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Original Research Article

PREVALENCE OF OUTWARD DEVIATION OF FEET IN HUMAN GAIT: A NON-PARTICIPANT OBSERVATION

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ABSTRACT

Introduction: Physiotherapists have been trained to possess unique superspeciality potential to conduct biomechanical analyses by visual observations and decode the kinetics of various static and dynamic postures. This distinct skill of Physiotherapists enables them to make accurate clinical diagnosis with credible rationale in many occasions without even the support of any specialized equipment. Additionally, apart from the ability to directly examine the patients elaborately in the clinical settings, Physiotherapists are also inherently capable of Non-participant observation to endlessly upgrade their knowledge and interpretation skills by just visually observing various movement patterns in sports, household activities, occupational tasks etc. Gait is one of the commonly seen dynamic postures which can also be analysed to certain extent using Non-participation observation method. The determination to research the alignment of feet in human gait developed after noticing the prevalence of walking with Outward Deviation of Feet (ODF) among various individuals in public spaces.

Methodology: Non-participant visual observation of the ODF was carried out in various public spaces like roads, railways stations, streets, fitness clubs etc. Additionally, the walking patterns of people of other countries were also searched in social media like YouTube. Both anterior view and posterior view of the gait of the individuals were observed and possible biomechanical interpretations were made for the development of new theories and research pathways.

Results: Large number of children were found consistently aligning their feet straight except few sporadically. Walking with ODF was found frequent among many adolescents, middle age adults and older adults.

Conclusion: Taking into account of the increased foot progression angle and narrowed step width, ODF should be viewed as a potential biomechanical problem that would probably be acquired from the adolescence (or even before the adolescence) as one of the earliest asymptomatic biomechanical dysfunctions of unhealthy ageing.

KEY WORDS: Foot Progression Angle, Gait, Non-participant Observation, Step width, Physiotherapy Rehabilitation.

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INTRODUCTION

Physiotherapists have been trained to possess unique superspeciality potential to conduct biomechanical analyses by visual observations and decode the kinetics of various static and dynamic postures. This distinct skill of Physiotherapists enables them to make accurate clinical diagnosis with credible rationale in many occasions without even the support of any specialized equipment. Additionally, apart from the ability to directly examine the patients elaborately in the clinical settings, Physiotherapists are also inherently capable of Non-participant observation to endlessly upgrade their knowledge and interpretation skills by just visually observing various movement patterns in sports, household activities, occupational tasks etc. Non participant observation means the observer stands apart from the individuals being observed, interacting minimally if at all [1] Surprisingly, Physiotherapy researches based on Non-participant observation looks rare though very important qualitative researches could be conducted when it is used as a research method. Non participant observational research is primarily useful for descriptive research which does not include systematic manipulation of variables as in the experimental studies but wide spread use of systematic recording and quantitative analysis had dwindled and attenuated the use of non-participant observation methods in psychology and zoology [2].

Non-participant observation can offer a more 'nuanced and dynamic' appreciation of situations that cannot be easily captured through other methods and it usually takes a period of days or months depending on the phenomenon in question and ends when theoretical saturation is reached which occurs when further observations begin to add little or nothing to researchers' understanding [3].

Non-participant observation is a collection of rich and directly observed data for relatively low costs [4]. Non-participation observation researches need expertise in field work to collect qualitative or quantitative data which could reveal an unnoticed problem, forecast its risks, suggest solutions or seek interventions. Qualitative social analysis requires expertise in field work [5]. The scope for field work of Non-participant observation has been infinite as it can be done at any public spaces like parks, roads, railway stations, airports, fitness clubs, tourist attractions, social media etc.

Gait is one of the commonly seen dynamic postures which can also be analysed to certain extent using Non-participation observation method in public spaces. The determination to research the alignment of feet in human gait developed after noticing the prevalence of walking with Outward Deviation of Feet (ODF) among various individuals in public spaces. Researching the positions of feet during gait has been in practice since decades ago. Great disparity between the angles of the gait on the two sides in the same individual and inconstancy of the angle on the same side during successive steps [6]. The toe out (or toe in) is the angle in degrees between the direction of progression and a reference line on the sole of the foot that varies from one study to another; it may be defined anatomically but is commonly the midline of the foot, as judged by eye [7].

