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RESEARCH ARTICLE

INTERGENERATIONAL BIOMECHANICAL ANALYSIS OF JOINT ADAPTATIONS INDUCED BY REGULAR PLAYING BEACH FOOTBALL IN COASTAL COMMUNITIES OF BENIN

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Abstract

Beach soccer is a sport played by all generations and is an integral part of life in coastal communities in Benin. The unstable sand on which it is played imposes specific biomechanical constraints. Joint adaptations related to these constraints remain poorly studied in sub-Saharan Africa. This study aimed to observe and compare changes in lower limb movements between three generations of Beninese beach soccer players.

Methods. Seventy-four male beach soccer players, divided into three generational groups (18 young men (15-25 years); 18 adults (26-40 years); 14 veterans (41-60 years)), and 24 sedentary control subjects, were recruited in Sèmè, Fidjrossè, and Akpakpa. Ankle, knee, and hip ranges of motion were measured during standardized functional tasks using Kinovea video analysis. The data were analyzed using one-way ANOVA and Pearson correlations ($\alpha = 0.05$).

Results: Beach soccer players had significantly greater ankle dorsiflexion ranges of motion than the control group. In younger players, this range was $52.4 \pm 4.1°$ versus $40.3 \pm 4.6°$. The difference was very pronounced ($p < 0.001$). Greater joint ranges of motion were also observed in hip abduction and knee flexion. The more years of experience the players had, the greater their ankle ($r = 0.74$) and hip ($r = 0.78$; $p < 0.001$) joint ranges of motion. Furthermore, weight-bearing asymmetry decreased with age. A decline in adaptations was observed from one generation to the next. However, veterans maintained a better biomechanical profile than sedentary individuals of the same age.

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Conclusion: Regularly playing beach soccer leads to beneficial and lasting changes in the joints, especially the ankle and hip.

Introduction:-

Beach football is a sport played barefoot on sand. It has become a significant social and sporting phenomenon in coastal communities of West Africa over the past twenty years. In Benin, with its 125 kilometers of Atlantic coastline, this sport has evolved from a simple pastime into a community tradition that brings together players aged 12 to over 60 on the beaches of Cotonou, Ouidah, and Grand-Popo. Internationally, this sport is now sufficiently organized to be regularly monitored by FIFA and national federations. Numerous studies conducted on this sport have identified very specific injury profiles, such as injuries to the thighs and feet, and a high rate of musculoskeletal injuries. All of these injuries are linked to the biomechanical stresses required for playing football on sand [1,2].

Unlike traditional football, which is played on hard surfaces or grass, beach football places very different neuromuscular and musculoskeletal demands. The nature of the sand provides an unstable surface that profoundly affects walking and running. Indeed, sand is the key element that distinguishes beach football from other team sports. With each step, the foot sinks into this soft substrate, creating an unstable and asymmetrical support environment. This forces the musculoskeletal system to continuously compensate for energy losses and changes in foot position [3,4]. This dynamic leads to several specific neuromuscular adaptations, such as prolonged and more vigorous activation of the muscles in the back of the leg and hip stabilizers, as well as variation in balance strategies due to the unpredictability of the terrain [3,5].

Several biomechanical studies show that running on sand reduces the range of motion of the ankles and knees. Furthermore, they reveal a decrease in the strength of the plantar flexors and a shift in electromyographic activity towards the stabilizing muscles closer to the body [3,5]. This instability increases the stress on the ankle stabilizing muscles, the knee ligaments, and the muscles around the hip, resulting in much greater gait variability than on firm surfaces [4]. These repeated stresses accumulated over years or decades of practice can lead to morphological and functional adaptations, particularly in foot posture and arch structure, in those who regularly play barefoot [6].

