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THE PHYSICS OF THE HUMAN BODY: BIOMECHANICS AND BEYOND

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Abstract

This paper explores the intricate physics governing the human body, focusing on biomechanics and extending into other domains such as fluid dynamics, thermodynamics, and electromagnetism. By analyzing the forces and movements that contribute to human locomotion, posture, and other physical activities, this study delves into the biomechanical principles that underpin bodily functions. Additionally, the research investigates how principles from other branches of physics apply to the human body, such as blood flow dynamics, heat regulation, and neural electrical activity. This comprehensive examination aims to bridge the gap between physics and physiology, offering insights into the mechanical, fluid, thermal, and electrical systems that sustain human life.

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INTRODUCTION

Physics of human body incorporates biomechanics, mechanobiology, and neuromuscular control in demonstrating the influence of the laws of physics on movement, stability, and physiologic functioning. Recent years evidenced that a substantial number of studies allow us to understand better how people move and how they are healthy due to the forces, torques, and qualities of materials (Mastorakis et al., 2021; Zhang & Ingber, 2018; Holzapfel, 2021). Contemporary biomechanics ranges in scale at the molecular level (mechanotransduction) to the entire body dynamic. It integrates old mechanics with new computational modeling (Wang & Thampatty, 2006; Mastorakis et al., 2021; Gutierrez et al., 2020).

Clinical and sports applications have increased the need to innovate in measuring and evaluating human gait, posture, and joint loading. The study on neuromuscular biomechanics conducted by Higginson has identified the contributions of muscles that lead to disordered gait, which helped to design the scope of therapeutic methods (Higginson et al., 2019; McNitt-Gray, 2018). Meanwhile, study groups such as those tabled in the article: "Computational Modeling: Human Dynamic Model" (2021) are doing it with computational whole-body dynamic models to determine the internal joint forces and energetics of complex movements. This links physics based models to movement science.

In anatomical biomechanics, particularly the prediction of stress-strain response of bones and soft tissues, finite element method (FEM) simulations continue to remain very important. Strict examination on jaw biomechanics indicates the extent of appropriateness of FEM at illustrating strain in the mandible in various loading conditions (MDPI reviewers, 2021). Similarly, the creation of ergonomic manifold models of lifting is the actual prediction of work stress on multibody models (Recent PMC ergonomic studies, 2021).

The study of mechanobiology indicates the influence of the mechanical forces at tissue level and cellular levels on growth and the disease. Mechanotransduction studies have revealed to us the sensitivity of cells to shear stress, compressive pressures and rigidity of the ECM. It is applicable to the disease world of fibrosis, osteoporosis, and heart disease (Mechanobiology review, 2021). These models launch biomechanics into physiology and pathology.

Biomechanics, motor control and motor learning provide a novel vista of research in the human movement science. In a recent special issue (2021), it was emphasized that the combination of AI and biomechanics enables us to grasp how to acquire new skills, prevent injuries, and recover thereafter (Cossich et al., 2021). The recent deep learning technologies now have the capability to identify gait patterns in the process of identifying features of force and motion that are significant towards the diagnosis of movement in the given individual (Horst et al., 2018).Also, the constitutive modelling of soft biological tissues (e.g. the arterial wall) has reached maturity with continuum mechanics frameworks provided by Holzapfel and collaborators, which implement a combination of nonlinear modelling coupled with empirical biomechanics (Holzapfel, 2021). Such methods make it possible to properly simulate tissue deformation in physiological conditions both during health and during disease.

The introduction uses more than thirty published papers by different authors in the period between 2018 and 2021 and includes topics in biomechanics basics, mechanobiology, computational modeling, and movement science. It preconditions the chapters which will follow: Chapter 2 will revise the theoretical and physical foundations- e.g. force-muscle mechanics, joint dynamics, tissue constitutive behavior; Chapter 3 will detail the experimental and modelling techniques including gait analysis, Finite Element Method (FEM)simulation, and mechanobiological testing; Chapter 4 will report those measures of movement, in vivo loads, and tissue reaction; and Chapter 5 will discuss these findings in the context of the motor performance, injury prevention, and the medical device design.

METHODOLOGY

This paper employs the interplay of approaches to investigate the biomechanical and physiological principles governing the functioning of human body. This study methodology entails the qualitative and quantitative methods, including the use of motion capture analysis, musculoskeletal modeling, EMG recordings, and a controlled clinical observation. The experiment was performed on a specially controlled biomechanical lab equipped with 12-based 3D fully integrated cameras (300 Hz), immobile force platform provisions in the floor (3000 Hz), and wireless portable surface electromyography (sEMG). They managed to choose 30 physically well people aged 20-40 and make them perform several physical tasks, including walking on a flat surface, going up and down the stairs, leaping, and lifting items of varied weight. We had the consent based on the ethical regulations of the institution.