METHODOLOGY

Non-participant observation of the prevalence of the ODF was carried out in various public spaces like roads, railways stations, streets, fitness clubs etc in some parts of India like Karnataka (Bangalore) and Tamilnadu (Tirunelveli, Rajapalayam and Virudhunagar). Both anterior view and posterior view of the gait of the individuals were observed and possible biomechanical interpretations were made for the development of new theories and research pathways. Individuals were not excluded from the observation based on their somatotype features, dress wear, foot wear, bare feet, age, gender, socioeconomic conditions, ethnicity and place of living (urban or rural). Additionally, the walking patterns of people of other countries were also searched in social media like YouTube and included in this Non-participation observation.

RESULTS

Table 1 and Figure 1 to 8 show the visual observations made on the individuals with tendency of ODF during walking with different speeds in public spaces. Figure 3 shows the schematic view of possible foot placements to understand the different types of ODF in relation to Line of Progression of Gait (LPG).

Large number of children were found consistently aligning their feet straight during walking except few sporadically. Walking with ODF was found frequent among adolescents, middle age adults and older adults. Generally, adolescent boys and men displayed ODF higher than the adolescent girls and women. ODF was found the highest among the elderly men and women. In rural areas, ODF was found almost equally prevalent among both males and females. In all the age groups, many males and females were found walking without ODF also.

Table 1: Visual observations made on the individuals with tendency of ODF during walking with different speeds in public spaces.

Anterior view (Figure 1)	1. ODF during heel strike and stance phase. 2. External rotation of the entire lower limb during swing phase. 3. ODF with heel strike just on the line of progression of gait (LPG), just lateral to the LPG or sometimes crossing the line of the LPG. 4. All the aforementioned patterns were found as bilateral or unilateral.
Posterior view (Figure 2)	1. ODF during heel strike and stance phase. 2. Medial whip of the heel. 3. ODF with heel strike just on the LPG, just lateral to the LPG or sometimes crossing the LPG. 4. All the aforementioned patterns were found as bilateral or unilateral.

Fig. 1: Anterior view of Straight alignment of feet versus ODF during walking. 1a – Walking with straight alignment of feet ensuring optimal base of support. 1b – Walking with ODF and external rotation of lower limbs with heel strike closer to line of progression of gait (LPG). 1c – Walking with ODF and external rotation of lower limbs with heel strike in line with or crossing the LPG.

Fig. 2: Posterior view of Straight alignment of feet versus ODF during walking. 2a – Walking with straight alignment of feet and effective push-off. 2b – Walking with ODF and medial whip (MW) of heel. 2c – Walking with ODF and medial whip (MW) of heel with too narrow base of support.

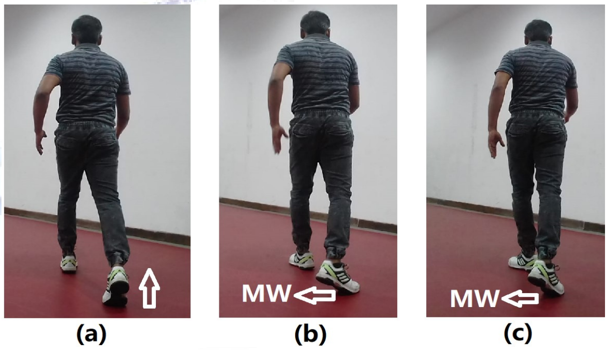


Fig. 3: Schematic superior view of Straight alignment of feet versus ODF during walking. 3a – Walking with straight alignment of feet ensuring optimal base of support. 3b – Walking with ODF and external rotation of lower limbs with heel strike closer to the LPG. 1c – Walking with ODF and external rotation of lower limbs with heel strike in line with or crossing the LPG.

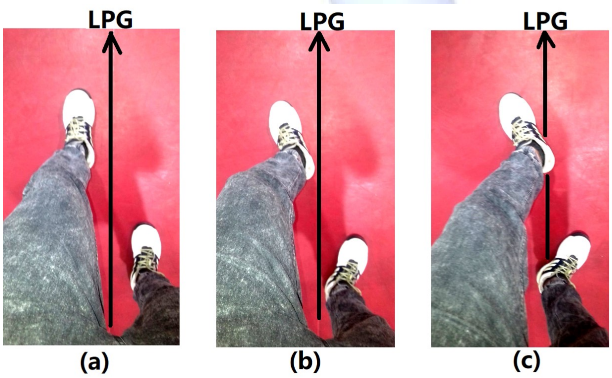


Fig. 4: a - Anterior view of a man displaying ODF with heel strike in the LPG. b1 - Anterior view of ODF with MW and external rotation of lower limbs. b2- Posterior view of ODF with heel strike in the LPG.