Regarding the knee and hip, research in traditional football has shown that certain movements, such as changes of direction, landings from jumps, and aerial duels, lead to significant changes in joint angles, especially knee flexion and internal or external hip rotation. This phenomenon largely explains the kinematic variability observed in players [7,89,10]. Deficient motor coordination is also linked to a stiffer hip pattern and increased knee valgus. This shows that joint kinematic patterns are influenced by skill level and playing surface type [810]. Specific beach soccer techniques, such as clearances, diving headers, and bicycle kicks, require extreme hip rotation and abduction.

This is corroborated by data from other sports using repetitive explosive movements on unstable surfaces, where ligament adaptations and internal rotation deficits have been observed in the most stressed joints [911]. Research on the biomechanics of beach soccer has begun to intensify in recent years. This literature focuses primarily on injury epidemiology and video analysis of game situations, mainly in men's international beach soccer [1,2,7,10]. However, very few studies exist on the joint adaptations of the lower limbs related to this practice, particularly in the specific socio-economic and environmental contexts of Benin. This gap is all the more detrimental given that sub-Saharan African populations have morpho-functional characteristics of the foot that are still poorly documented in the international biomechanical literature [118]. This lack of information not only hinders the scientific understanding of the motor adaptations induced by sand sports, but also the development of biomechanical references adapted to these populations.

The intergenerational aspect of our study provides an important temporal dimension. Research on joint flexibility and range of motion in young athletes shows that early training, before the end of growth, promotes more significant and lasting gains in joint range of motion than those obtained with training beginning in adulthood. However, the results vary depending on the joints studied and the protocols used [12]. Players who started playing beach soccer in childhood or adolescence are therefore likely to show more pronounced structural differences than those who started later, due to the greater tissue plasticity at these younger ages. The main objective of this study is to analyze and compare the joint adaptations of the lower limbs in three generations of barefoot beach soccer players in coastal communities in Benin.

Methodology:-

Study Type and Ethical Framework:-

This was a comparative (descriptive and analytical) observational cross-sectional study conducted between March 2025 and May 2026 in the coastal municipalities of Sèmè and Cotonou (Benin). The Biomechanics and Performance Research Unit (LaBioP) of the National Institute of Youth, Physical Education and Sport (INJEPS) at the University of Abomey-Calavi (UAC) provided the framework for the design of the protocol and the processing of the collected data.

Population, Participant Characteristics, and Selection Criteria:-

A total of 97 subjects were initially recruited. After applying the exclusion criteria, 74 beach soccer players and 24 from the control group were retained to form part of our sample. Table 1 presents the descriptive characteristics of the four groups.

Table 1 : Anthropometric and sporting characteristics of the participants

Characteristic	FP Youth (18)	FP Adults (18)	FP Veterans (14)	Control (24)
Age (years)	**19.4 ± 2.8**	**32.1 ± 4.3**	**48.6 ± 5.7**	**34.2 ± 9.1**
Size (cm)	**174.2 ± 5.6**	**172.8 ± 6.1**	**170.3 ± 5.9**	**171.5 ± 6.4**
Body mass (kg)	**68.4 ± 7.2**	**72.1 ± 8.4**	**74.8 ± 9.1**	**73.2 ± 10.2**
BMI (kg/m²)	**22.6 ± 1.9**	**24.2 ± 2.3**	**25.8 ± 2.7**	**24.9 ± 3.1**
Years of practice	**4.7 ± 2.1**	**11.3 ± 3.8**	**21.6 ± 5.2**	**00**
Sessions/week	**4.2 ± 0.9**	**3.8 ± 1.1**	**3.1 ± 1.2**	**00**

FP = Beach soccer player; SD = standard deviation; BMI = Body mass index.

The four groups were comparable in terms of anthropometric parameters (height, mass, BMI), with no statistically significant difference (ANOVA, $p>0.05$).
The following criteria were used to select subjects for our sample.

Inclusion Criteria:-

For beach soccer players, the following criteria were used to include them in our study sample:-

- ✓ Regularly playing soccer on the beach (≥ 3 sessions/week) for at least 12 consecutive months;
- ✓ Playing soccer exclusively on sand at the beach;
- ✓ Being a native and/or permanent resident of these coastal areas for more than 12 months;
- ✓ No musculoskeletal injuries of the lower limbs in the 6 months preceding the study.