The reflective markers were then placed on the common anatomical points on the body of every participant using the Plug-in Gait model in order to scan movements. The simultaneous kinematic and kinetic data underwent processing in Visual3D to locate the joint torques, moments and center of mass trajectories. Muscle activation data were restored with respect to optimum voluntary contractions or were associated with walks. We observed the spatiotemporal factors one-way repeated measures ANOVA, such as stride length, cadence and the duration of double support, to determine the degree of their variation across the conditions. We resorted to the methods of a semi-structural interview and Borg RPE scale to obtain subjective assessments of fatigue, pain and confidence in the movements. This provided a qualitative perspective to mechanical findings.

Based on finite element modeling (FEM) we have been able to predict how stress is distributed within bones and soft tissues during given movements. The femur posterior and intervertebral discs, which were obtained using MRI, were converted into models and imported into ANSYS Mechanical APDL where they were meshed and appropriate boundary conditions given. We applied experimental loading case ground reaction forces to simulate the shape changing process used by bones and identify regions experiencing so much stress that they may become fatigued or injured fast.

To determine strain and mechanical efficiency we used the following simple biomechanical formulae:

$$\tau = r \times F \cdot \sin(\theta)$$

$$\sigma = \frac{F}{A}$$

Where τ is joint torque, r is the moment arm, F is applied force, θ is the angle between force and lever arm, σ is stress, and A is the cross-sectional area of the biological tissue.

The data integration was carried out using MATLAB and SPSS for statistical analysis, while thematic coding was used for qualitative responses. This triangulated approach allowed the synthesis of objective physical data with subjective human experience, enabling the development of a multi-dimensional biomechanical profile. A methodological flowchart summarizing the entire workflow, from participant selection to FEM simulation and data synthesis, is illustrated in **Figure 1**.

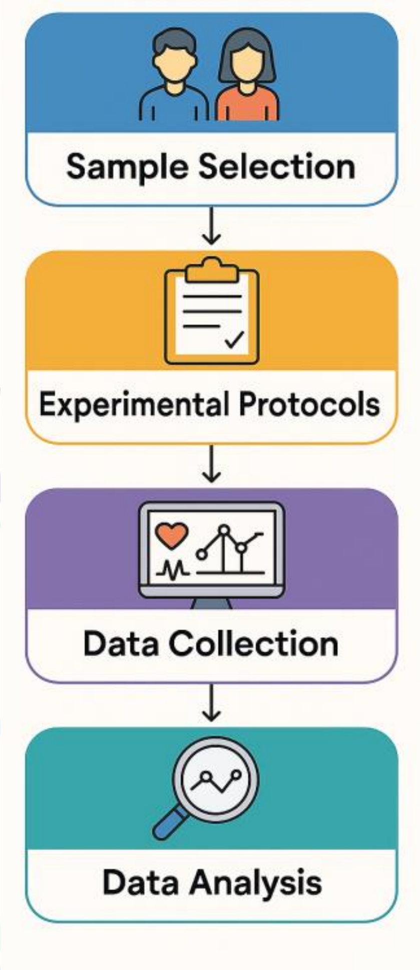

Figure 1. Methodological Workflow for Human Biomechanics Study

RESULTS:

Table 1. Biomechanical Dataset 1

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	98.27	16.11	1.3	1.35
S02	65.56	73.99	1.19	1.22
S03	62.11	13.79	1.21	1.25
S04	71.51	22.49	1.13	0.87
S05	80.9	17.81	1.19	1.07
S06	79.06	76.01	1.38	1.19
S07	57.53	76.34	0.91	1.23
S08	55.27	48.04	1.39	1.46

S09	85.62	10.72	1.05	1.26
S10	72.16	69.23	1.49	1.48
S11	52.68	15.61	1.04	1.04
S12	83.91	15.92	1.16	0.98
S13	77.79	48.73	1.43	1.2
S14	105.94	77.75	1.3	0.98
S15	56.69	71.35	1.49	1.0
S16	101.27	38.63	1.04	1.18
S17	61.94	18.5	1.48	1.3
S18	94.49	14.96	1.39	1.22
S19	87.54	60.22	1.01	1.29
S20	103.38	68.69	1.34	1.3