Searching for the prevalence of ODF among people in other countries was attempted in YouTube by typing 'People walking on the street'. Plenty of YouTube videos appeared as a result of this search and few screenshots (Figure 4 to 6) from one of that videos are presented here to reveal the ODF patterns found in public spaces as documented in Table 1.

Fig. 5: Unilateral MW of a male. 1a & 1b - His left foot progresses without MW but the right foot shows MW. Two females (a2 & a3) also display medial whip.

(a) (b)

Fig. 6: Heel strike of a male occurring in the LPG (1a & 1b). Another female displays ODF with bilateral MW wearing slippers (2a & 2b).

(a) (b)

Figure 7 shows the screenshot of a video in which the world class sprinters were warming-up before the race and some of them were walking with ODF on the race track. But while sprinting, it looked like almost all the sprinters were aligning their feet straightly (perhaps slight ODF unilaterally or bilaterally in some sprinters). The success rate of athletes with ODF in all types of competitions (Sprint, Long jump, Gymnastics, Marathon etc) should be investigated in comparison with the athletes without ODF.

Fig. 7: ODF of some world class sprinters. Usain bolt was almost walking without ODF. (Courtesy: 200m Semi Finals RIO Olympics, 2016. https://www.youtube.com/watch?v=YzXhe7h4IJc&t=35s Tarokajya Sports Channel. Viewed on 26.12.2019)

Quite consistently, ODF was found in men and women vendors pushing their vendor cart and in also in some manual labourers (Figure 8). Some documentary videos of forest dwelling humans of this contemporary era also reveal few hunter-gatherers with ODF gait patterns.

Fig. 8: a- ODF pattern of a vendor pushing vendor cart. b - ODF pattern of a manual labourer carrying load on the top of his head.

(a) (b)

YouTube videos about the distant past of India and various other countries also reveal ODF gait characteristics among some men and women who were living during that time. Some individuals who have been fully dedicated to yoga and body building (including fitness instructors with muscular physique) were also found walking with ODF. It was also noticed that individuals with ODF gait characteristics were not changing their ODF while walking uphill, downhill, staircase (both ascending and descending) and uneven terrain. The long arch of the human foot is highly evolved to both suit elastic absorption of energy and provide a stiff foot to push against the ground [8].

Habitually barefoot children tend to have a higher medial longitudinal arch which could be protective for the development of a hallux valgus [9]. Individuals with well-defined medial arch of feet (observed on individuals who were walking barefoot and wearing slippers on the streets) also displayed ODF probably due to influence of other biomechanical factors or past medical history. No obvious knee deformities (genu valgum, genu varum) were also noticed among all the individuals walking with ODF but occasionally some individuals were exhibiting bowing of their knees. Untreated neglected ODF could mature, develop deformities in lower limbs including foot problems especially as a result of unhealthy ageing. There is a compelling evidence of a relationship between foot problems and frailty that strengthens as the frailty levels becomes more profound [10].

DISCUSSION

This Non-participant observation research had chiefly focused on the foot placement during walking (and also running to some extent) and found the prevalence of ODF. One of the key determinants of gait is push-off and this study believes in straight placement of foot to avail efficient push-off action from the ankle plantar flexors, so ODF is a biomechanical error regardless of age. The foot placement is crucial in maintaining a stable gait pattern and in ageing there appears to be an impaired coordination between Centre of Mass (CoM) movement and foot placement [11]. Though this research did not exclude any individuals from the observation (whenever the researcher was doing field work in public spaces) but in future experimental studies, categorization of individuals based on their age, sex, somatotype, place of living, life style habits, foot morphology, occupation etc can be made to obtain specific deeper insights to understand the diversity of ODF in laboratory settings. Human locomotion admits great variation, plasticity, and subtle differences in gait, style, speed and endurance [12].

There is a need to include data from participants with different somatic structures to develop a normative database or a need to limit the database results to a specific population [13]. Much lower prevalence of ODF among children and highest prevalence of ODF among older adults increases the curiosity to know if ODF is an acquired biomechanical fault from adolescence that progressively worsens with age if neglected or untreated but the variables responsible can always be identified through experimental studies. Children aged 4-5 were found to have an average out-toeing of 2.8 degrees and the average foot progression angle increased with age to 7.3 degrees at age 16 [14]. Foot strike patterns differ between children growing up barefoot and those regularly using shoes and foot strike patterns seems to be influenced by footwear habituation, age, sex, speed, ground surface, applied footwear and running experience [15].