For the control group in our sample, the following criteria were used:-

- ✓ No regular sports activity (< 1 session/week);
- ✓ Residence in a coastal area for at least 2 years;
- ✓ No history of chronic joint disease.

Exclusion criteria:-

The following participants were excluded from our sample:-

- ✓ A neurological condition affecting lower limb motor function,
- ✓ A body mass index > 30 kg/m²,
- ✓ Orthopedic surgery of the lower limbs within the previous 12 months, or an inability to maintain single-stance weight-bearing for 10 seconds.

Non-inclusion criteria:-

- ✓ Professional football players on any type of surface;
- ✓ Football players not playing on sand;
- ✓ And the practitioners who refused to participate in the study despite the confidentiality guarantees offered to them.

KinoveaVideo Acquisition Protocol:-

- ➢ **Acquisition Equipment:-**

Video acquisition was performed using two Sony RX100 VII digital cameras (Sony Corporation, Tokyo, Japan) equipped with a high-speed capture function (120 frames per second at 1920×1080 pixel resolution). The cameras were positioned on stable tripods at a distance of 4 meters from the subject, perpendicular to the sagittal plane (lateral view) and the frontal plane (anterior view), in accordance with Winter's recommendations and previous studies using Kinovea in field settings.

Spatial calibration was performed before each measurement session using a metric standard (1-meter stick) positioned in the analysis plane. Reflective markers 25 mm in diameter (3M Scotchlite) were placed on standardized anatomical landmarks: anterior superior iliac spine, greater trochanter, lateral femoral condyle, fibular head, lateral malleolus, and head of the fifth metatarsal.

Kinovea configuration and kinematicanalysis:-
Video processing was performed using Kinovea version 0.9.5. The configuration parameters used were: spatial calibration using a reference standard (1 m), analysis frequency: 120 frames/second, filtering of joint trajectories using Butterworth splines (cutoff frequency: 6 Hz), and measurement of joint angles using an integrated goniometer. The ranges of motion measured for each lower limb were: ankle dorsiflexion and plantar flexion (sagittal plane), maximum knee flexion and extension (sagittal plane), and hip abduction and internal rotation (frontal and transverse planes). Each measurement was repeated three times per task; the median value was used for statistical analysis.

StandardizedMotorTasks:-
Six motor tasks were used for kinematic assessment, performed on the natural sand of Fidjrossè, Akpapa, and Sèmè beaches: Normal walking over 10 meters; Light running at 3 m/s over 10 meters; Maximum vertical jump with bipedal landing; 45° change of direction (agility cut); Ball striking (dominant side); Static single-leg balance for 30 seconds. Eachtaskwaspreceded by threeunrecorded habituation trials.

Analysis of Support Asymmetry:-
In the absence of a force platform, support asymmetry was estimated by video analysis of ground contact times during the task (running) and (change of direction). The asymmetry index (AI) was calculated using the formula: AI (%) = $[(MD - MG) / (MD + MG)] \times 200$, where MD and MG represent the mean stance durations of the right and left limbs, respectively. An AI > 10% is considered clinically significant according to the proposed standards [14].

Statistical Analysis:-
Analyses were performed using IBM SPSS Statistics version 21 (IBM Corporation, Armonk, NY). The normality of distributions was verified using the Shapiro-Wilk test. Intergroup comparisons were performed using one-way ANOVA for post-hoc comparisons. Correlations between quantitative variables were assessed using Pearson's correlation coefficient (r). The threshold for statistical significance was set at $p < 0.05$. The effect size (η^2)

Results:-
Comparative Joint Range of Motion:-
One-way ANOVA revealed significant differences between groups for all joint range of motion parameters studied ($p<0.001$ for the majority of variables). Table 2 summarizes the mean values per group and the significance levels.