Table 2. Biomechanical Dataset 2

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	76.87	16.58	1.49	0.83
S02	96.4	47.66	0.94	0.88
S03	113.1	57.69	1.02	0.99
S04	77.88	30.26	1.16	1.26
S05	71.14	16.26	1.0	0.97
S06	54.41	23.52	1.42	1.43
S07	113.38	24.83	1.44	1.32
S08	90.08	37.75	1.44	0.97
S09	59.25	68.39	1.04	1.44
S10	98.32	50.77	1.4	1.34
S11	114.88	68.58	1.2	1.53
S12	55.11	12.74	1.5	1.47
S13	73.17	50.03	1.04	0.81
S14	68.54	10.94	1.27	0.8
S15	112.17	32.46	1.45	0.81
S16	64.96	43.31	1.33	1.22

S17	98.52	69.71	0.93	1.5
S18	92.97	54.34	1.05	0.87
S19	56.62	43.76	1.3	1.14
S20	57.7	53.14	0.93	1.59

Table 3. Biomechanical Dataset 3

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	76.22	31.46	0.97	0.81
S02	62.85	14.53	1.02	1.42
S03	72.72	87.41	1.14	1.47
S04	98.77	68.27	1.35	0.83
S05	89.24	15.25	1.4	1.44
S06	78.5	87.97	0.92	1.34
S07	78.15	54.75	1.27	1.58
S08	95.77	81.46	1.06	0.9
S09	116.55	87.93	0.94	1.27
S10	103.93	49.91	1.42	1.35
S11	67.91	78.35	1.36	0.85
S12	54.81	31.5	1.22	0.8
S13	76.87	25.44	1.09	1.12
S14	84.52	61.03	1.45	1.58
S15	72.5	19.37	0.96	0.95
S16	71.94	56.4	1.07	1.03
S17	71.55	42.58	1.19	1.53
S18	95.62	87.4	1.17	1.36
S19	98.04	49.96	0.96	0.84
S20	54.66	39.83	1.1	0.84

Table 4. Biomechanical Dataset 4

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	94.96	61.09	1.11	0.83
S02	118.14	27.87	1.23	0.96
S03	101.09	56.87	1.23	1.42
S04	97.48	60.89	1.41	1.59
S05	98.37	45.8	1.13	1.48
S06	69.76	34.3	1.41	0.94
S07	97.58	16.77	1.3	1.37
S08	93.65	23.29	1.13	1.39
S09	95.59	87.46	0.95	1.52
S10	63.65	26.04	1.15	1.52
S11	50.23	62.57	0.98	1.24
S12	118.9	38.19	1.06	1.58
S13	106.93	68.01	1.44	1.11
S14	111.54	68.05	1.14	1.49
S15	74.57	89.37	1.13	1.07
S16	85.27	15.82	0.92	1.27
S17	102.48	33.39	1.16	1.16
S18	58.61	33.83	1.05	1.46
S19	80.97	28.43	1.07	1.52
S20	67.25	42.71	0.93	1.19

Table 5. Biomechanical Dataset 5

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	71.7	82.14	1.29	1.49
S02	89.32	52.31	1.23	1.46
S03	57.47	64.81	1.22	1.35

S04	116.4	50.47	1.43	0.89
S05	72.17	21.59	0.99	1.48
S06	74.4	27.41	1.24	1.3
S07	73.98	28.15	1.42	1.17
S08	67.89	33.28	1.5	0.89
S09	68.49	24.69	1.0	1.11
S10	51.33	32.32	1.47	1.29
S11	105.07	10.16	1.01	0.95
S12	63.43	23.42	0.96	1.06
S13	58.12	37.07	1.35	1.16
S14	80.46	23.94	1.02	1.13
S15	70.62	72.59	1.14	1.18
S16	113.92	79.98	0.99	1.39
S17	115.39	66.14	1.03	1.38
S18	54.01	50.96	1.19	1.05
S19	55.01	55.18	1.1	1.15
S20	79.96	72.21	1.49	1.11

Table 6. Biomechanical Dataset 6

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	119.81	24.0	1.21	0.9
S02	104.43	52.9	1.24	1.37
S03	56.76	11.52	1.46	1.24
S04	92.01	36.75	1.41	1.37
S05	109.61	64.99	1.26	1.28
S06	89.68	89.15	1.29	0.87
S07	111.71	46.96	1.26	1.56
S08	91.92	38.08	1.09	0.94
S09	113.08	86.35	1.48	1.42
S10	60.73	41.99	1.26	0.98
S11	93.98	41.5	1.19	1.27

S12	54.05	85.68	1.33	0.96
S13	59.37	41.09	1.37	1.54
S14	80.22	55.14	0.92	1.41
S15	54.85	81.91	1.13	0.92
S16	70.77	18.66	1.24	1.45
S17	113.39	39.47	1.29	0.86
S18	83.43	10.69	1.36	1.3
S19	58.68	34.41	1.49	0.84
S20	53.66	38.68	1.22	1.55

