga training on muscular strength abilities among elite volleyball players.	60M	17 ± 1 years	<ul style="list-style-type: none"> Arm muscles strength assessed by Pull ups Leg muscles measured by Vertical jump Abdominal muscles strength assessed by Sits ups Yogasans,(shavasana, naukasana, sarvangasana, Bhujangasana , dhanurasana, Paschimottan asana, vajrasana, bakasana, chakrasana, tikonasana, vrikshasana) Ujjayi Suryabhedan Anulom-Vilom pranayama 	8 weeks	<ul style="list-style-type: none"> Experimental (yoga) group showed significant changes in arm muscles strength. Leg muscles strength Abdominal muscles strength
14.	Hurley <i>et al.</i> , (2018)	To examine scapular stabilizer muscle activation	20F	29 ± 11 years	<ul style="list-style-type: none"> Hot yoga 6 times Flow yoga 5 	15-20 days	<ul style="list-style-type: none"> Muscle activity varied between yoga postures.

		during various yoga postures			<ul style="list-style-type: none"> ▪ Moksha 4 times ▪ Power 2 times ▪ Vinyasa 2 times ▪ Ashtanga 2 times ▪ Hatha 2 times 		<ul style="list-style-type: none"> ▪ posture “locust arms forward” elicited the highest activity from the upper, middle and lower trapezius. ▪ Postures elicited moderate activity from the serratus anterior.
15.	Błażkiewicz <i>et al.</i> , (2020)	To examine centre of pressure (COP) regularity in both yoga instructors and novices during the performance of four yoga poses.	40 F	21 to 31 years	<ul style="list-style-type: none"> ▪ Yogasanas ▪ Standing Knee Hug pose ▪ Tree pose ▪ Eagle pose ▪ King – Dancer pose 	Each pose maintained in 20s.	<ul style="list-style-type: none"> ▪ Significant main effects of group yoga and not yoga ▪ No significant effects of two factors: group x position interaction
16.	Hasan <i>et al.</i> , (2020)	To investigate the effect of yoga training on balance and knee proprioception after mental fatigue in amateur male athletes	36M	Not Available	Yoga training	8 weeks	<ul style="list-style-type: none"> ▪ Active and passive knee proprioception were significant after yoga training.

Note: JMOF (joint moments of force), OLB (one leg balance), RAL (rectus abdominis), EOA (External oblique abdominis), RAU (rectus abdominis), FHP (female high a a performance), MHP (male high performance), LBP (low back pain), MVIC (maximum voluntary contraction), COP (centre of pressure), Y (yoga), NY (not yoga)

Table 2: Disruptive statistics of Age of participants in each study

S.no	Study	Age (in years)		
		Mean Age	±	SD
1	Silver <i>et al.</i> , (2005)	27.5	±	7.32
2	Busko <i>et al.</i> , (2006)	24	±	6.1
3	Yu <i>et al.</i> , (2012)	70.1	±	3.8
4	Meng <i>et al.</i> , (2014)	32	±	12.3
5	Meng Ni <i>et al.</i> , (2014)	31.6	±	12.6
6	Flao <i>et al.</i> , (2015)	36	±	6.9
7	Nara <i>et al.</i> , (2016)	19.55	±	2
8	Campos <i>et al.</i> , (2016)	29.4	±	8.8
9	Chen <i>et al.</i> , (2017)	34	±	4
10	Pereira <i>et al.</i> , (2017)	28	±	9
11	Ratthore <i>et al.</i> , (2018)	19	±	3
12	Yadav <i>et al.</i> , (2018)	20	±	2
13	Patil <i>et al.</i> , (2018)	17	±	1
14	Hurley <i>et al.</i> , (2018)	29	±	11
15	Błażkiewicz <i>et al.</i> , (2020)	26	±	5
16	Hasan <i>et al.</i> , (2020)	NA	±	NA

Note: NA = the age not mentioned; Minimum mean age = 17 ± 1 Maximum mean age = 70.10 ± 3.8, Average mean age = 29.54 ± 6.32

Table 3: Treatment Protocol/ Intervention (Acute/ Chronic)

S.no.	Study	Types of Intervention/Treatment Protocol	
		Acute (Minutes)	Chronic (Days)
1	Silver <i>et al.</i> , (2005)	-	45
2	Busko <i>et al.</i> , (2006)	-	180
3	Yu <i>et al.</i> , (2012)	-	90
4	Meng <i>et al.</i> , (2014)	-	240
5	Meng Ni <i>et al.</i> , (2014)	2.45	-
6	Flao <i>et al.</i> , (2015)	2.45	-
7	Nara <i>et al.</i> , (2016)	60	-
8	Campos <i>et al.</i> , (2016)	5	-
9	Chen <i>et al.</i> , (2017)	1	-
10	Pereira <i>et al.</i> , (2017)	-	90
11	Ratthore <i>et al.</i> , (2018)	30	-