Though this Non-participant observation research could not measure the gait variables cadence, step length, step width but could easily interpret the narrowed step width (minimizing the base of support and stability) associated with ODF in many individuals. Walking with such narrowed step width might worsen, disrupt the gait biomechanics and evolve as a risk factor for co-morbidities and fall as the age advances. Extreme (either too little or too much) step width variability is associated with falls in older persons who walk at or near normal gait speed and not in older persons who walk slowly [16]. Step width variability appears to be a robust indicator of step-to-step balance during walking, especially when measured accurately over a sufficient number of steps [17]. For healthy younger and older adults step width variability is a more meaningful descriptor of locomotion control than step length variability and step time variability [18]. Increasing step width altered both antero-posterior and medio-lateral stability as well as stability variability, whereas changing step length only affected AP stability and these changes in stability should be considered when asking individuals in fall prevention training or other gait rehabilitation programs to adopt altered gait characteristics [19]. On the other hand, ODF was also found in the literatures as intentionally utilized in the treatment programs and yielded therapeutic outcomes. Participants with medial knee osteoarthritis were instructed in a ten weeks of gait modification to increase the toe-out angle of their study limb (most painful in the case of bilateral involvement) by 10 degrees over and above the self-selected amount measured at a baseline assessment [20].

A 4-month walking program that involved toe-out gait modification produced significant improvements in knee joint loading, and similar improvements in knee pain compared to a similar walking program without toe-out gait modification [21]. But taking into account of the increased foot progression angle and narrowed step width in walking, this Non-participant observation research views ODF as a potential biomechanical problem that probably begins from the adolescence (or even before the adolescence) as one of the earliest asymptomatic biomechanical dysfunctions of unhealthy ageing. The foot progression angle (FPA) is related to the transverse plane rotation of the lower extremities and is defined as the angle made by the long axis of the foot from the heel to 2nd metatarsal and the line of progression of gait [22]. To understand ODF as a problem, the possible adverse influence of the increased foot progression angle and narrowed step width on push-off and windlass mechanism must be predicted. The plantar fascia shortening that results from hallux dorsiflexion is the essence of the windlass mechanism principle [23]. Windlass mechanism in the late phase of stance is responsible for raising the arch of the foot [24].

Windlass mechanism contributes to stiffening of the foot by pulling on the heel, causing inversion at the subtalar joint and 'locking' the midtarsal joint [25]. This study believes that the push-off and windlass mechanism should be under the agonistic control of ankle plantarflexors (perhaps accompanied by co- contraction of evertors and invertors of foot to align the foot perfectly for push-off – Fig 2a) to generate forward propulsive forces but if the foot progression angle increases, push-off and windlass mechanism cannot be accomplished effectively to facilitate transverse plane rotation of pelvis for either forward progression of gait or change of direction of gait (Figure 9).

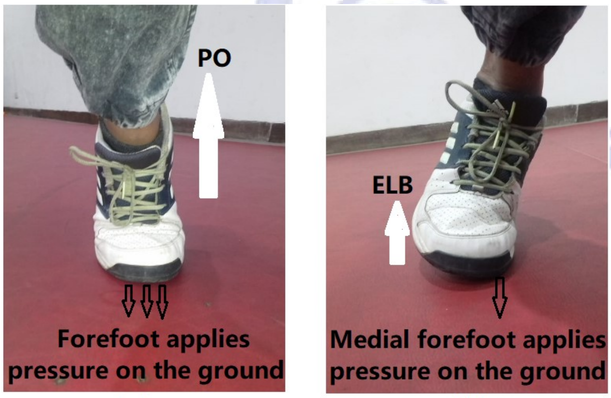
Fig. 9: a – Walking with ODF. b – For individuals with ODF, turning the body in the transverse plane and changing the direction of walking may be difficult as compared to the individuals who are walking with straight placement of feet. c – With the help of closed kinetic chain action of evertors (instead of ankle plantar flexors doing effective push-off), the transition of body is kept in control to some extent in the LPG associated with ODF characteristics.

(a) (b) (c)

Push-off work is derived mostly from ankle plantarflexor muscles and tendons [26]. Without effective push-off during walking, energy is lost in transition between steps and must be compensated for by elevated hip muscle work, resulting in an increased rate of metabolic energy consumption and less efficient gait [27].