Table 2 : Joint range of motion according to study group

ROM parameter	FP Youth	FP Adults	FP Veterans	Control	p
Ankle dorsiflexion (°)	**52.4 ± 4.1**	**48.7 ± 3.8**	**44.1 ± 5.2**	**40.3 ± 4.6**	**<0.001**
Plantar flexion (°)	**48.3 ± 5.2**	**45.1 ± 4.7**	**41.2 ± 6.1**	**38.6 ± 5.3**	**<0.001**
Knee flexion (°)	**138.2 ± 6.8**	**132.5 ± 7.4**	**124.8 ± 8.3**	**120.1 ± 9.2**	**<0.001**
Knee extension (°)	**-2.1 ± 1.8**	**-3.4 ± 2.1**	**-5.2 ± 2.8**	**-6.1 ± 3.2**	**0.003**
Hip abduction (°)	**48.7 ± 5.3**	**43.2 ± 4.8**	**39.4 ± 6.1**	**35.8 ± 5.9**	**<0.001**
Internal hip rotation (°)	**42.3 ± 4.9**	**38.7 ± 5.2**	**34.1 ± 6.4**	**31.2 ± 5.8**	**<0.001**

ROM: range of motion; $p<0.005$. Overall effect size $\eta^2=0.41$ ($\eta^2 \geq 0.14$ = large effect).

Ankle Range of Motion:-
Figure 1 illustrates the differences in ankle dorsiflexion between the groups studied. Young beach soccer players exhibited the greatest dorsiflexion (52.4 ± 4.1°), significantly greater than that of adults (48.7 ± 3.8°; $p=0.042$),

veterans (44.1 ± 5.2°; $p<0.001$), and controls (40.3 ± 4.6°; $p<0.001$). Even veteran beach soccer players showed greater dorsiflexion than the control group in their age group (44.1°; 36.8°; $p=0.008$).