12	Yadav <i>et al.</i> , (2018)	-	-
13	Patil <i>et al.</i> , (2018)	-	60
14	Hurley <i>et al.</i> , (2018)	-	20
15	Błażkiewicz <i>et al.</i> , (2020)	2	-
16	Hasan <i>et al.</i> , (2020)	-	60

Note: Those studies with “-” Depicts the studies which have not mentioned clearly the number of minutes and days involved and hence were excluded.

Minimum duration of intervention in minutes = 1min
 Minimum duration of intervention in days = 20 days
 Maximum duration of intervention in minutes = 60 min
 Maximum duration of intervention in days = 240 days
 Average duration of intervention in minutes = 14.7 min
 Average duration of intervention in days = 98.13 days

According to table 3, the minimum duration of intervention for acute is 1 minutes and for chronic is 20 days. The maximum duration of intervention for acute is 60 minutes and for chronic is 240 days. The average duration of intervention for acute is 14.7 and for chronic is 98.13 days

Table 4: Frequency Distribution of Studies Conducted in Yoga in the Areas of Biomechanics

S.no	Intervention	Frequency	Ranking
1	Pranayam	1	2.5
2	Asanas	13	1
3	Meditation	2	1.5
4	Suryanamaskar	2	2
5	Walking	1	3

According to table 4, asanas were ranked 1 followed by Pranayama, Meditation, Suryanamaskar, Walking.

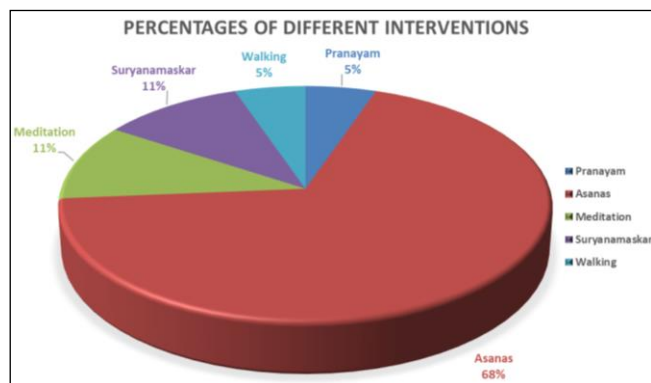


Fig 2: Percentages of Different Interventions

Discussion

The studies done in the field of yoga in the area of biomechanics have explored many different question ranging from but not confined to studying the muscle activation pattern in different yogic poses (Hurley *et al.*, 2018; Meng Ni *et al.*, 2014; Ratthore *et al.*, 2018; Busko *et al.*, 2006; Yu *et al.*, 2012) [18], some attention has been given to studying the kinematics of yoga poses (Campos *et al.*, 2016; Chen *et al.*, 2017; Yadav *et al.*, 2018) [5, 17], balance (Hasan *et al.*, 2020; Silver *et al.*, 2005) [15, 16], gaining muscular strength (Patil *et al.*, 2018) [11], COP (Błażkiewicz *et al.*, 2020) [2] and comfort of yoga mats (Flao *et al.*, 2015) [6].

The findings suggest that yoga is able to intervene by changing maximal muscle torque (Busko *et al.*, 2006), change activation pattern of muscles (Hurley *et al.*, 2018; Meng Ni *et al.*, 2014; Ratthore *et al.*, 2018; Yu *et al.*, 2012) [18], improve kinematics of limbs and torso (Campos *et al.*,

2016; Chen *et al.*, 2017; Yadav *et al.*, 2018) [5, 17], and can also help gain muscular strength in many ways (Patil *et al.*, 2018; Hasan *et al.*, 2020) [11, 15].

There have been none studies exploring the kinetic features of yogic poses and the kinetic features as they can inform about the static and dynamic balance that takes place during a yogic pose. Studies are also missing on the yogic training on locomotion of healthy people.

Conclusions

Yoga practices improves the static and dynamic balance, muscle torque, joint Moment of force, muscle activation, stabilizer of muscle, angular and linear kinematic, centre of pressure and range of motion. The conclusions summarized that yoga practice imparts significant effect on biomechanical variables.

