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A NOVEL APPROACH TO DETECT MUSCLE STRENGTH IMBALANCES VIA MOTION ANALYSIS USING SENSORY INPUTS

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ABSTRACT: *The healthy practice of movements in every athlete is essential in the context of sports and exercise medicine. Since the incorrect biomechanics can result in injuries that would take a considerable amount of time to recover through rehabilitation. Thus, the domain experts have focused their research studies on injury prevention based on analysis of biomechanics of athletes when doing a certain exercise. These manual movement screening mechanisms bear multiple issues including the excessive time consumption, the essential presence of a domain expert as well as the erroneous observations. Thus, there is a need to evaluate injury risks accurately. The primary purpose of this research is to explore the suitability of a motion capture device when analyzing movement patterns to identify muscle imbalances biomechanical errors in order to prevent injury risk in the context of collegiate athletes.*

KEYWORDS: Musculoskeletal imbalance, Movement analysis, Motion tracking

INTRODUCTION

The participation of college athletes in sports has increased in the last decade according to the sports sponsorship and participation research done by the National Collegiate Athletic Association in 2016-17 [1]. With this growing numbers, the musculoskeletal injuries have increased as well. Rehabilitation after injury is the way usually the injuries are being handled. But researchers have found the rehabilitation focused around a single region of the musculoskeletal system is not sufficient enough to reinstall the performance to the previous state [2]. The studies have identified that the injuries in one body region affect in terms of weakness, tightness or pain in another region away from the injury [3]. In other words, muscle imbalances surrounding joints. Thus, the best way to counter injuries is to eliminate injury risk altogether. In order to identify potential injury risk factors, there needs a criterion to routinely assess an athlete's quality of the musculoskeletal system or the overall movement pattern.

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a. Background

Musculoskeletal movements in our body are initiated and controlled by the muscles surrounding the joints. A muscle imbalance is caused when one of the opposing muscle groups becomes weaker and tighter due to reasons such as performing certain movements excessively over a long period of time, holding incorrect body postures or biomechanics for prolonged time periods and emotional stress [4]. It is essential for athletes to maintain balanced muscle groups throughout the whole body to ensure their health

A sports injury is defined as impairment during the period of practice or competition, due to acute trauma or overuse, which leads the athlete to take time off from training or requires medical care [5]. Nearly 10 to 55% of muscle injuries occur during sports activities [6]. There are mainly two types of injuries associated with sports; Acute and Overuse injuries. Acute injuries are caused by a sudden traumatic event like spraining an ankle or shoulder dislocation. Overuse injuries are a category that caused by repetitive use and stress in movement, mainly in muscle, soft tissues and joints. This can be explained as a result of the accumulation of micro-injuries happening over a period of time [7]. This also can occur when there was not enough time provided to properly heal the injured area [8]. According to a study done by Yang et al in 2012 comparing the rate of overuse and acute injuries in college athletes which a total of 1317 injuries were recorded from 573 athletes, nearly 30% of the injuries were discovered to be overuse and 70% were acute [7]. Overuse injuries occur due to the weak musculature surrounding a joint exposed to repeating movements. These weaknesses can cause muscle imbalances [8].

b. Significance

The factors contributing to these injuries have been studied in the literature, focusing around a specific injury. Even though musculoskeletal imbalances are mentioned as one of the causing factors, there is very little documentation available on the relationship between muscle imbalance and the extremity injuries [9]. As stated in [7], the overuse injuries are hard to detect since the symptoms gradually increase. Which can be lead to serious injuries later on. A previous study has found that the athletes possessing hamstring to quadriceps (H:Q) strength ratio below the normal range of 60% have a higher chance of overuse knee injuries [10] and muscle imbalance is a possible risk factor in hamstring injuries of competitive sprinters [11] and professional male soccer players [12]. Preseason isokinetic muscle strength screening have helped athletes to identify the risks of hamstring muscle injuries [11], [12]. Another study done with athletes in various sports including soccer, volleyball, field hockey, tennis, fencing and basketball, concluded that imbalance in muscle flexibility has contributed to muscle injuries [5] where as Witvrouw et al [12] has demonstrated a significant association between preseason hamstring muscle tightness and subsequent development of muscle injuries. Not only that, a previous study done with wheelchair athletes has found that the shoulder muscle imbalance is one of the causes for the development of rotator cuff impingement syndrome [13]. In [9], they have observed recurrent hamstring injuries in athletes who previously suffered the same injury. They have concluded that athletes who are not fully rehabilitated and still have muscle weaknesses and imbalance increase the recurrence of muscle injuries. Muscle balance between bilateral limbs, in required proficiency is crucial for an athlete to enhance their in-field performance [14], thus an imbalance is a hindrance for athletic performance. The early diagnosis and prevention