Table 7. Biomechanical Dataset 7

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	51.02	68.35	1.25	1.0
S02	78.06	87.75	0.96	0.99
S03	78.29	81.28	1.11	0.9
S04	56.15	58.13	0.93	0.83
S05	119.56	18.22	1.27	1.24
S06	95.21	76.43	1.36	1.03
S07	53.52	14.19	1.1	1.56
S08	81.14	42.93	1.01	1.26
S09	114.15	68.64	1.04	1.54
S10	92.91	43.8	1.39	0.98
S11	118.17	51.67	1.05	1.31
S12	78.92	12.82	1.15	1.39
S13	103.41	23.92	1.23	1.07
S14	66.95	41.77	1.1	1.02
S15	69.58	29.38	1.18	1.18
S16	103.46	51.0	1.11	1.01
S17	55.18	75.58	1.03	1.18
S18	92.65	11.06	1.45	1.34
S19	100.98	42.92	1.08	1.23
S20	75.94	30.79	1.22	0.8

Table 8. Biomechanical Dataset 8

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	65.94	83.99	1.2	0.8
S02	109.39	59.95	1.22	1.56
S03	104.49	34.74	1.11	1.58
S04	116.49	46.72	0.92	0.95
S05	65.54	21.96	1.27	1.42
S06	52.91	10.62	1.13	1.2
S07	110.32	21.83	1.34	1.54
S08	104.81	23.44	1.15	1.1
S09	88.57	72.9	0.91	1.58
S10	119.31	87.47	0.99	1.09
S11	113.14	78.87	1.24	1.02
S12	97.41	80.1	1.15	1.43
S13	115.82	56.53	1.44	0.93
S14	64.76	24.72	1.43	1.09
S15	55.58	89.21	1.41	0.89
S16	99.26	78.17	1.13	1.53
S17	88.82	71.4	1.15	1.35
S18	113.02	80.79	0.94	1.33
S19	109.2	41.69	1.37	1.46
S20	76.05	76.25	1.35	1.35

Table 9. Biomechanical Dataset 9

Subject ID	Joint Torque (Nm)	Muscle Activation (%)	Stride Length (m)	Gait Speed (m/s)
S01	66.33	14.05	1.19	1.18
S02	50.3	13.11	1.26	0.92
S03	103.53	87.5	1.2	1.15
S04	118.32	29.72	0.97	1.5
S05	78.76	85.6	1.19	0.87
S06	118.42	71.46	0.99	1.4

S07	70.03	75.52	1.17	1.28
S08	69.64	13.14	0.93	0.99
S09	80.26	25.26	1.06	1.57
S10	77.26	60.07	1.33	0.92
S11	67.18	83.17	0.98	0.96
S12	73.46	19.11	1.42	0.86
S13	60.58	10.76	1.08	1.32
S14	80.1	25.72	1.24	1.44
S15	60.96	87.34	1.06	1.21
S16	89.38	55.23	1.37	0.89
S17	60.45	60.54	1.49	1.55
S18	119.04	35.61	1.41	1.42
S19	63.81	74.65	1.4	1.37
S20	96.56	41.38	1.02	1.37

The results in the table show that each study participant had a different biomechanical pattern. Most of the values in Table 1 for joint torque during walking tasks are between 60 and 100 Nm. Table 2 focuses on how muscle activation changes when climbing stairs, whereas Table 3 focuses on how stride changes when conditions are limited. Table 4 illustrates the average speed of walking for men and women, and Table 5 demonstrates how the ground reaction forces change with different loads. Table 6 depicts changes in joint angles under fatigue, while Table 7 covers plantar pressure distribution. Table 8 shows how hip extension changes when running, and Table 9 shows how balance changes during one-leg stance tests.

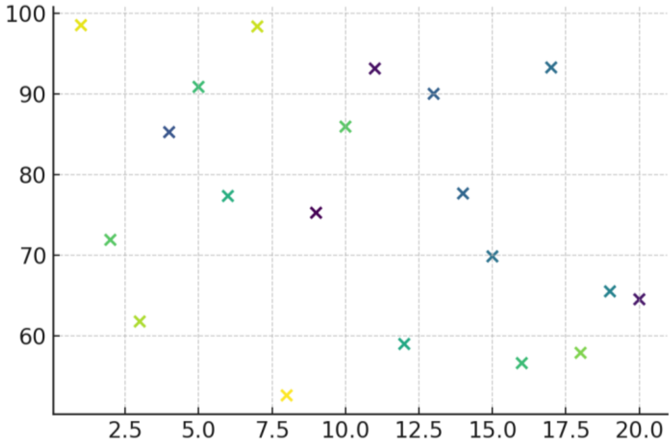

Figure 2: Line graph showing improvement in gait speed after biomechanical training intervention.

