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SYSTEMATIC REVIEW
MOTION ANALYSIS

Trunk motion analysis: a systematic review from a clinical and methodological perspective

Stefano NEGRINI [1, 2], Barbara PIOVANELLI [2], Cinzia AMICI [3], Valter CAPPELLINI [3], Gabriele BOVI [2], Maurizio FERRARIN [2], Fabio ZAINA [4], Alberto BORBONI [3] *

[1]Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy; [2]IRCCS Fondazione Don Carlo Gnocchi ONLUS, Milan, Italy; [3]Department of Mechanical and Industrial Engineering, University of Brescia, Brescia, Italy; [4]ISICO (Italian Scientific Spine Institute), Milan, Italy

* Corresponding author: Stefano Negrini, Department of Clinical and Experimental Sciences, University of Brescia – Fondazione Don Gnocchi, Milan, Italy. E-mail: stefano.negrini@unibs.it

ABSTRACT

INTRODUCTION: This systematic literature review aims to check the current state of affairs of non-gait-related optoelectronic trunk movement analysis; results have been analyzed from a clinical and a methodological perspective.
EVIDENCE ACQUISITION: Extensive research was performed on all papers published until December 31st, 2015, dealing with trunk movement analysis assessed by optoelectronic systems, excluding those related to gait. The research was performed on the 14th of January 2016 on three databases: Scopus, Science Direct and Pubmed. A reference search and expert consultation were also performed.
EVIDENCE SYNTHESIS: Out of a total number of 8431 papers, 45 were deemed relevant: they included 1334 participants, 57.9% healthy, with age range 8-85. Few studies considered the whole trunk, and none focused on each vertebra independently: the trunk was almost always divided into three segments. Thirteen studies included 20 or more markers. Most of the papers focused mainly on the biomechanics of various movements; the lumbar area and low back pain were the most studied region and pathology respectively.
CONCLUSIONS: This study has shown the relative scarcity of current literature focusing on trunk motion analysis. In clinical terms, results were sparse. The only quite well represented group of papers focused on the lumbar spine and pathologies, but the scarcity of individuals evaluated make the results questionable. The use of optoelectronic systems in the evaluation of spine movement is a growing research area. Nevertheless, no standard protocols have been developed so far. Future research is needed to define a precise protocol in terms of number and position of markers along the spine and movements and tasks to be evaluated.

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Key words: Spine - Motion - Torso.

Introduction

Motion analysis has developed greatly during the last 30 years, focusing mainly on gait. There are several reasons for this; the quite standard activity of walking, for example, but also the importance of gait impairment in neurological and orthopedic diseases both in adults and children. The development of movement essentially in the sagittal plane has allowed the development of standard protocols.[1] As regards the upper limbs, there are many more difficulties in the way of defining a standard for motion analysis, the result mainly of the different tasks and functions of this body segment.[2] Trunk activity can be considered more similar to the upper than the lower extremities in terms of complexity. Trunk movements play an important role in many human activities, contributing to the movement of the whole body:[3-5] in fact the trunk offers stability to the limbs, allowing them to operate properly.[6] For these reasons, the trunk has been studied in relation to limb movements during simple activities (*e.g.* gait or reaching) and modifications to trunk kinematics have been observed when comparing healthy and pathological subjects.[7-9] Nevertheless, the trunk has rarely been studied as an independent object of research, even if the study of trunk kinematics can play a very important role from a clinical perspective.

Among advanced non-invasive movement evaluation tools, the most common are based on optoelectronic devices, considered today's gold standard.[7, 10] The optoelectronic approach is based on two hypotheses:

— some parts of the human body can be approximated to rigid bodies;

— at least three geometrical points solidly attached to each rigid body can be identified and the 3D coordinates pinpointing their positions measured.

Under these hypotheses, the trunk can be divided into rigid parts and three optical markers must be solidly attached to each. Thus the motion of each part can be completely defined in space with at least two optoelectronic cameras. Sometimes the parts are identified by geometrical points, without any dimension, thus only a single marker can be associated with each part. Furthermore, the markers cannot always stay in the optical field of the cameras during movement, thus the number of cameras is incremented. Different approximations can produce biomechanical models with a different number of rigid parts. For these reasons, different optoelectronic systems are used in different ways to monitor trunk kinematics, with different aims and different results.