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of these injuries is an important task since those may hinder the performance and also athletes may not be able to participate in competitions [6]. Stretching exercises, muscle strengthening and correction of muscle imbalances have proven to be effective preventive mechanisms [6]. A previous research was conducted to improve the upper and lower limb muscle imbalances in elite fencing athletes [15]. Which showed statistically significant improvement in balance over 12 weeks of preventive exercises. By identifying muscle imbalances and taking preventive mechanisms, the injury risk can be reduced and the overall movement quality can be improved.

An injury caused during a sports activity may take a considerable amount of time to recover which will prevent an athlete from taking part in competitions as well as obstruct the continuous training programmes [6]. As previously mentioned, such injuries can be caused due to imbalances in the musculoskeletal system and there lies a necessity to identify potential overactive and underactive muscles for injury prevention. Once these issues are identified, the progress of treatments to fix the imbalances in the musculoskeletal system should also be tracked.

1. Current clinical evaluation methods of muscle imbalance

The clinical way of identifying muscle imbalances is heavily dependent on the patient's history of complaints, the clinician's fundamental knowledge as well as the visual observations as mentioned in previous sections. When it comes to functional evaluation of muscle imbalance, the clinician needs to patch together all these parts of information he gathers into a big picture, that explains the current condition of the patient.

a. Gait and Posture Analysis

Gait cycle is explained as the time period or the sequence of movements happens during one foot touches the ground to the next time the same foot contacts ground. Simply it's the way of walking. Gait cycle is also known as a Stride [16]. Gait cycle can be classified into two main phases; stance phase and swing phase, which include eight sub-phases as depicted in "Fig.1".

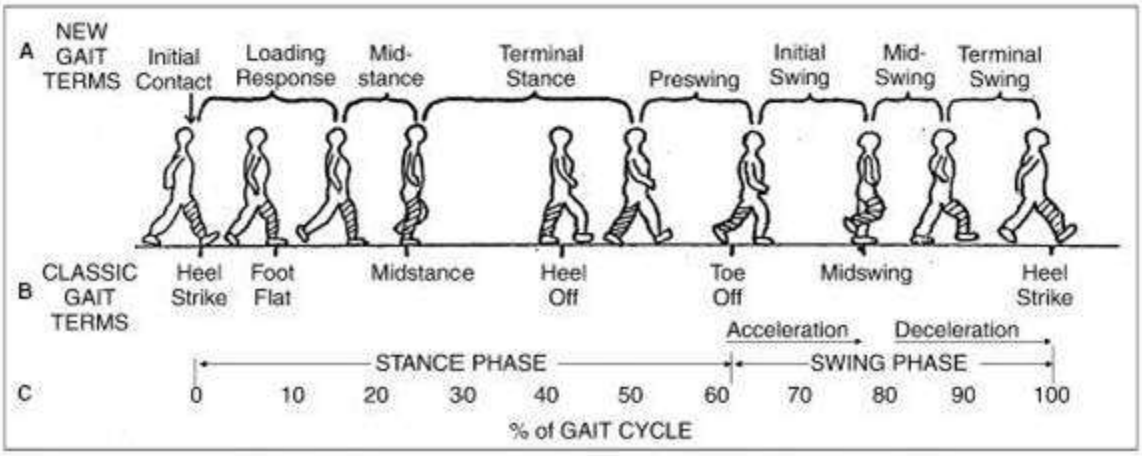

Figure 1: Gait Cycle

The first 60% of the Gait cycle is occupied by the stance phase, where it starts from the Heel Strike of one leg and goes until the same leg gets off the ground at Toe Off [Fig.1]. The next 40% of the cycle occupied by the Swing Phase. It includes the phases until the same leg does a Heel Strike. There are specific ranges of angles associated with