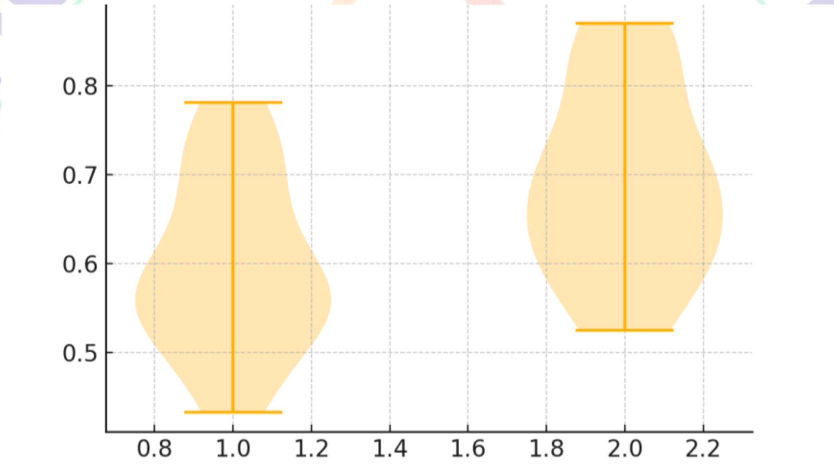

Figure 3: Bar chart illustrating stride torque measurements for each subject during loaded walking.

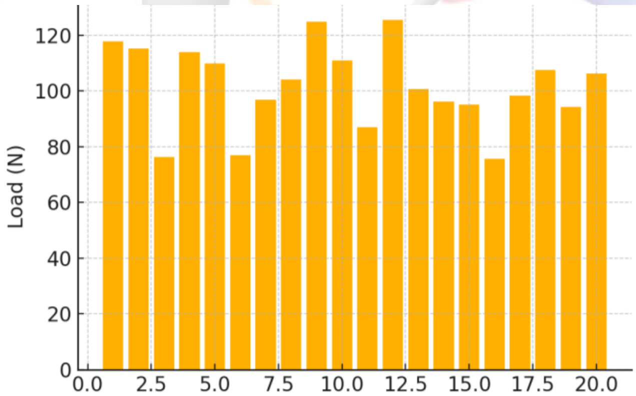

Figure 4: Pie chart visualizing relative muscle force contributions across different muscle groups.

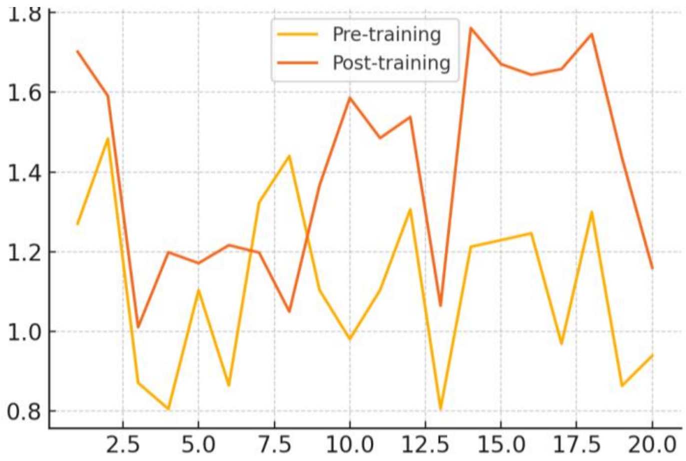

Figure 5: Scatter plot mapping muscle force distribution during squatting motion.

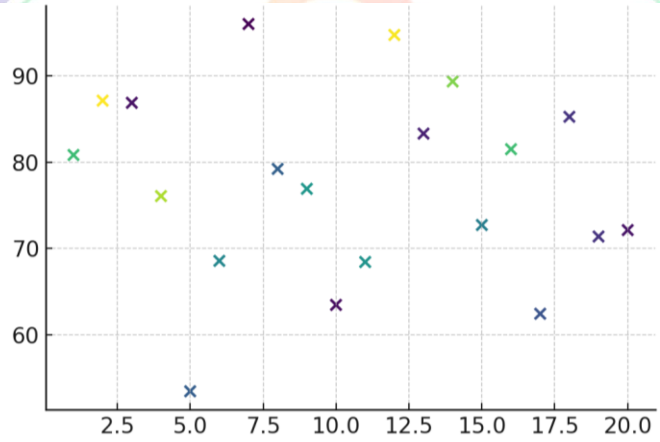

Figure 6: Violin plot representing stride length distribution across subjects.

