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Original Article

Dependency Coefficient in Computerized GALS Examination Utilizing Motion Analysis Techniques

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Objectives: The GALS (Gait, Arms, Legs and Spine) examination is a compact version of standard procedures used by rheumatologists to determine musculoskeletal disorders in patients. Computerization of such a clinical procedure is necessary to ensure an objective evaluation. This article presents the first steps in such an approach by outlining a procedure to use motion analysis techniques as a new method for GALS examination.

Method: A 3D motion pattern was obtained from two subject groups using a six camera motion analysis system. The range of motion associated with GALS was consequently determined using a MATLAB program.

Results: The range of motion (ROM) of the two subject groups was determined, the validity of the approach was outlined, and the symmetry of movement on both sides of the body was quantified through introduction of a dependency coefficient.

Conclusion: Analysis of GALS examination and diagnosis of musculoskeletal problems could be addressed more accurately and reliably by adopting motion analysis techniques. Furthermore, introduction of a dependency coefficient offers a wide spectrum of prospective applications in neuromuscular studies .

Key words: Motion analysis, GALS examination, Musculoskeletal disorders, Dependency Coefficient

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Introduction

Visual evaluation of joints is an integral part of human motion assessment. Implementation of cinematography in biomechanical studies using motion capture technologies made a tangible contribution to further developments of human motion analysis systems. This particular combination of software and hardware has found diverse applications in such areas as the military and computer vision. Motion analysis systems are also comfortably relied on by medical professionals in quantitative evaluation of musculoskeletal performance in rehabilitation, neurology and sports medicine. Individual disciplines, however, require tailored software for a more coherent quantitative analysis. Examples of dedicated tools for disciplinary applications are numerous. Software for 3D analysis of the musculoskeletal system has been developed by Leardini et al (1). The reliability and validity of standing balance measurements using motion analysis systems is discussed by Kejonen et al (2). Patient positioning verification is also addressed utilizing real-time three dimensional motion analysis (3).

Einas (4) and his colleagues worked on pelvic skeletal asymmetry and its influence on trunk movement. The range of motion and effect of foot structure in musculoskeletal overuse injuries has also been studied (5). Prediction of patellar tendon reflex is another disorder which is evaluated by 3D analysis of human movements (6). The range of motion of human segments is a related parameter to musculoskeletal system and Schmidt et al (7) addressed the issue by investigating the unconstrained motion of wrist and elbow. Finger flexion and extension following a 3D video analysis has been presented by Rash (8). Other muscular parameters like belly length with a potential for the assessment of contracture has also been investigated by Fry et al (9).

The motion analysis systems are widely adopted as diagnostic tools for investigating musculoskeletal

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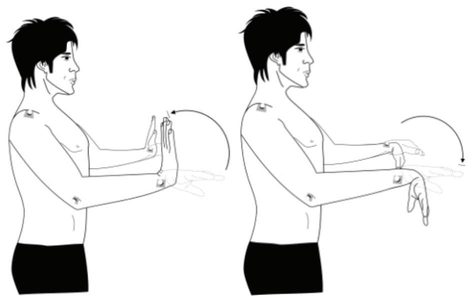
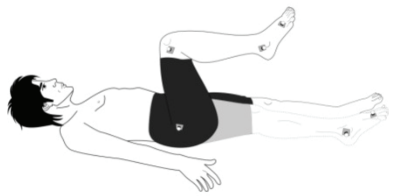
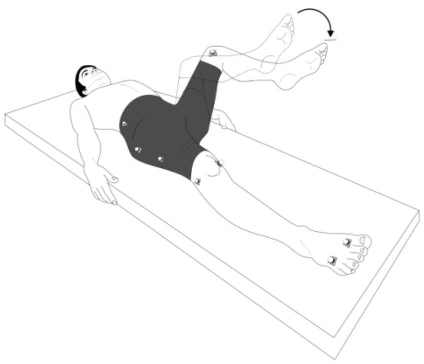
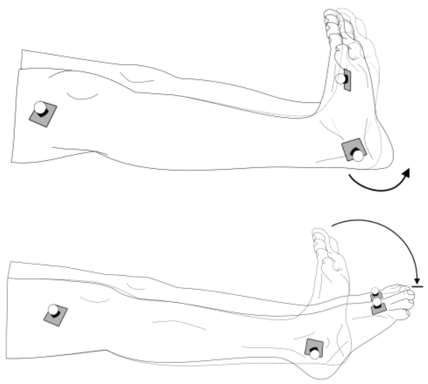
disorders. However, the preliminary evaluation of patients is still subject to manual intervention by physiotherapists, rheumatologists and orthopedic surgeons. There are a number of slightly different routines for such an evaluation. The GALS examination (gait, arms, legs, and spine) has been validated as a new approach for screening musclo-skeletal disorders in primary care (10, 11, 12). Here, the sensitivity, reliability and specificity of this examination procedure have been investigated by physiotherapists to detect rheumatoid arthritis (13).
This paper represents a novel approach in adopting a dedicated motion analysis system for automatic evaluation of a patient musculoskeletal condition through substitution of the visual segment of GALS examination.