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knee, hip and ankle, which relate to each of the sub-phases [16], [17]. Deviations identified from these joint motion ranges can be used to evaluate the muscle imbalance. It's usually detected using a treadmill. When considering the Posture analysis, standing position can be taken as a static posture. Gait cycle which discussed above can be categorized as dynamic posture. The postural analysis is done more of as a subsequent or an assisting test[18].

b. Joint range of motion Analysis

The Joint range of motion analysis is done by assessing the ranges a person can move their joints in a particular direction. Each of these joint has a maximum range in a certain direction, thus clinician needs to be careful not to move joints beyond that. This can be assessed mainly in three ways.

- Active Range of Motion – patient moves joint by himself.
- Active-Assisted Range of Motion – patient moves joint but requires assistance to complete the joint range.
- Passive Range of Motion - patient is unable to move joint at all and requires complete assistance of another person for joint to move.

The evaluator (Clinician) should first explain how to do the motion that requires, or he can show the person how to do it. Then he can actively observe the joint movement and compare the ability of movement and the quality side by side. It can be assessed in terms of speed, stiffness, joint swelling, coordination and alignment [19]. The key join motions that assessed include shoulder, elbow, wrist, hand/fingers, hip, knee, ankle, head/neck, and trunk. If the assessment results show a considerable deviation from the defined ranges of joints, it can be concluded as the patient having a muscle imbalance.

c. Muscle Length Analysis

In Muscle length testing, it assesses the resistance to passive lengthening of muscles. This involves stretching out the muscle in the opposite direction to its action. The stretching of the muscle should be done slowly in order to avoid muscle contraction and damage [18]. There are four steps in assessing the muscle length test.

- Ensure maximal lengthening of the muscle from origin to insertion
- Firmly stabilize one end (usually the origin)
- Slowly elongate the muscle
- Assess the end feel

d. Movement Analysis

Functional Movement of the human body is not a work of an isolated muscle group since movement is produced as a combined process of several muscle groups working together[18]. Assessing these movement patterns can be done by analyzing the body behaviour when a person is doing a specific movement. In order to understand the quality and control of these movement patterns, the clinician should focus on all the muscle groups involved in the movement as well as the strength the person put into these movements when doing them. Thus the knowledge and experience of the evaluator are indeed essential in these studies [20]. Specific movement pattern chosen for the evaluation can differ according to the purpose of evaluation, in order to focus on a specific set of muscle groups[18].

Clinical evaluation methods of detecting muscular imbalances involves applying a force on a muscle group and measuring the resistance force from the isolated muscle

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group. However, the mechanism is inadequate because the functional movement is never isolated and requires several muscle groups to work together as prime movers, synergists, and stabilizers. Therefore, movement pattern analysis is more reliable than isolated muscle strength analysis [18]. There are numerous methods and grading systems to evaluate muscle strength and endurance when considering the movement analysis.

I. Functional Movement Screen (FMS)

FMS is a widely used screening tool to categorize the functional movement patterns, which includes a series of 7 tests. These tests are identified as fundamental movements that operate as the basis for more complex movement patterns that are being used in sports activities [21]. Thus, it is used to predict the injury risk of athletes by routinely assessing their overall quality of movements which depends on muscle strength, endurance, flexibility and correct biomechanics. Yet, a previous study [22] has been done regarding the reliability of the FMS in real time field settings comparing the gradings scores from FMS and grading athletes using objective data from an inertial-based motion capture system (IMU). In real time, the evaluators have to focus on multiple areas when performing a complex movement pattern like the overhead squat. Hence, it's noted that there's a higher probability in missing vital kinematic information when using such observation based tools [22]. This study also explains a few drawbacks of FMS. Such as to assess the movement pattern with higher accuracy, it needs to be done repetitively for a few time, which consumes a considerable amount of time. The ambiguity of the grading criteria should also be noted here since FMS is a criterion based test tool, the understandability of each of these criteria can be highly subjective.``Fig.2" explains the 7 test components.