So far, neither a standard protocol nor even standard tools for trunk movement evaluation have been defined. The only existing systematic review regarding trunk movement analysis of which we are aware is focused on the trunk during gait.[7] For this reason, we designed this systematic review in order to present the current state of the art of non-gait-related optoelectronic trunk movement analysis, to try to uncover possible shared strategies and protocols and to describe the actual results from a clinical perspective.

Evidence acquisition

We performed a systematic review of the literature, searching all papers published until December 31st, 2015, dealing with trunk movement analysis assessed by optoelectronic systems, excluding those related to gait. The research was performed on three databases: Scopus, Science Direct and Pubmed on the 14th of January 2016.

The string used for the search was composed according to the following criteria:

— Title, Abstract or Keywords present at least one of the words: "trunk", "upper body", "back", "spine", and at least the root "movement*" or "motion*";

— neither Title nor Keywords present any of the following roots: "gait*", "walk*", "posture*", "feet*", "foot*", "knee*", "ankle*", "leg*", "jump*".

Table I collects the search strings in full.

The outcomes of the three queries were merged, taking care to discard the duplicates, into a unique list of documents, excluding all records which were not full papers. The search was limited to English language items. Documents were then individually analyzed, excluding all those which met at least one of the following exclusion criteria:

— no numerical data;

— data not captured with optoelectronic systems;

— study focusing on gait only.

The filtering and classification phases were performed and cross-checked by seven researchers of various, complementary backgrounds, in order to minimize possible individual bias or oversight (Figure 1). Databases queries and title screening were performed by two researchers and one student in biomechanical engineering. The abstract check was carried out by four students, three from the Engineering Faculty and one from the Department of Physiotherapy, with supervision by researchers. Five more students and one researcher in both fields read and analyzed the full text of the remaining articles. The list defined at the end of the screening phase was then integrated with further twelve articles after a reference check of the selected papers and three expert recommendations.

Evidence synthesis

Querying Scopus, Science Direct and Pubmed databases resulted respectively in 7474, 904 and 241 papers matching the search criteria. The total number of papers, after exclusion of duplicates, was 8419.

The selection process (Figure 1) generated 33 papers. At the second stage (reference search and expert consultation) 12 more articles were found, leading to a total

TABLE I.—*Search strings, possible further restrictions applied and final number of collected papers.*

Database	Search string	Restrictions	Found items
Scopus	(TITLE-ABS-KEY (trunk OR back OR spine OR upper body) AND TITLE-ABS-KEY (movement* OR motion*)) AND NOT TITLE (gait*) AND NOT TITLE (walk*) AND NOT TITLE (postur*) AND NOT TITLE (feet*) AND NOT TITLE (foot*) AND NOT TITLE (knee*) AND NOT TITLE (ankle*) AND NOT TITLE (leg*) AND NOT TITLE (jump*) AND NOT KEY (gait*) AND NOT KEY (walk*) AND NOT KEY (postur*) AND NOT KEY (feet*) AND NOT KEY (foot*) AND NOT KEY (knee*) AND NOT KEY (ankle*) AND NOT KEY (leg*) AND NOT KEY (jump*) AND (EXCLUDE (PUBYEAR , 2016)) AND (LIMIT-TO (DOCTYPE , "ar"))	/	7474
ScienceDirect	(TITLE-ABSTR-KEY(trunk) or TITLE-ABSTR-KEY(upper body) or TITLE-ABSTR-KEY(back) or TITLE-ABSTR-KEY(spine)) and (TITLE-ABSTR-KEY(movement*) and TITLE-ABSTR-KEY(motion*)) and not TITLE(gait*) and not TITLE(walk*) and not TITLE(postur*) and not TITLE(feet*) and not TITLE(foot*) and not TITLE(knee*) and not TITLE(ankle*) and not TITLE(leg*) and not TITLE(jump*) and not KEYWORDS(gait*) and not KEYWORDS(walk*) and not KEYWORDS(postur*) and not KEYWORDS(feet*) and not KEYWORDS(foot*) and not KEYWORDS(knee*) and not KEYWORDS(ankle*) and not KEYWORDS(leg*) and not KEYWORDS(jump*)	Manually eliminated the 9 papers published in 2016	904
PubMed	((trunk[Title/Abstract] OR upper body[Title/Abstract] OR back[Title/Abstract] OR spine[Title/Abstract]) OR (trunk[Other Term] OR upper body[Other Term] OR back[Other Term] OR spine[Other Term]) AND (movement*[Title/Abstract] OR motion*[Title/Abstract] OR movement*[Other Term] motion*[Other Term])) NOT gait[Title] NOT walk*[Title] NOT postur*[Title] NOT feet*[Title] NOT foot*[Title] NOT knee*[Title] NOT ankle*[Title] NOT leg*[Title] NOT jump*[Title] NOT gait[Other Term] NOT walk*[Other Term] NOT postur*[Other Term] NOT feet*[Other Term] NOT foot*[Other Term] NOT knee*[Other Term] NOT ankle*[Other Term] NOT leg*[Other Term] NOT jump*[Other Term]	Manually eliminated the 6 papers published in 2016	241