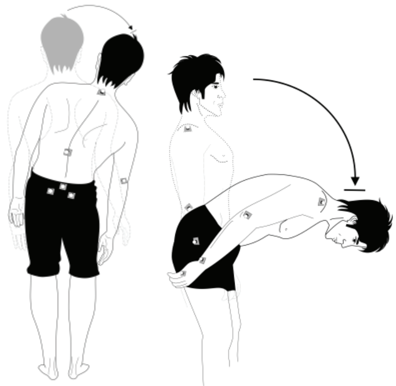
Methods

A 3D motion pattern was obtained from two subject groups using a six camera motion analysis system. The visual evaluations constitute an integral and critical part of the GALS examination. During these clinical assessments, the physician attempts to extract features associated with body segments; at the same time the whole body configuration is kept in mind. Here factors such as ROM (range of motion), swelling, deformity, smoothness and symmetry of movements, tenderness and gripping ability are assessed. The visual evaluation however, concentrates primarily on assessment of ROM for individual joints. In the following sections the development of a protocol for parameter estimation during these examinations is explained. A number of issues that define the existing tests such as GALS should also be taken into consideration. In the first instant, the objectives of the original test should be adhered to and both sides of the body should be assessed (13). Furthermore, no additional or external forces should be applied to the subject's body during evaluation of the active range of motion. Table (1) presents the basic structure of this protocol.

Table 1. Structure of the protocol developed for the Automatic GALS screening

Subcategory	Movement	Description	Assessment Method
	Gait		
	Walking at comfortable pace	3D Gait Analysis	Evaluation of walking pattern by tracking ankle landmark
	Arm		
	Shoulder external rotation	Dressing ability: Elbow-shoulder is pulled back from coronal plane	The angle of rotation of the arm

Subcategory	Movement	Description	Assessment Method
	Arm flexion	Standing upright with arms hanging, the arm is then rotated upwards	The angle of rotation of the arm
	Wrist flexion & extension	Arms hanging freely, hands are kept horizontally at right angles to arms, wrist is rotated upwards and downwards	Wrist rotation
Leg			
	Knee flexion	Lying on the couch, foreleg is free while thigh is brought up	The angle of knee flexion
	Hip internal rotation	Passive internal rotation of individual hips	Lateral rotation of foreleg
	Ankle Dorsi & Plantar Flexion	Rotating foot from vertical position, moving back and forth	Foot-foreleg angle
Spine			

Subcategory	Movement	Description	Assessment Method
	Waist Lateral Bending	Keeping waist stationary, bending the upper extremity laterally	Angle of motion of the T10-S1 line
	Waist Flexion	T10-S1 bending forward	T10-S1 forward angle

The positioning of the passive or active markers plays an important role in this screening protocol. Here the Helen-Hayse marker-set (15) is adopted for location of the markers. The other practical issue is what the patient wears during screening. Skin marking requires the male subjects to wear stretch shorts. The female subjects additionally wear a simple but specially prepared top which is similar to a kitchen apron with an open back.