Figure 2: 7 test components of FMS

II. Janda's basic movement patterns

Vladimir Janda has identified basic movement patterns that can be used to assess the quality and control of a person's movements. Which covers all the key regions of the musculoskeletal system. The tests include hip extension, hip abduction, trunk curl-up, cervical flexion, push-up and shoulder abduction [18]. He had also identified the key indicators for each of these tests to identify whether there exists a muscle imbalance in the subject. Just like the other movement analysis systems, Janda's approach also heavily rely on the domain knowledge and the observation skills of the evaluator[18], since these are rule-based observational based mechanisms.

III. Overhead Squat Test

The Overhead Squat test is the one test specifically used for the clinical identification of muscle imbalance [4]. When considering the assessment of movement dysfunctions, overhead squat has a few advantages over above-mentioned screening methods. The time consumed for the evaluation is considerably less than when performed multiple movements as in FMS. It also covers all the key joints in the kinetic chain and it is also a commonly used movement pattern in strength and conditioning context [23]. By observing the behaviour of the person when performing the overhead squat, a clinician can draw a conclusion as to whether he holds an imbalance or not. The movement is observed in three angles; Anterior view, Lateral view and Posterior view [``Fig.3'].

Figure 3: How overhead squat is done correctly

Any deviations from the correct angles [``Fig.3"] can be concluded as the patient having a muscle imbalance in associated joint muscle groups.

National Academy of Sports Medicine (NASM) has suggested that screening tools that use multiple movement patterns like FMS and Movement Competency Screen (MCS) are useful indicators of muscle quality [23]. The overhead squat is used in both of these screening tools as an essential movement pattern. According to [22], who compared the real-time reliability of FMS, mentioned that when using multiple exercises to assess similar functions can affect the overall compound score of the screening tool. Which again gives an erroneous result. For example in FMS, it uses deep squat, hurdle step, and in-line lunge to assess frontal plane stability component. Thus, it's more appropriate to use one exercise that can assess overall functionality like the overhead squat.

A previous study [24] has been done to analyze the muscle activity and flexibility of patients with medial knee displacement (MKD), which is a commonly observed movement dysfunction pattern. They have used the observed data during the overhead squat to identify patients with MKD and validated the results by using EMG sensors and goniometers to analyze the actual muscle activation and range of motion in joints during overhead squat. The results from this study indicated there were significant differences in strength and flexibility between the MKD patients and normal control group. Thus, this study validates the use of visual observations of overhead squat to identify muscle imbalances in certain muscle regions in the musculoskeletal system.

2. Technical Analysis Methods

There are several technical analysis methods that incorporated in the field of Medicine to identify the changes in muscle function and imbalances.

a. Electromyography and Surface Electromyography

Electromyography is a procedure to detect nerve-to-muscle signal transmission [25]. An Electromyography procedure is conducted by inserting a thin needle (electrode) into the muscle and observing the electrical activities in the muscles when the muscles are contracted or in a relaxed state. The electrical signals are displayed on a monitor known as oscilloscope [26]. A nerve conduction velocity test is often conducted along with an EMG test to differentiate between a nerve dysfunction and a muscle dysfunction [26].

Surface electromyography tests do not pierce the skin and electrodes are placed over the skin to detect electrical signals in muscles. Despite not causing any pain to the subject, SMEG is unable to specifically monitor deep muscles [27]. At present, both EMG and SMEG are used to detect muscle functionality by observing the electrical signals from muscles.

b. UltraSound Analysis

The Ultrasound scan is a very commonly used test to detect issues related to the musculoskeletal system. Ultrasound imaging is considered safe compared to x-ray or CT scan since it does not use any ionizing radiation in the imaging process. The scanning process uses high-frequency sound waves to create images real time and is very suitable to diagnose sprains, strains, tears and other similar soft tissue conditions [31]. It is also used currently to get biofeedback regarding muscle bulk and strength.