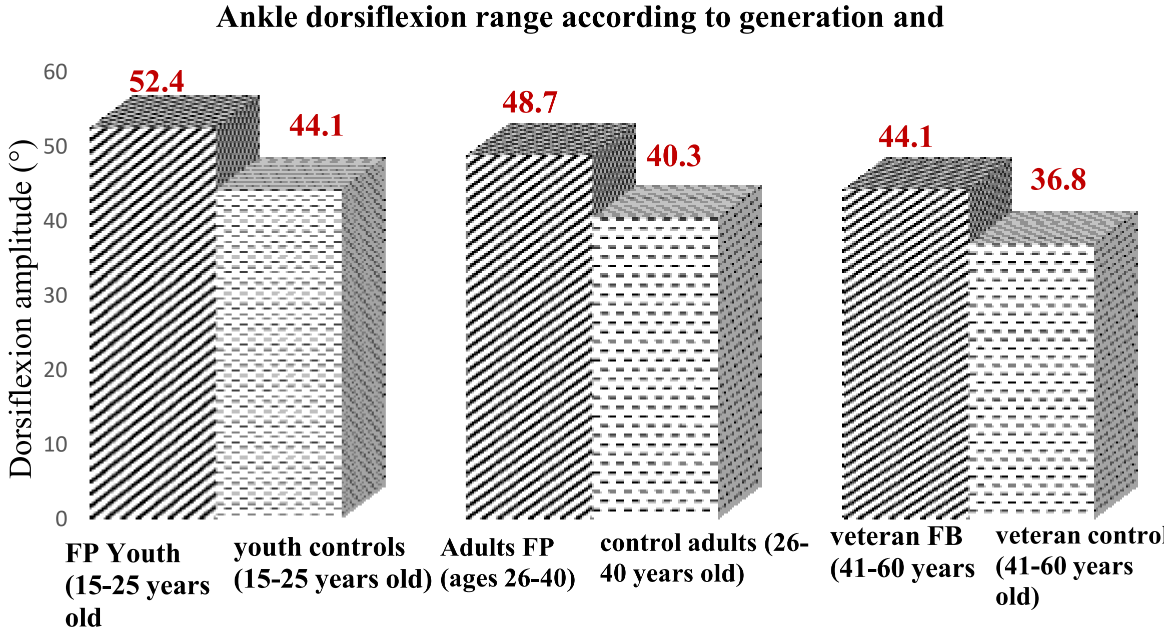

Figure 1: Ankle dorsiflexion ranges according to generation and sporting status

Knee Range of Motion During the Locomotor Cycle:-

Analysis of knee flexion angles during the four phases of locomotion reveals significant differences between the beach soccer groups and the control group (Figure 2). Young beach soccer players exhibit significantly higher landing flexion angles from jumps (55.3 ± 6.2°) than those in the control group (38.5 ± 5.8°; $p<0.001$), suggesting a more efficient shock absorption strategy. This trend persists but diminishes with age (veteran beach soccer players: 44.2 ± 7.1°).

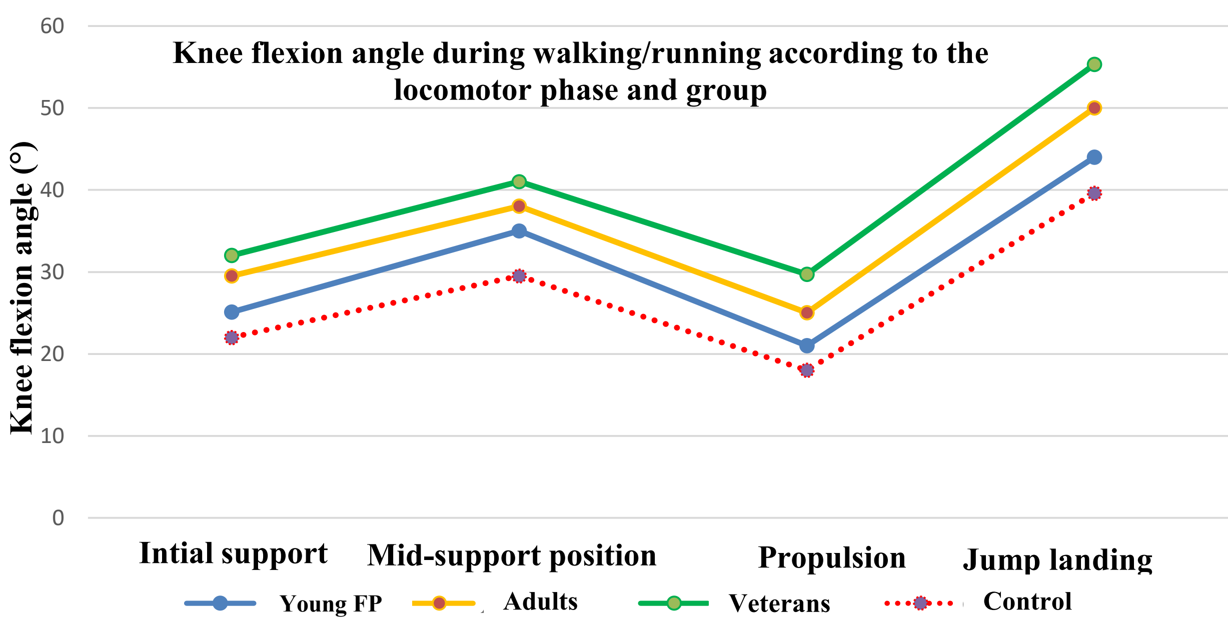

Figure 2: Knee flexion angles according to the locomotor phase and group.

Correlations between years of practice and joint range of motion:-
Pearson correlation analyses reveal significant positive associations between years of beach soccer practice and joint range of motion. The strongest correlation observed is between years of practice and joint range of motion in hip abduction ($r=0.78$; $p<0.001$). These results indicate that an additional year of practice is associated with an average gain of 1.35° in joint range of motion in hip abduction (regression equation: $y = 28.4 + 1.35x$).