The motion analysis system adopted for this study is a 'six infrared cameras Vicon system' with Vicon data station & workstation software. The motion was captured at 60 fps. this speed is highly suitable for this type of movement. The results are in the form of Microsoft Excel Sheets. An M-File code is then prepared for Matlab R2007b. The code is responsible for accepting the motion analysis software output and provides the corresponding stick figures and the associated joint ROM.

For practical implementation of the protocol eight undergraduate Biomedical Engineering students at Amirkabir University of Technology (AUT) formed the two study groups. Table (2) illustrates the demographic profiles of the two subject groups.

Table 2. Descriptive profiles of two study groups

Variable	Male	Female
Age (Yr)	20.25±0.5	19.25±0.5
Weight (Kg)	69.50±10.345	59.25±1.259
Height (Cm)	173.25±7.676	160.25±6.397
BMI (Kg/m^2)	23.05452±1.894	23.14453±1.736

Results

The ROMs for the two subject groups was determined and tables 3 & 4 represent the subject data summary for male and female participants. Total average and standard deviations were calculated for individual rows in tables (3) and (4). Here the average of female and male participants was determined separately for individual movements.

Table 3. GALS examination results for males measured with motion analysis system. All data are in degree scale.

	Case 1	Case 2	Case 3	Case 4	Average	STD	Normal
Right Lateral Bending	24.0246	29.7182	35.2918	40.0987	32.2833	6.950	0-25
Left Lateral Bending	23.9208	33.4874	31.5047	35.292	31.0513	4.999	0-25
Waist Flexion	60.5308	104.3238	109.8251	125.152	99.9579	27.72	0-90
Right Shoulder External Rotation	17.3221	31.926	24.4186	41.997	28.9159	10.56	0-45
Left Shoulder External Rotation	15.1735	34.5632	28.3996	44.212	30.5872	12.16	0-45
Right Elbow Flexion	86.2745	69.9636	93.0814	75.689	81.25225	10.384	0-150
Left Elbow Flexion	84.3018	72.9452	90.3523	66.247	78.46165	10.879	0-150
Right Wrist Flexion	92.0787	57.4011	83.1725	75.600	77.0632	14.736	0-60
Left Wrist Flexion	88.3375	46.6831	-	69.836	68.2858	20.870	0-60
Right Wrist Extension	42.7776	56.7274	46.5528	51.401	49.3649	6.045	0-60
Left Wrist Extension	28.0795	51.2704	51.2363	45.084	43.9177	10.951	0-60
Right Knee Flexion	116.5022	126.0008	110.4196	127.351	120.0684	8.042	0-150
Left Knee Flexion	120.3755	126.675	130.9287	127.891	126.4677	4.437	0-150
Right Hip Internal Rotation	13.1893	30.7545	29.5033	33.355	26.70065	9.149	0-45

	Case 1	Case 2	Case 3	Case 4	Average	STD	Normal
Left Hip Internal Rotation	14.734	33.5029	34.6577	38.629	30.381	10.659	0-45
Right Ankle Dorsi Flexion	8.3628	41.5896	22.5732	27.309	24.9587	13.701	0-20
Left Ankle Dorsi Flexion	7.9059	47.0624	24.0755	30.878	27.4804	16.225	0-20
Right Ankle Plantar Flexion	7.3029	12.9306	17.4082	29.824	16.8665	9.577	0-50
Left Ankle Plantar Flexion	8.1441	16.4978	23.6389	34.735	20.75415	11.268	0-50
Left Knee in Gate Process	75.23	63.9687	85.781	111.7	84.1699	20.400	0-120
Left Hip in Gate Process	51.52	45.1286	62.2004	63.79	55.6597	8.886	0-80

Table 4. GALS examination results for females measured with motion analysis system. All data are in degree scale.