3. Related work

There are several research studies that have been done to detect muscle strength imbalance and asymmetry using a variety of sensors. One of such studies has been done with the objective of detecting muscle imbalances by identifying abnormalities in the gait cycle. A markerless motion capturing device was used to capture different phases in the gait cycle. Three graphs were generated to denote the variation of the ankle, knee and hip angles against time. The resulting graphs were compared against the standard gait cycle graph to detect a person with muscle imbalances. Despite the fact that the solution can be used to self-evaluate muscle imbalances, it does not detect muscle imbalances in the upper body and it can not help identify possible overactive and under-active muscle groups [32].

A previous study [33] was done to validate the reliability of the vertical jump force test(VJFT) in assessing the strength asymmetry of athletes. A single force plate was used to measure the force exerted on each leg during the execution of the jump. One leg was placed on the force plate and the other on a level wooden platform while the leg on the force plate was alternated during jumps. The reading from the force plate was compared against the results of the isokinetic leg extension test and the isometric leg press test. The results have shown a strong correlation between the readings from the vertical jump force tests and the two tests mentioned above which validates the reliability of using vertical jump force test for assessing bilateral strength asymmetry. However, the vertical jump force test does not allow the evaluation of different muscle groups in the lower limb but only considers the force exerted from the entire lower limb as a whole.

A similar study [34] was done to examine the bilateral differences in the ground reaction forces during the overhead deep squat test. As mentioned earlier in section II, the overhead deep squat can be used to detect bilateral muscle imbalance which is a key component in promoting the musculoskeletal health in athletes. A twin-force plate system was used to measure the peak ground reaction force during the deep overhead squat. The study was done on a sample of young soccer athletes and the results indicate that there appears to be a 'trigger point' during early adolescence that mark bilateral imbalance and the magnitude of imbalance increases as the players get older. The results of this study suggest that early detection of bilateral imbalances and taking corrective measures is crucial in preventing musculoskeletal injuries.

According to Mauntel et al [35], there can be biomechanical differences between the male and female during the overhead squat. Their study was using an electromagnetic motion tracking system interfaced with a force platform to measure the lower extremity kinematics and kinetics during the descent phase of the squat. The results have indicated several differences between the males and females such as males having a greater peak knee valgus angle, peak hip flexion angle, peak vertical ground reaction forces, peak hip extension moments, less ankle dorsiflexion with the knee extended and less hip internal and external rotation than females. It can be concluded that gender-specific injury prevention programs should be developed based on the results of this study.

The deep overhead squat used in the two studies mentioned above is a component of the functional movement screen which is explained in section II. A study was done to compare the objective methods and manual (real-time) methods in grading the functional movement screen [22]. The study was done by comparing the FMS grades given by a certified FMS tester and those given by an objective inertial-based motion capture system. The inertial measurement unit sensors were placed in the subject's body and the readings obtained while executing the components of the FMS was used to score the subjects. According to Whiteside et al, manual evaluation of the FMS is susceptible to error and there lies a need to develop a standard procedure in grading FMS performance.

Only one research has been previously conducted to detect muscle imbalance using a motion sensor and it was limited to the lower body. Furthermore, there was no positive identification of potential overactive and under-active muscles. All the other above mentioned studies have used force plate systems, electromagnetic tracking systems and inertial movement sensors to detect human movement which cannot be considered as practical solutions to detect muscle imbalances due to the high cost of the equipment [23]. We hope to provide a solution which is cost effective and can be used to identify muscle imbalances by oneself. The proposed solution will be able to detect potential overactive and under-active muscles and also track the progress of the treatments while avoiding the errors caused when evaluating muscle imbalances manually. The summary

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of the above mentioned previous studies and the evaluation of them regarding various factors are stated in the Table 1.