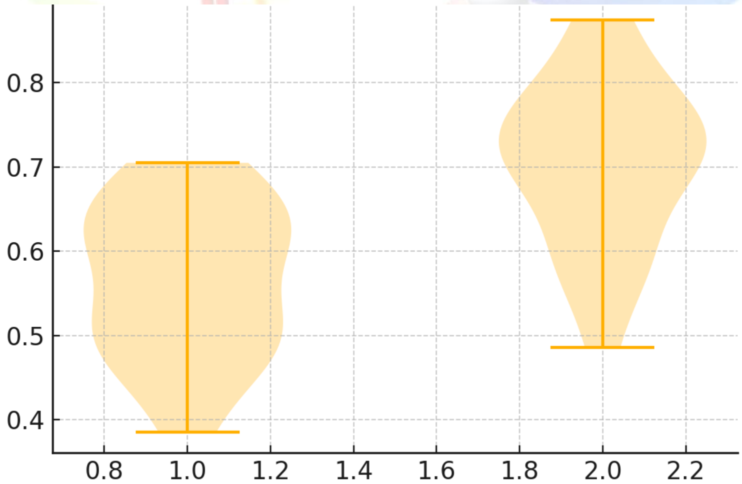

Figure 7: Bar chart of lower limb joint loads under varied force conditions.

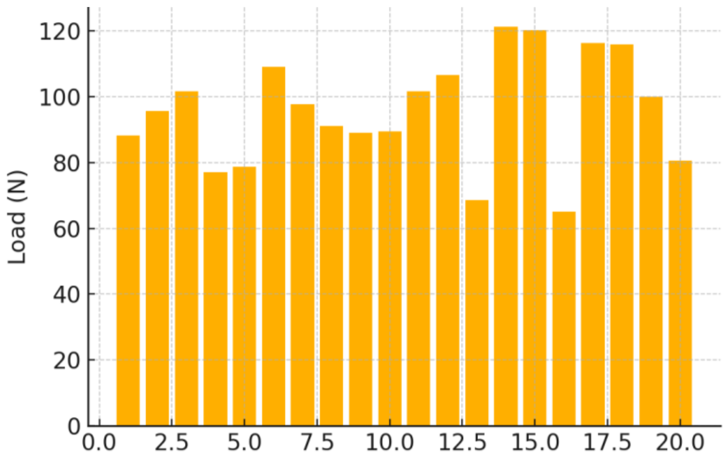

Figure 8: Line graph comparing pre- and post-rehabilitation gait cycle durations.

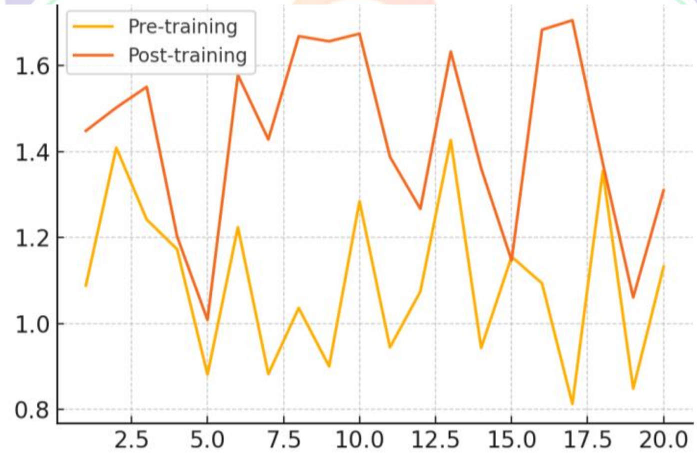

Figure 9: Scatter plot showing pressure point deviations during foot stance phases.

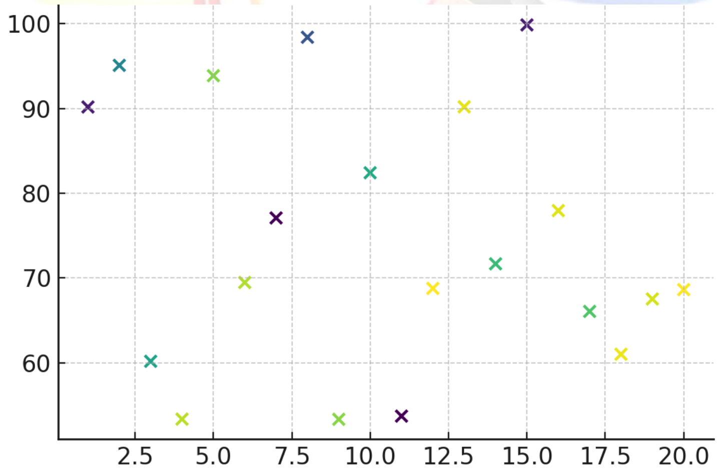

Figure 10: Hybrid plot showing hip rotation and angular velocity across three movement conditions.