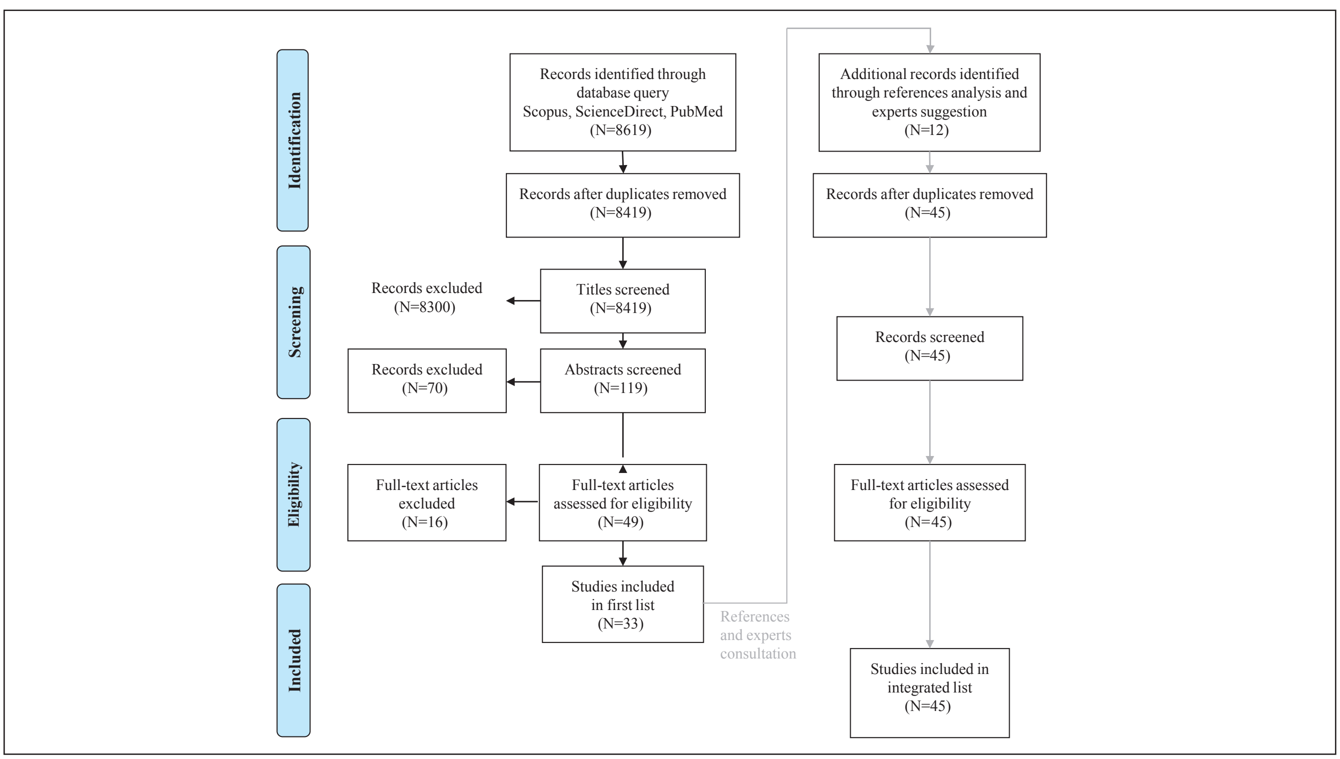

Figure 1.—Flow chart of the study.