Related Work (Reference No)	[32]	[33]	[34]	[35]
Economical	Yes	No	No	No
Non-Invasive	Yes	Yes	Yes	No
Ease of Implementation	Yes	Yes	Yes	No
Self-Evaluation	Yes	No	No	No
Whole Body	No	No	No	Yes

Table 1 :Related works gap summary

4. Proposed Research Design

The sensors listed under section V are able to capture 19 or more joints in the human skeleton. The number of joints that can be tracked may vary depending on the sensor and the SDK used. The sensors use an Infrared emitter and a depth sensor to capture X, Y, Z coordinates of the joint locations in the world coordinate platform. The coordinates can be used to obtain angle values such as the knee, ankle, hip, shoulder and elbow [32] using a mathematical model.

A suitable movement pattern to detect musculoskeletal imbalance such as the deep overhead squat will be selected and the standard joint angle specifications of a healthy individual would be identified. Once the mathematical model is developed, it will be used to identify angles of joints based on the movement pattern selected. The angles will be compared with the standard angle specifications to determine if the subject has any musculoskeletal imbalances. A physiotherapist will supervise the process in order to ensure the quality and reliability of the results produced by the proposed research solution. ``Fig.4" shows the high-level architecture of the proposed research solution.

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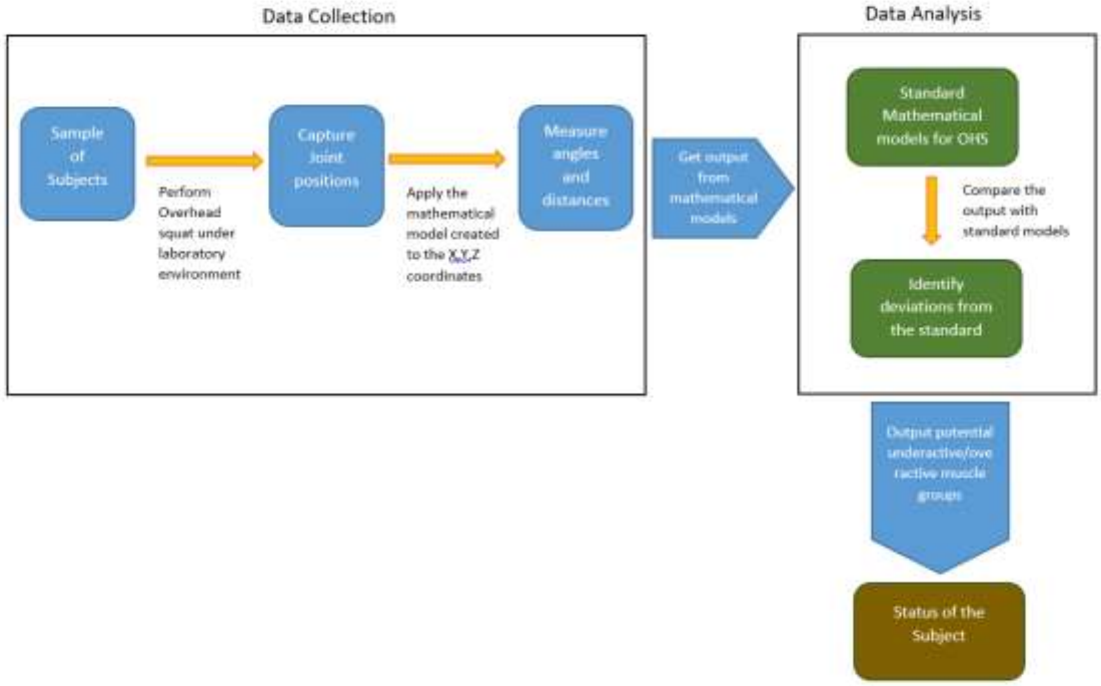

Figure 4 : Proposed research process design

5. Sensors that can be used

One of the most popular markerless motion capturing sensors within the time period of 2010 to 2015 was There are two main types of sensor technologies that are being used in motion capturing. Which are the Optical sensor technology and On-body sensor technology. Applications of Optical sensor motion capture can be done in two methods; Marker-based and Markerless. Prior to the use of markerless motion capturing systems, optical motion capturing systems were used in the field of sports medicine. Optical motion capturing systems which use reflective or active markers are considered to be highly accurate when tracking human motion. During a study done using a calibration and measurement robot [36], the optical motion tracking system performed with an overall accuracy of 65 +/- 5 µm and overall precision (noise level) of 15 µm.