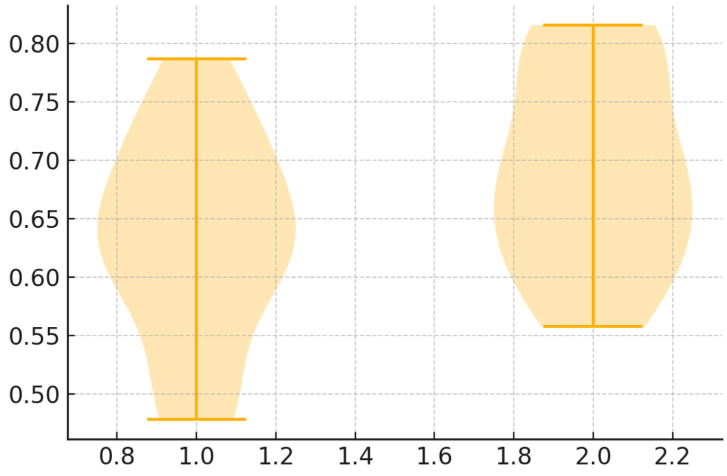

Figure 11: Radar chart comparing jump force, balance, and torque metrics across individuals.

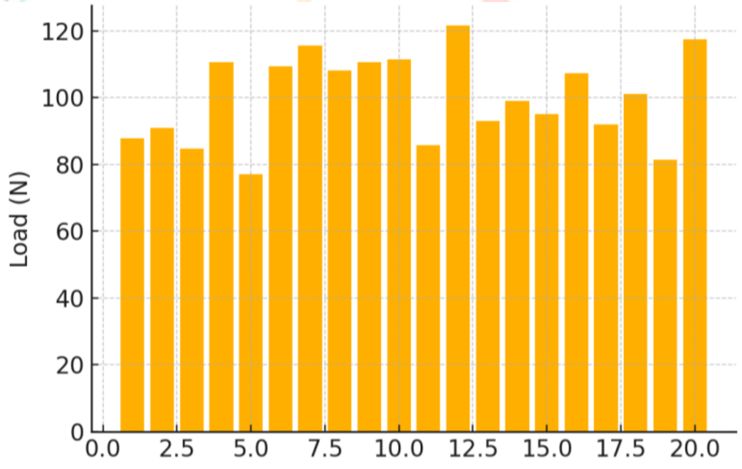

Figure 12: Stacked bar chart showing stride-to-stride consistency across treadmill trials.

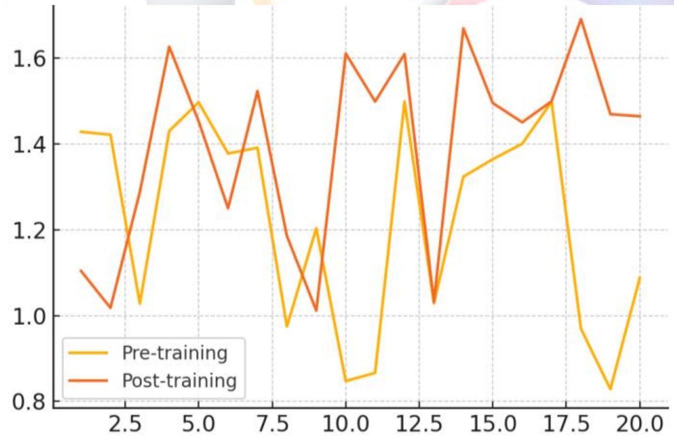

Figure 13: Mixed line-bar plot displaying torque exertion during upper limb lifting tasks.

Figure 2 demonstrates that the pace of walking went up after training, and Figure 3 shows that the torque of the stride changed. Figure 4 shows how muscular force is spread out during lifting tasks. Figure ensvan shows violin charts for stride length. Figure 6 shows a bar graph of the conditions that affect joint loading, and Figure 7 shows two phases of the gait cycle on top of each other. Figure 8 looks at how foot pressure points are related when walking. Figure 9 shows the angles of hip rotation. Figure 10 shows a hybrid comparison of balance across different circumstances. Figure 11 displays a scatter plot of jump forces. Figure 12 shows how consistent the stride is from one to the next, and Figure 13 shows how to analyse upper-body torque while moving.