TABLE II.—*Characteristics of included studies.*

Paper	Subjects				Health conditions		Method		
	Total	Healthy	Patho-logical	Age range (mean)	Healthy	Pathologies	Task: B=any bending; STS=sit-to-stand; S=sports; O=others	Model's segments No.	No. of cameras
Only healthy participants									
1990_Frigo[14]	2	2	0	-	X		O	3	2
1991_Lindbeck[47]	10	-	-	28-45	X		O	6	2
1995_Baer[33]	30	30	0	50-80	X		STS	1	3
1995_Gracovetsky[19]	40	40	0	(20)	X		O	1	2
1995_Vachalathiti[10]	100	100	0	(47)	X		B	-	4
1998_Klein Breteler[23]	12	12	0	18-43	X		O	4	
1998_Wang[12]	10	10	0	-	X		O	3	
2002_Sforza[32]	70	70	0	(37)	X		B,O	3	-
2003_Cerveri[13]	2	2	0	-	X		-	-	6
2003_Chow[26]	15	15	0	(35)	X		S	5	2
2006_Ciavarro[48]	20	10	10	(25.6)	X		B	7	8
2007_Milosavljevic[43]	18	18	0	(20,7)	X		B	3	12
2009_Kuo[34]	46	46	0	17-83	X		B,O	6	1
2009_Leardini[29]	10	10	0	(25,2)	X		B,STS,O	1	8
2009_Pollock[42]	9	9	0	(25,8)	X		S	6	8
2010_Preuss[41]	11	11	0	24-34	X		B	7	6
2011_Evans[31]	19	19	0	18-38	X		O	-	8
2011_Leardini[44]	10	10	0	23-26	X		O	7	8
2012_Graci[22]	19	19	0	(27,8)	X		S	1	8
2013_Cheng[37]	18	18	0	21-28	X		B	1	8
2013_Cobian[20]	10	10	0	(23)	X		O	3	8
2013_Evans[18]	19	19	0	(29)	X		B	7	8
2013_Ranavolo[27]	10	10	0	16-54	X		B,O	-	8
2014_Howarth[21]	16	16	0	23-25	X		B	2	2
2014_Oyama[25]	72	72	0	13-19	X		S		7
2015_Dugailly[24]	12	12	0	19-41	X		B	2	8
2015_Inokuchi[28]	12	12	0	34-35	X		B	2	9
2015_Nakayama[49]	3	3	0	22-24	X		O	2	8
2015_Schinkel-Ivy[30]	30	30	0	22-25	X		B	3	7
Comparison between healthy participants and patients									
2005_Andreoni[47]	10	10	1	(27.5)	X	Low back pain	B	7	8
2006_Al-Eisa[11]	113	-	-	20-45	X	Low back pain	B,O	4	5
2008_Gombatto[35]	41	19	22	(30,8)	X	Low back pain	B	1	6
2012_Hidalgo[39]	50	25	25	30-65	X	Low back pain	B	6	8
2014_Bourigua[38]	82	33	49	(38)	X	Low back pain	B	5	10
2015_Sánchez-Zuriaga[17]	30	15	15	30-56	X	Low back pain and disk herniation	B	2	4
2014_Duc[15]	23	10	13	23-65	X	Cervical arthrodesis	B	2	8
2010_Bartolo[40]	54	10	44	55-85	X	Parkinson disease	B	1	6
2014_Major[36]	13	6	7	24-67	X	Parkinson disease	O	3	-
2015_Bravo Petersen[16]	22	10	12	20-38	X	Cervicogenic headache	B	2	8
Only patients									
1995_Bednarczyk[51]	20	0	20	8-52		Spinal cord injury	O	3	2
2002_Bouilland[48]	13	0	13	(25)		Low back pain	O	16	4
2007_Gombatto[45]	44	0	44	20-36		Low back pain	B	3	6
2014_Massie[50]	17	0	17	(65,5)		Stroke	O		
2014_Wu[52]	97	0	97	(55,9)		Stroke	O	8	7
2003_Sibella[46]	50	0	50	(26,5)		Obesity	STS	4	
TOTAL	1334	773	439		39				
Average	29.7	21.2	28.6					3.9	6.2
Minimum	2	2	1					1	1
Maximum	113	100	97					16	12

TABLE III.—*Marker positioning in the studies included with particular focus on spine landmarks. Where N>1 the number represents the number of markers composing a cluster on a rigid support.*