One of the most popular markerless motion capturing sensors within the time period of 2010 to 2015 was Microsoft Kinect. A study was done in 2012 to evaluate the accuracy of the Microsoft Kinect sensor against an optical motion capturing system [37]. According to the study, an approximate error of 10° has occurred when therapists visually control the range of motion. When compared, the Kinect performed with errors less than 10° in the knee and hip angles and highest error of shoulder angle being slightly above 10°. The results of this study prove that Kinect motion tracking system is suitable for rehabilitation treatments.

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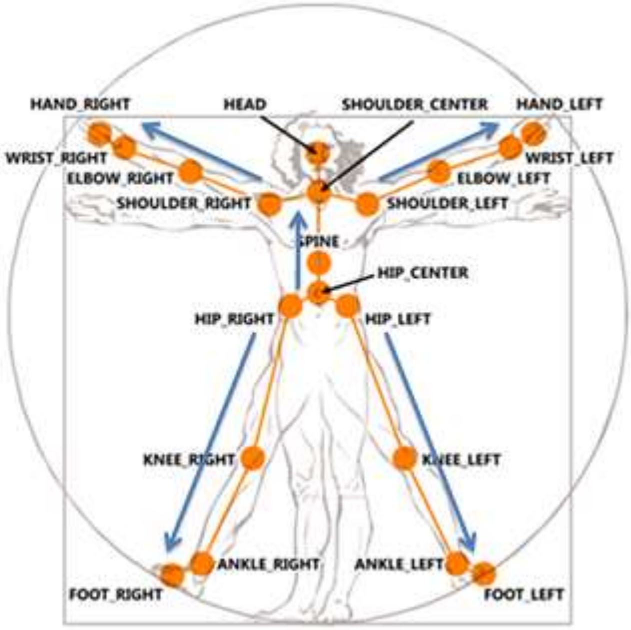

Figure 5 : Joint map of Kinect SDK

Kinect was discontinued in 2015 and there have been several alternatives since then. Asus Xtion [38], Intel RealSense [39], Orbbec Astra and Orbbec Persee [40] are some of the popular sensors that can provide skeletal tracking data similar to Microsoft Kinect and act as a suitable replacement. The number of joints tracked and the quality of the skeleton data may vary based on the SDK used. ``Fig.5", ``Fig.6" and ``Fig.7}" shows the joint maps of Kinect SDK, Orbbec SDK and Nuitrack SDK [41] respectively.

Figure 6 : Joint map of Orbbec

Figure 7 : Joint map of Nuitrack SDK

6. Conclusion and Discussion

Injury prevention in the field of sports is a crucial element that should be looked upon. Once an injury occurs, it may force the athlete to refrain from taking part in training and competitions along with additional costs on rehabilitation treatments. Furthermore, it may reoccur in the future and prevent the athlete from reaching his/her full potential.

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Thus, there is a need to identify potential overactive and under-active muscle groups which may cause biomechanical disadvantages and injuries in the long run.

Current clinical evaluation methods are highly dependent on an external evaluator and the experience level of the evaluator. This may require an athlete to visit a clinician and spend a considerable amount of time regularly which may discourage the athlete from doing so. In addition, current research solutions which use equipment such as force plates and electromagnetic tracking systems may involve high costs depending on the quality of the equipment used. The proposed research solution will enable athletes to self-evaluate and identify biomechanical imbalances cost effectively as well as minimize the damage caused.

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