Curbing of the push-off and windlass mechanism is a biomechanical disadvantage to locomotion and as a result of ODF the foot is coerced to apply force on the ground using the medial aspect of its forefoot for which the peroneal muscles must be more active like an agonist (instead of ankle plantar flexors as agonist) at the terminal stance phase of gait. The extent of utilization of peroneal muscles and pressure development in the medial aspect of forefoot could vary in direct proportion with the magnitude of ODF. Closed kinetic chain action of peroneal muscle groups would predominantly contribute to displacement of the body to the contralateral side instead of forward propulsion (Figure 10) affecting the gait efficiency and locomotor stability.

Fig. 10: a – During push-off (PO) with straight foot placement, closed kinetic chain action of ankle plantar flexors enable forefoot to apply pressure on the ground to lift the heel (Newton's third law). b – During push-off with ODF, closed kinetic chain action of peroneal muscle groups (instead of ankle plantar flexors) forces the medial side of forefoot to apply pressure on the ground to facilitate Elevation of the Lateral Border (ELB) of foot. Higher the magnitude of ODF, greater the role of peroneal muscles could be in association with ineffective push-off, perhaps little force supply from ankle plantar flexors also. In such situation, if ankle plantar flexors do not contribute to push-off at all, then ODF will have to inevitably accompany medial whip of heel powered by external rotators of hip.



(a) (b)

Medial whip of the heel of the foot at the terminal stance phase of gait could also accompany the action of peroneal muscle groups to reduce the work load on the peroneal muscle groups and to enable foot clearance in gaits with ODF. Steindler defines a closed kinetic chain as a combination of several successively arranged joints constituting a complex motor unit, where the terminal joint of the chain meets with considerable resistance [28]. Medial whip of the heel is most likely powered by the external rotators of hip (Piriformis, Inferior Gemullus, Superior Gemullus, Obturator Externus, Obturator Internus). Heel whips, defined as the medial or lateral rotation of the foot in the transverse plane during initial swing [29]. Whips may not be needed if ankle plantar flexors act as strong agonist to support push-off associated with smooth foot clearances.

Gait with ODF characteristics often include forward swinging of the leg with the hip externally rotated (as in Figure 4), probably demanding the work from hip adductors to perform the swing phase. It should be noted that medial whip was found in some individuals without ODF also. The advantage of pendulum (inverted pendulum model of gait) is that it conserves mechanical energy and thus requires no mechanical work to produce motion along an arc [30]. For the stance extremity to work efficiently like an inverted pendulum, its foot must be aligned properly without ODF to facilitate effective push-off and windlass mechanisms. Additionally, in the narrowed step width pattern of gait associated with ODF, the heel strikes are almost occurring in tandem or even crossing the line of progression of gait, perhaps attenuating the efficiency of this inverted pendulum. The walking base (also known as the stride width or base of support) is the side-to-side distance between the line of the two feet and in the pattern of walking known as tandem gait, the heel of one foot placed directly in front of the toes of the other, the walking base approaches close to zero [31].

A healthy gait pattern depends on an array of biomechanical features, orchestrated by the central nervous system for economy and stability but injuries and other pathologies can alter these features and result in substantial gait deficits, often with detrimental consequences for energy expenditure and balance [30]. The exact biomechanical reasons for the ODF is unknown but most probably due to tightness of external rotators of hip joint and weakness of calf muscles that can be rectified by specific stretching and strengthening or perhaps no biomechanical faults but just a postural habit that can be modified through education of posture. The structural contributions (angulations, torsions, physiologic valgus of knee) of femur and tibia leading to different magnitude of ODF should also be verified by future studies. Comparative studies and longitudinal studies about ODF (foot progression angle) in all the age groups is highly recommended because it looks like many other gait variables associated with age have already been sufficiently researched. No age-related differences in gait parameters or mental representation (MREP) between young and older healthy adults found (variables opted in this experiment were weight, height, physical activity, step length, stride length, swing time, stance time, load response time, single support time, pre-swing time) and the human gait and its

Table 2: Male (38 years). He often walks with ODF despite possessing sufficient overall muscular strength, jumping and running ability. Flexibility tests revealed below-average sit and reach score and, tightness of external rotators of hip joints. To certain extent he could manage to avoid ODF based on the posture education but his ODF is likely to persist until relieving the tightness of lower limb muscles.