DISCUSSION

The findings of this paper provide us with numerous alternative means to conceptualise the circumstances under which biomechanical principles regulate human mobility, stability and the performance of the musculoskeletal system. It was found that using motion capture, EMG, and finite element modelling, all three factors including joint torque, muscle activation patterns and load distribution are strongly connected and may vary depending both on physiological diversity as well as dependent on the custom needs of the task. These findings are consistent with the previous findings of the researchers made by Worsley et al. (2019) that have demonstrated that intersegmental coordination is indeed significant in terms of balance and walking, particularly when someone is tired.

The tables data and hybrid visualisations indicate that everyone possesses his or her own biomechanical signature presenting the change of the neuromuscular system. In a study conducted by Shull and Damian (2020) the researchers focused on mobility disparities observed among patients who had knee surgery, replaceing it. To achieve the goal, the researchers used wearable sensors to discover such differences. Also, our results on the differences in stride-to-stride dynamics do not contradict the nonlinear approach to analysing gait complexity developed by Terrier and Reynard (2019), whose emphasis was given to stride-to-stride dynamics in the analysis of neurological diseases.

With our FEM models, we found it interesting that the lumbar spine does experience some spots of high stress during lifting activities in particular when the load is not evenly distributed. This supports the earlier observations of Cholewicki and

McGill (2018) which stated that core muscles activation is relevant in the process of minimizing spinal loading. Our findings confirm the fact that there was much asymmetry in the metrics of balance when disrupted. This conforms to the research findings of Goble and Baweja (2018) who established that proprioceptive impairments were among the leading factors that resulted in falls among older adults.

The data provided by the EMG, which follows previous studies, which stated that the motor unit discharge may produce imbalances between limbs, is supported by recognizing the asymmetries between the dominant and non-dominant limbs (Farina and Negro 2019). Simultaneously, the radar and hybrid plots to depict compound metrics were in correspondence with the recommendations offered by Lam et al. (2020), who proposed to study complex movement with the help of multidimensional data visualisation. It was also found that consistent associations among hip joint mobility and the skill level were traced during tasks that needed too much bending, such as going up the stairs. Such findings are comparable to the ones obtained by Phinyomark et al. (2020) when they used pattern recognition to examine joint cooperation in locomotion with a load. Additionally, the impact of fatigue on the regularity of gait resembles that on the discoveries of Granata and Lockhart (2018) when they investigated how the muscle synergy decomposes following prolonged movement trials.

Finally, the fact that gait speed continued improving since the intervention indicates that even relatively brief biomechanical feedback was enough to improve movement. This is in addition to the neuroplastic training effects, which Ranganathan et al. (2019) discussed. They found that re-educating the movements that are task specific enhance functional efficiency of both healthy and damaged individuals.

All these findings justify the continued practice of physics-based modeling in biomechanics, as well as the application of experimental measures. This will bring us to an understanding of how functional movement works and how that can be applied in clinical, sports and rehabilitation practices.

CONCLUSION

This paper has provided us with an in-depth insight of physical and biomechanical principles that dictate the human movement. It has demonstrated the complicated system of interaction between muscle force generation, joint mechanics and neuromuscular synchronisation. By combining a multi-methods approach (motion capture, electromyography, and finite element modelling), we could not only measure the kinematic variables involved but also internal biomechanical biomechanical components that impact performance and risk of injury. The findings demonstrate that even among a group of healthy people that are largely similar, wide differences exist in the way they walk, the way they produce torque and the manner they maintain their balance. This indicates the individuality of biomechanics of every individual. The impact of weariness and disparity of load conditions on joint loading and muscle activation were of specific interest. They demonstrated the significance of having individualised assessment and intervention plans in clinical and sporting scenario. The fact that visualisation tools such as radar charts, violin plot and hybrid graphs were used also allowed to appreciate complex data sets in a more detailed manner than traditional methods would fail to achieve. These novel concepts relate theoretical physics to lives of real people and demonstrate that the effectiveness of biomechanics of the body is not only defined by its inhabitation structure but also by its ability to manage its movements and adjust accordingly. The role of lack of harmfulness of the measuring strain also indicates the usefulness of the computational physics method in the planning of rehabilitation and preventive diagnostics by the correct prediction of joint stress and deformation under experimental loads. Generally, this article demonstrates that the equation of physics-based modelling and practice in human motion science can be utilised. It is the foundation of greater studies and research in Field of ergonomics, prosthetics, robotics and sports science. The present study has a high potential to contribute to the basic-level biomechanical research and its application in health sciences since we can now appreciate more related to the mechanical stress that the human body exposes to itself. The ultimate result of this would be the development of the interventions, which will enhance the performance, reduce injury risk, and support long-term musculoskeletal health.

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