	Case 5	Case 6	Case 7	Case 8	Average	STD	Normal
Right Lateral Bending	35.3272	27.0138	41.8696	30.0579	33.567	6.513	0-25
Left Lateral Bending	33.7315	27.3634	40.5171	31.6614	33.319	5.483	0-25
Waist Flexion	81.4195	73.2734	78.9933	63.1135	74.20	8.141	0-90
Right Shoulder External Rotation	29.9495	42.9042	52.0556	43.6244	42.135	9.123	0-45
Left Shoulder External Rotation	40.2838	34.6775	53.0795	49.1322	44.29	8.349	0-45
Right Elbow Flexion	73.062	88.854	98.3156	103.1699	90.850	13.265	0-150
Left Elbow Flexion	65.4103	74.5736	99.2266	89.4009	82.152	15.075	0-150
Right Wrist Flexion	56.7717	52.5711	61.2721	78.1051	62.18	11.195	0-60
Left Wrist Flexion	69.6553	68.8519	58.7572	86.1088	70.843	11.320	0-60
Right Wrist Extension	18.7698	58.7179	53.5452	46.5443	39.62	18.392	0-60
Left Wrist Extension	15.6217	53.1221	60.8213	59.4073	47.243	21.344	0-60
Right Knee Flexion	127.2142	126.1644	125.0407	117.1573	123.895	4.578	0-150
Left Knee Flexion	123.4088	126.6062	127.6217	114.5348	123.043	5.949	0-150
Right Hip Internal Rotation	44.6373	38.5630	35.2774	32.0348	37.316	6.544	0-45
Left Hip Internal Rotation	46.8059	36.304	42.3485	30.703	39.040	7.029	0-45
Right Ankle Dorsi Flexion	-	-	39.1348	29.6971	34.415	6.673	0-20
Left Ankle Dorsi Flexion	27.9981	14.4352	46.0564	27.0056	33.686	10.723	0-20
Right Ankle Plantar Flexion	7.3029	-	11.4411	18.7717	15.106	5.183	0-50
Left Ankle Plantar Flexion	24.2201	20.4623	36.9028	16.6293	25.917	10.242	0-50
Left Knee in Gate Process	113.6394	127.741	133.7182	61.98	109.269	32.630	0-120
Left Hip in Gate Process	69.8592	91.1451	78.2261	43.7	70.732	20.036	0-80

The segmental range of motion found in references is also presented in the last column of each row. Fig. (1) represents the right and left lateral bending against one another.

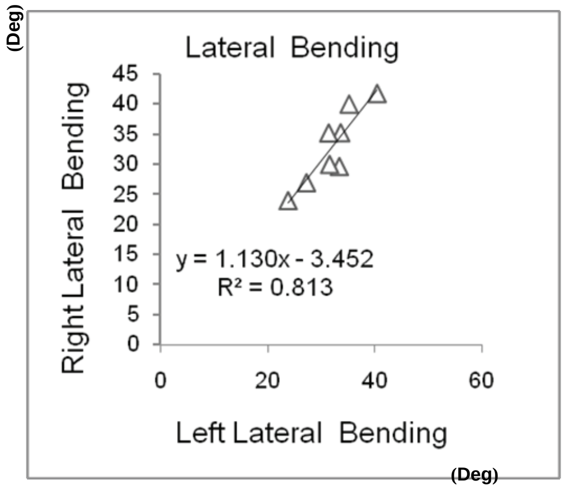


Fig. 1: Right lateral bending against left lateral bending

The left and right shoulder extensions are also illustrated in Fig. (2). Fig. (3) presents the forearm flexion data in both left and right sides. Figures (4) and (5) show wrist flexion and extension from both left and right sides. Furthermore, knee flexions in both sides are shown in Fig. (6).