References

- Bista S, Sciences N, Bhargav H, Sciences N. Biomechanics of Yoga Presented by: Chair Person, 2020. <https://doi.org/10.13140/RG.2.2.12292.76160/1>
- Błażkiewicz M. Nonlinear measures in posturography as compared to linear measures in base on yoga poses performance. Acta of Bioengineering and Biomechanics,2020;22(4):1-14. <https://doi.org/10.37190/ABB-01629-2020-02>
- Buško K, Rychlik R. Changes of the maximal muscle torque in women training Power Yoga (Astanga Vinyasa). Human Movement,2006;7(2):168-177.
- Campos MH, Giraldi NM, Gentil P, de Lira CAB, Vieira CA, de Paula MC. The geometric curvature of the spine during the sirshasana, the yoga’s headstand. Journal of Sports Sciences,2017;35(12):1134-1141. <https://doi.org/10.1080/02640414.2016.1211310>
- Chen Y, Lee CW, Chen YL, Lin HT, Chang JH. Biomechanical characteristics in yoga sirshasana. Journal of Mechanics in Medicine and Biology,2017;17(3):1-9. <https://doi.org/10.1142/S0219519417500531>
- Le Flao E, Imbert C, Wloch H, Gueguen N. Perceived grip, balance and comfort of yoga and gym mats correlate with biomechanical and mechanical assessment. Computer Methods in Biomechanics and Biomedical Engineering,2015;18:1980-1981. <https://doi.org/10.1080/10255842.2015.1069585>
- Nara S, Kaur M, Bhatia D, Shaw D. Co-Contraction of Knee Stabilizer Muscles during Sustained Squat Posture (A Yogic Posture) in Athletes. Journal of Yoga & Physical Therapy, 2016, 06(04). <https://doi.org/10.4172/2157-7595.1000256>

8. Ni M, Mooney K, Harriell K, Balachandran A, Signorile J. Core muscle function during specific yoga poses. *Complementary Therapies in Medicine*,2014;22(2):235-243.
<https://doi.org/10.1016/j.ctim.2014.01.007>
9. Ni M, Mooney K, Balachandran A, Richards L, Harriell K, Signorile JF. Muscle utilization patterns vary by skill levels of the practitioners across specific yoga poses (asanas). *Complementary Therapies in Medicine*,2014;22(4):662-669.
<https://doi.org/10.1016/j.ctim.2014.06.006>
10. Nara S, Kaur M, Bhatia D, Shaw D. Co-Contraction of Knee Stabilizer Muscles during Sustained Squat Posture (A Yogic Posture) in Athletes. *Journal of Yoga & Physical Therapy*,2016, 06(04).
<https://doi.org/10.4172/2157-7595.1000256>
11. Patil SS, Bera T. Research article YOGA FOR IMPROVING MUSCLES STRENGTH IN ELITE VOLLEYBALL PLAYERS, 2018.
12. Pereira ILR, Queiroz B, Loss J, Amorim C, Sacco ICN. Trunk Muscle EMG during Intermediate Pilates Mat Exercises in Beginner Healthy and Chronic Low Back Pain Individuals. *Journal of Manipulative and Physiological Therapeutics*,2017;40(5):350-357.
<https://doi.org/10.1016/j.jmpt.2017.02.010>
13. Ratthore M, Periyasamy R, Sharma DK. Electromyographical Analysis of the Effect of Yoga Posture on the Trunk Muscle Activities and Its Significance: A Pilot Study. *Indian Journal of Clinical Anatomy and Physiology*,2015;2(2):74-80.
14. SAV. Effect of Deep Heat Combined Static Stretching on the Triceps Surau Muscle Extensibility in Athletes Recovering from First Degree Lateral Ligament Sprain of Ankle Joint. *Journal of Adapted Physical Education and Yoga*,2011;1(1):29-36.
https://www.researchgate.net/publication/256095615_
15. Sarhad Hasan M, Haydary M, Gandomi F. The Effect of an 8-Week Yoga Training Program on Balance and Knee Proprioception after Mental Fatigue in Amateur Male Athletes. *Journal of Sport Biomechanics*,2020;5(4):228-239.
<https://doi.org/10.32598/biomechanics.5.4.3>
16. Silver T, Mokha MB, Shores M. Effects of 6 wks of yoga training on selected measures of static and dynamic balance. *Motor Control*, 2005, 679-683.
17. Yadav D, Verma S. Kinematic analysis of chakrasana in yoga,2019;4(1):868-870.
18. Yu SSY, Wang MY, Samarawickrame S, Hashish R, Kazadi L, Greendale GA, Salem GJ. The physical demands of the tree (Vriksasana) and one-leg balance (Utthita Hasta Padangusthasana) poses performed by seniors: A biomechanical examination. *Evidence-Based Complementary and Alternative Medicine*, 2012.
<https://doi.org/10.1155/2012/971896>