Table 3: Pearson correlation matrix between practice variables and biomechanical parameters

Variable	Practicalyears	ROM ankle	ROM hip	Asymmetry (%)
Years of practice	1.00	r=0.74**	r=0.78**	r=-0.62**
ROM ankle (dorsiflexion)	r=0.74**	1.00	r=0.69**	r=-0.58**
Hip ROM (abduction)	r=0.78**	r=0.69**	1.00	r=-0.54*
Asymmetry index	r=-0.62**	r=-0.58**	r=-0.54*	1.00
* p<0.05 ; ** p<0.001. Pearson correlation coefficients (r). n=74 beach soccer participants.				

Weight-Bearing Asymmetry:-
The weight-bearing asymmetry index (WBI) showed significant differences between the groups (ANOVA: $F(4,69)=12.4$; $p<0.001$; $\eta^2=0.42$). Figure 5 illustrates these differences. The young beach soccer players had the lowest weight-bearing asymmetry index (4.2 ± 1.1%), well below the clinical threshold of 10%. The veteran beach soccer players (11.3 ± 2.1%) slightly exceeded this threshold but remained significantly lower than those in the adult control group (13.7 ± 2.3%). The red dotted line represents the clinical threshold of 10%. All intergroup differences were less than 0.01.

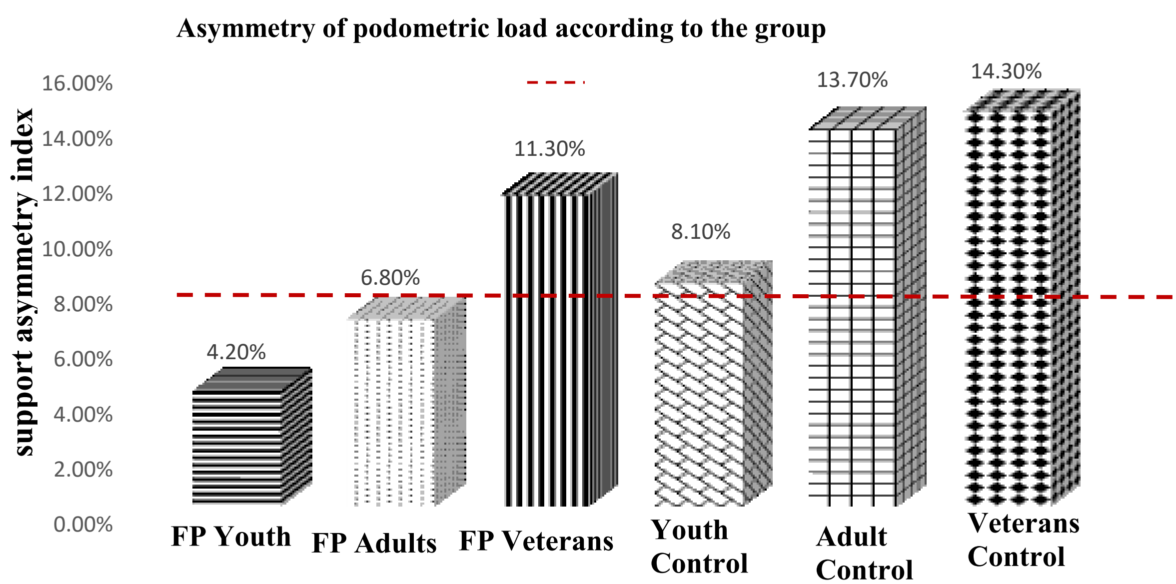

Figure 3 : Asymmetry of support index (%) per group (mean ± SD).

Discussion:-

Interpretation of observed joint adaptations:-
The results of this study confirm our initial hypothesis. Beninese beach soccer players have significantly greater joint ranges of motion than sedentary individuals for all the joints studied. These changes are consistent with the biomechanical mechanisms expected after intense activity on an unstable surface. The significant difference in ankle dorsiflexion between young beach soccer players and the control group is particularly noteworthy.