Fig. 2. Right shoulder external rotation against left shoulder external rotation

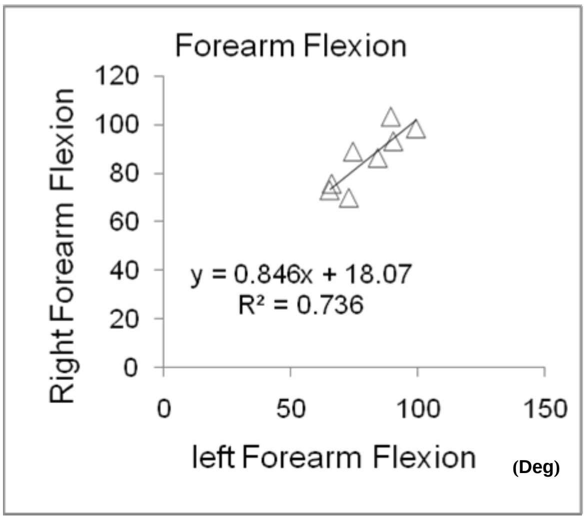


Fig. 3. Right forearm flexion against left forearm flexion

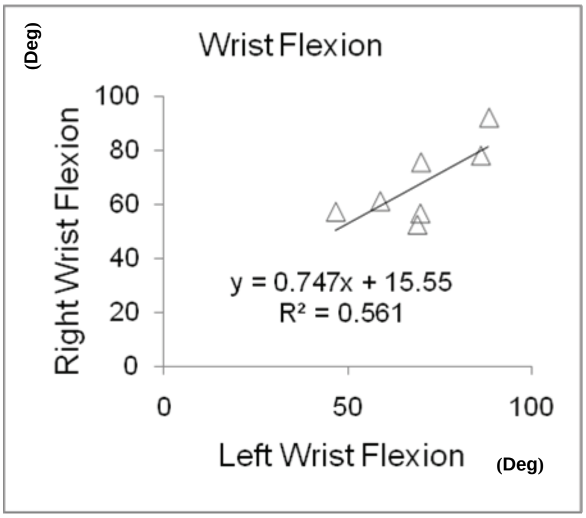


Fig. 4. Right wrist flexion against left wrist flexion

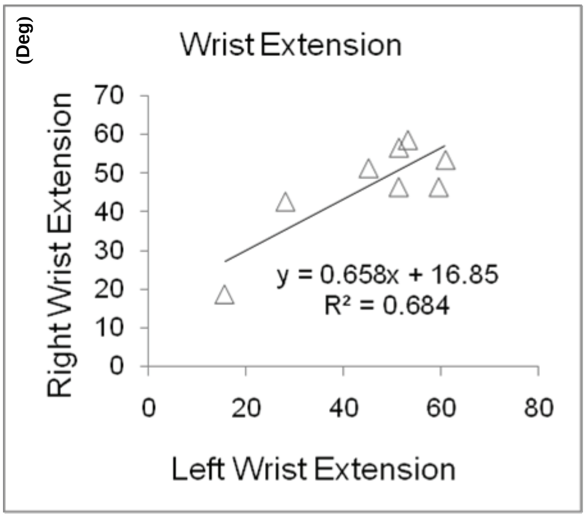


Fig. 5. Right wrist extension against left wrist extension

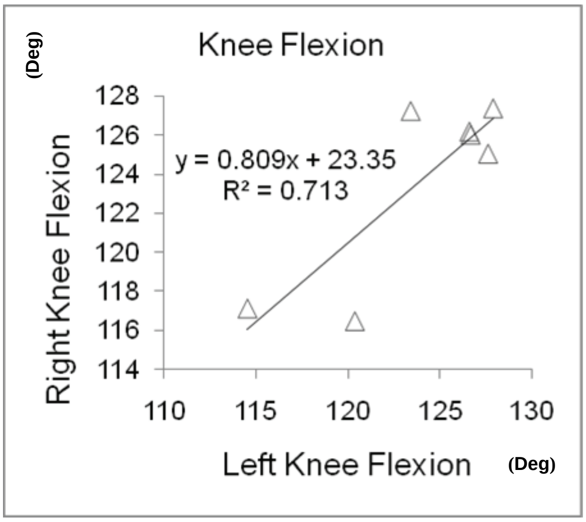


Fig. 6. Right knee flexion against left knee flexion

Internal rotation of the hip in both left and right sides are shown in Fig. (7). The ankle has two separate sets of data in plantar flexion and dorsi flexion as illustrated in Fig. (8) and Fig.(9). And Fig. (10) shows the left knee angle against left hip angle in gait analysis.