Height = 167 cm. Body weight = 70 Kg. Fat % = 32 (above average). No pes planus.	
Sit and Reach	minus 10 cm (below-average)
Standing Long Jump	194 cm (average)
Run	14.5 Km/h for 200 meters with step length equaling 1.35 meters.

MREPs are stable until the age of 60 [32]. Although gait is a largely automated motor task, cognitive resources are required for normal walking [33]. Decline in gait speed takes place from the seventh decade of life [34]. Compared to young adults, older adults walk with smaller propulsive forces and a redistribution to more proximal leg muscles for power generation during push-off [35]. Step width variability of older adults was significantly larger than that of young adults [36].

Sometimes individuals with adequate calf muscle strength also would demonstrate ODF and the possible reasons for ODF in such individuals could be tightness of external rotators of hip or rectifiable postural faults or both. Table 2 shows the data of a regularly exercising individual with overall average muscular strength and evidence of adequate calf strength who walks with ODF perhaps due to inflexibility of muscles of lower limbs (especially due to inflexibility of external rotators of hip joints).

Thus, the individual-specific causes for ODF in all age groups should be identified based on thorough examination of flexibility, muscular strength and various postures (static and dynamic as in squats, lunges, jump etc apart from the locomotion on over-ground, treadmill, staircase, slope, uneven terrain etc) in combination with foot morphology. Future study of locomotion biomechanics shall consider the foot morphological characteristics [37]. ODF was noticed in many individuals regardless of their somatotype features though examining their foot morphology was not the part of this study (except noticing the definition of medial arch of feet of people walking with bare foot or wearing slippers). Morphology of the feet of obese adults differ significantly from those of overweight and healthy weight adults [38]. If a foot classification method combines data on structure with information on foot function in dynamic loading situations, it should relate more closely to the functional behaviour of the foot during locomotion [39].

ODF could begin as a deviation of smaller magnitude and curb the locomotor efficiency when it matures as a major biomechanical dysfunction in association with adverse changes in kinanthropometric variables, probably leading to inevitable wear and tear of joints of lower extremities, deformities of lower extremities (genu varum, genu valgum) and foot disorders (hallux valgus, metatarsalgia, plantar fasciitis). In the rehabilitation of various disorders, Physiotherapists should try to relate unilateral or bilateral ODF in their patients and the possible impediments it would pose in the rehabilitation of lower limb disorders (like Cerebral palsy, Hemiplegia, Amputation, Sports injury, Osteoarthritis, Knee arthroplasty, Fractures etc). Many biomechanical dysfunctions and health disorders could be due to inadequate exposure to or faulty exposure to gravitational force. Gravitational Torque Deficiency Syndrome can affect any age group and chiefly accompanies Altered Body Composition with Disabilities (ABCD) [40].

CONCLUSION

Outward Deviation of Feet (ODF) in human gait could be an adaptation to tightness of external rotators of hip and weakness of calf muscles leading to compensatory utilization of hip adductors to support the swing phase and evertors of foot to support the push-off during stance phase. If these are the biomechanical factors causing ODF, then a longitudinal study specifically administering strengthening of calf muscles, stretching of external rotators of hip and postural awareness education could reveal if it could be rectified. It was noted in this Non-participation observation research that the prevalence of ODF was far lesser among children and higher among older adults, hence, strong presumption arises if this walking pattern is an acquired biomechanical flaw that onsets probably from adolescence and worsens as the age advances. Perhaps this is the first research that found the prevalence of ODF in human gait and attempted to rationalize it as a biomechanical fault and the possible biomechanical factors causing it. Physiotherapists can use these findings to research further with the help of technologies like Electromyography, Electrogoniometry, Foot print analysis etc and combine other clinical findings (flexibility, muscular strength, erroneous postures) to elucidate if ODF should be considered as normal or pathological, and define the level of ODF that should be called as Excessive Outward Deviation of Feet (EODF). Based on further deeper investigations of kinetics and kinematics of ODF gait characteristics in all the planes, if ODF is confirmed as pathological gait characteristic, it should be regarded as one of the earliest asymptomatic biomechanical dysfunctions of unhealthy ageing. Understanding the prevalence of ODF in human gait is exclusively important for Physiotherapists as they should forecast the intra-limb and inter-limb impact of ODF in various human ailments that come under their vast scope of superspeciality practice in the domain of prevention, management and rehabilitation.

Conflicts of interest: None

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