This ankle adaptation can be explained by two complementary mechanisms. Firstly, running barefoot eliminates the mechanical constraints imposed by shoes. A recent study compared runners accustomed to wearing shoes with barefoot runners. This study showed that barefoot runners had a significantly greater ankle dorsiflexion range of motion. The authors believe that wearing shoes limits the development of ankle mobility and foot musculature [16]. On the other hand, the instability of sand leads to constant neuromuscular activation of the ankle stabilizing muscles. Reviews of sand training and electromyographic studies comparing running on sand and running on a firm surface show that the muscles around the ankle and lower limb work harder and for longer periods due to the instability of the sand. This mechanism could explain a progressive lengthening of these structures depending on the length of time spent playing beach soccer [17,18].

At the knee, the greater flexion angles upon landing from jumps in young beach soccer players compared to those in the control group demonstrate the development of a strategic shock-absorbing adaptation. This strategy is consistent with data from the biomechanical literature on running and dynamic tasks in sand. This research also shows an increase in hip and knee flexion ranges when playing on sand compared to a firm surface. This allows joint reaction forces to be distributed over a greater range of motion and reduces stress peaks [18]. Greater knee flexion upon landing is also recognized as a biomechanical factor that protects against the risk of anterior cruciate ligament (ACL) injury. A recent systematic review of biomechanical risk factors for ACL loading consistently reports, across all included studies, that a decrease in knee flexion angle upon landing is associated with an increased load on the ACL. This is the opposite of, and therefore may be protective of, the adaptation observed in our beach soccer players [19].

Intergenerational Decline and the Protective Effect of Physical Activity:-

Our third hypothesis states that we observe a decline in adaptations with age. However, veteran beach soccer players maintain a better biomechanical profile than sedentary individuals of the same age. This is partially confirmed. We observe a clear decrease in range of motion between generations of beach soccer players. This undoubtedly reflects the effects of biological aging and the decrease in training volume with age. Yet, veteran beach soccer players still maintain better biomechanical profiles than sedentary subjects of the same age in the control group. This confirms that physical activity retains a protective effect on joint health.

This result is consistent with what the literature says about masters and veteran athletes. It has long been emphasized that degenerative joint disease affects most aging individuals. It is not inevitable. Its severity remains lower in those who maintain regular physical activity, primarily due to lasting gains in strength and soft tissue flexibility [20]. This result also aligns with what is known about joint plasticity throughout life. Research on flexibility development in young people shows that, even though tissue plasticity is greatest early in life, regular training can still increase joint range of motion at an advanced age [12]. In our specific case of beach soccer in Benin, where many veterans continue to play well into their fifties, this protective effect plays an important role in public health within coastal communities.

The negative correlation between the asymmetry index and years of practice suggests that regular practice into old age helps achieve better symmetry of support. This could stem from an optimization of postural control strategies on an unstable surface. This finding is of particular interest for prevention and rehabilitation. A recent systematic review showed a clear association between functional asymmetry of the lower limb and an increased risk of musculoskeletal injury. The authors note that asymmetry can limit an athlete’s movement strategies and encourage inefficient or harmful movement patterns, especially when repeated [21].

Comparison with International Literature:-

It is difficult to directly compare our range of motion data with those of international beach soccer groups. Biomechanical literature on this sport is scarce. Most published studies address the epidemiology of injuries, not joint kinematics [1, 22, 23]. The closest study is a Brazilian cross-sectional study. It compared isokinetic knee strength in beach soccer players, futsal players, and 11-a-side professional soccer players. The authors report higher peak extensor torque values in the knee in beach soccer players than in futsal players. They attribute this to the specific demands of playing on sand. Hamstring/quadriceps ratios are similar across disciplines but remain below the values recommended in the literature to prevent anterior cruciate ligament injuries [24]. This work suggests a neuromuscular profile of the lower limb specific to playing on sand. However, it does not allow for a direct comparison of joint ranges of motion with our group.