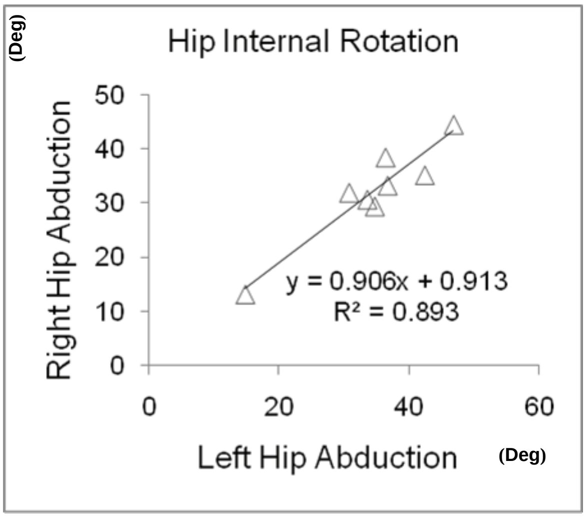


Fig. 7. Right hip internal rotation against left hip internal rotation

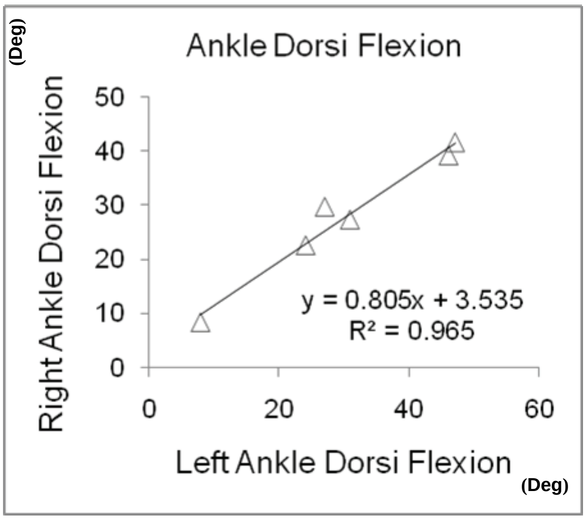


Fig. 8. Right ankle dorsi flexion against left ankle dorsi flexion

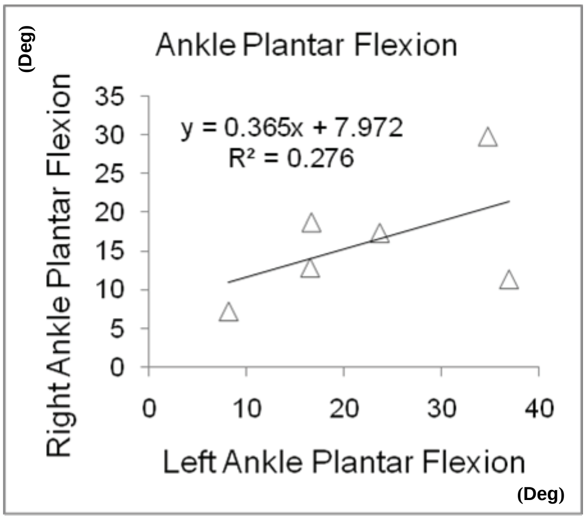


Fig. 9. Right ankle plantar flexion against left ankle plantar flexion

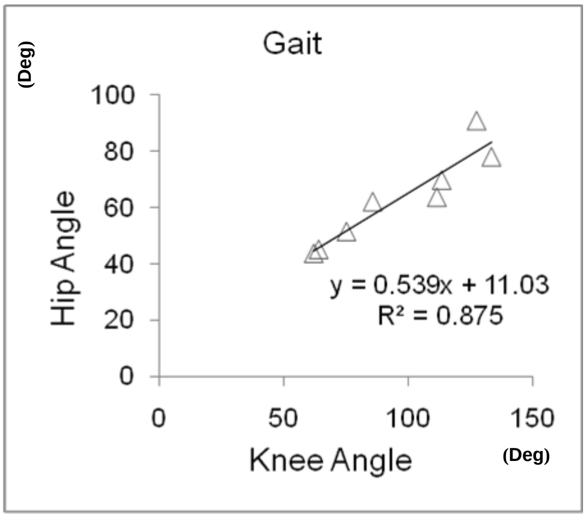


Fig. 10. Left knee angle against left hip angle in gait analysis

Discussion

In this paper a procedure based on motion analysis is presented as a new or an alternative means by which an important part of the GALS screening procedure can be performed. The current clinical procedure results in a predominantly experience-based and subjective grading arrived at by the physician. An automatic evaluation, however, could provide a far more reliable and repeatable result through objective screening. Here objectivity is obtained through motion analysis followed by an automatic comparison of the results against an accepted set of criteria (16), thus introducing a decision making platform using Matlab 2007 Rb to assist the physician a step further. The potential for addition of different algorithms to the automatic comparison stage is yet another benefit of this approach. For example, the symmetry of movement on both sides of the body could be quantified using a dependency coefficient 'R', which is a measure of asymmetry on individual body planes. This is exemplified by a dependency coefficient 'R', of waist lateral bending on both sides on the frontal plane, as shown in Fig. 10. This coefficient has values between 0 & 1, and the higher this value, the higher would be the symmetry. Higher values of R, on the other hand, are not necessarily associated with ROM. To exemplify this point, the spine and gait tests were taken to a diagnostic stage to see how the dependency coefficient (arrived at by automatic motion analysis) became clinically significant. In the case of subject 7, higher normal flexibility was encountered during waist lateral bending while the movement was quite symmetrical. Alternatively, in the case of subject 4, the results of automatic assessment of GALS procedure was indicative of a lack of symmetry at the same time that higher than normal flexibility was observed. Lack of symmetry can be associated with shortening of quadratus lumborum. Alternatively, S shape scoliosis in both thoracic and lumbar areas could lead to limitations which are here manifested by a smaller than expected dependency coefficient. The torsion and shearing in pelvis, caused by sacro-iliac dysfunction, could also be considered as yet another reason for limitations in lateral bending.