Due to a lack of directly comparable reference data in beach soccer, the knee flexion values observed upon landing in our study remain within the range reported by biomechanical studies comparing running and landing from jumps in sand to those on a firm surface. These studies consistently show greater knee and hip flexion angles on sand [18]. These data demonstrate the need to incorporate surface-specific analyses into biomechanical assessments of soccer.

They also highlight the need for more reference studies in beach soccer, which are almost entirely absent from the scientific literature.

Methodological Relevance of Kinovea in an African Context:-

The use of Kinovea as the primary motion analysis tool in this study demonstrates that rigorous biomechanical research can be conducted even with limited resources. The inter-rater reliability in our study is similar to that found in other studies that have validated Kinovea software against 3D motion capture systems. One earlier study showed very good inter-rater reliability, with an intraclass correlation coefficient (ICC) between 0.797 and 0.991. It also found good validity, with strong correlations (r greater than 0.90) between Kinovea measurements and those of a three-dimensional system for gait analysis in healthy subjects [14]. These results show that this method is valid and can be used in other sports research in sub-Saharan Africa, where access to commercial 3D systems remains very limited.

The main limitation of our study stems from the two-dimensional analysis, which is restricted to the sagittal and frontal planes. This does not allow us to capture all aspects of joint movement in three dimensions. For example, tibial rotation during knee flexion or transverse hip movements cannot be accurately captured by a 2D analysis. The future addition of markerless 3D systems or IMUs (inertial measurement units) could correct this problem at a reasonable cost.

Conclusion:-

To our knowledge, this study is the first to compare the biomechanics of joint adaptations related to beach soccer between different generations in Benin. The results show that regularly playing beach soccer in coastal communities in Benin leads to positive and lasting joint adaptations. These effects are most noticeable at the ankle and hip. A strong correlation is observed between these adaptations and the number of years of practice. They remain present, although weaker, in veterans over 40 years of age.

The kinematic data obtained with Kinovea provides a new biomechanical reference point for people who play this sport in sub-Saharan Africa. This fills a significant gap in the scientific literature. Beninese beach soccer players show better results than the available international values for certain parameters. This suggests that environmental and cultural factors, such as always playing barefoot or walking barefoot every day, may be highly beneficial. It would be worthwhile to investigate these elements in future research.

From a practical perspective, these results demonstrate the value of promoting beach soccer as a means of improving joint health in coastal communities. Physical education programs that include practice on sand, especially for young people, could help slow the age-related decline in joint function in these groups. Long-term prospective studies are needed. These studies should include women and utilize complementary measurements such as IMU and portable isokinetic dynamometry. This will allow us to better understand how joints adapt to beach football in coastal communities in Benin.

CRediT authorship contribution statement: -

Lafiou YESSOUFOU: Conceptualization, Methodology, Investigation, Formal analysis, Writing–review & editing, Validation.

Gérard Sèmako DOSSOU: Conceptualization, Methodology, Investigation, Formal analysis, Data curation, Writing– original draft, Writing – review & editing, Validation.

Mohamed Mansourou LAWANI: Conceptualization, Methodology, Investigation, Formal analysis, Writing– original draft, Writing– review & editing, Validation.

Kora Zaki Salifiou: Conceptualization, Methodology, Investigation, Formal analysis, Writing– original draft, Writing– review & editing, Validation.

Declaration of competing interest.

HOUETO Vignon Gratien: Conceptualization, Methodology, Investigation, Formal analysis, Writing– original draft, Writing– review & editing Validation All authors have indicated they have no financial relationships relevant to this article to disclose. The authors have no conflicts of interest relevant to this article to disclose.

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Compliance with ethical standards:-

Disclosure of conflict of interest:-

All the authors acknowledge that there is no conflict of interest. They all agree with what is written in this article. In accordance with the requirements of transparency and scientific integrity, we, the authors of this study, declare that we have no conflict of interest, whether financial, commercial or otherwise, that could influence the results or interpretations of our research on initiation rites in Benin, thus guaranteeing the independence and objectivity of our work and ensuring the credibility of our conclusions

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