In gait analysis two parameters were considered; knee angle and hip angle on sagittal plane for one complete cycle. A single side view analysis could be justified by the assumption that existence of any pathological states on one side directly affects both knee and hip angles on the other side. Cases 1, 2 and 3 in tables 3 and 4, could be considered as indications of center of mass swing deviation during the gait cycle which in turn, is an indication of knee compensation in response to weaknesses exhibited by the combination of hip and pelvis. Finally, there is a reasonable dependency between knee and hip angles in Fig. 10 that proves all the aforementioned explanations (17).

Understanding the functions affected by pathology and impairment may be critical in diagnosis. Furthermore, designing effective treatments for the prevention and cure of disabilities resulting from musculoskeletal diseases is very critical. Winter in 1990 explained that the joint mechanical power and energy reflect the underlying neuromuscular control mechanisms of human movement (18). Numerous possible solutions are required extremity kinematics (19). This flexibility in neuromuscular patterning potentially allows one to ambulate effectively with impairments. The hip is used to compensate for weakness in knee extensor and/or ankle plantar flexor muscles of otherwise healthy (20). Gait compensations for hip muscle weakness can produce independent (i.e. successful) ambulation, although at a reduced speed as compared to normal gait (21).

Conclusions

Motion analysis provides the instrumentation necessary for an objective evaluation of GALS examination and diagnosis of musculoskeletal problems. Accuracy of medical diagnosis can be effectively altered by adopting a reliable and repeatable procedure using motion analysis techniques. Introduction of the concept of dependency coefficient could pave the way towards further neuromuscular investigations and the lack of symmetry could lead to personalized conditioning programs tailored for both healthy weaknesses and pathological states. Although implementation of such a technology might at first, seem time consuming, expensive, and require specialized technical support for medical professionals, further development of this approach will undoubtedly prove the system to be an invaluable asset. This is particularly tangible when a large group of people like the numbers encountered in health screenings for company staff is intended.

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