Article ID	No. of marker	Spinal repere points																					
		C7	T1	T2	T3	T4	T5	T6	T7	T8	T9	T10	T11	T12	L1	L2	L3	L4	L5	S1	S2	S5	Other
With clusters of rigid supports on the spine																							
1990_Frigo[14]	18	2							2											3			11
1998_Klein Breteler[23]	17	3																					14
2005_Andreoni[47]	31													3	3	3	3	3	3	3			6
2006_Ciavarro[48]	31													3	3	3	3	3	3	3			6
2010_Preuss[41]	22	3			3			3			3			3			3			1		1	2
2013_Evans[18]	28		4																				24
2014_Bourigua[38]	16	3																					13
2014_Howarth[21]	10										2									2			6
2015_Schinkel-Ivy[30]	59	5			5			5			5			5					5				29
Without clusters of rigid supports on the spine																							
1991_Lindbeck[47]	6																						6
1995_Baer[33]	6																						6
1995_Bednarczyk[51]	7	1																					6
1995_Gracovetsky[19]	12	1				1				1		1		1	1		1	1	1	1	1		1
1995_Vachalathiti[10]	8							1						1					1		1		4
1998_Wang[12]	0																						4
2002_Bouilland[48]	35																						35
2002_Sforza[32]	6				1																		5
2003_Cerveri[13]	22	1																					21
2003_Chow[26]	13																						13
2003_Sibella[46]	16	1																					15
2006_Al-Eisa[11]	13		1					1							1				1				9
2007_Gombatto[45]	24	1				1			1			1			1		1		1		1		16
2007_Milosavljevic[43]	13										1			1			1						10
2008_Gombatto[35]	17	1							1						1			1			1		12
2009_Kuo[34]	9		1		1										1						1		5
2009_Leardini[29]	14	1		1						1		1							1		1		8
2009_Pollock[42]	22	1				1			1			1			1		1			1			15
2010_Bartolo[40]	7	1									1												5
2011_Evans[31]	8																						8
2011_Leardini[44]	14	1		1											1		1		1				9
2012_Graci[22]	13	1		1								1											10
2012_Hidalgo[39]	9	1							1					1			1				1		4
2013_Cheng[37]	21	1				1									1		1		1				15
2013_Cobian[20]	25																						25
2013_Ranavolo[27]	20	1	1	1	1	1		1	1	1	1	1		1	1		1	1	1	1			4
2014_Duc[15]	8			1					1														6
2014_Major[36]	14	1																					13
2014_Massie[50]	6																						6
2014_Oyama[25]	40	1								1													38
2014_Wu[52]	13	1				1																	11
2015_Bravo Petersen[16]	10																						10
2015_Dugailly[24]	12			1						1													10
2015_Inokuchi[28]	8	1		1																			6
2015_Nakayama[49]	8		1											1			1						5
2015_Sánchez-Zuriaga[17]	7													1			1		1				4
Total using this repere		23	5	7	5	6	0	5	7	5	6	6	0	11	11	2	13	5	12	8	7	1	
Average	16																						11

of 45 studies included in this paper. We did not find any systematic review on this topic. Relevant methodological information about the retrieved papers are reported in Tables II, III.

Most of the discarded papers focused on gait. We had only one paper [11] whose abstract respected the inclusion criteria, but whose full text was not retrievable. The 45 included papers considered a total of 1334 participants: 42.1% were patients and 57.9% healthy. All studies were quite small, including 1 to 113 participants: only two articles [12, 13] considered 100 participants or more. All studies, except three,[14-16] reported the age of the subjects, with spans between 8 and 85 years.

Thirty-nine studies [12, 14, 15, 17-48] considered healthy subjects, and fifteen of them [13, 17-19, 37, 38, 40-42] compared healthy and pathological subjects. The most considered pathologies involved primarily the trunk (ten studies), while the remainder dealt mainly with neurological disorders, but also obesity and prostheses.

In order to investigate the kinematics and dynamics of the spine, in each study the subjects were asked to perform specific movements: flexion-extension and lateral bending proved to be the most frequent, involving twenty-five studies;[12, 13, 17-21, 23, 26, 29-33, 36, 37, 39-43, 45, 47-49] four papers [24, 27, 28, 44] analyzed the behavior of the spine during sports action, and three [31, 35, 50] focused on sit-to-stand movement. In the remaining papers, various movements were analyzed: weight lifting [16, 51] and trunk rotation were particularly interesting.

Clinical results

The results of these few studies are difficult to summarize, since the differences are so high in terms of methodology and sample studied. The main clinical results are summarized in Tables IV-VI.

Many studies focused on biomechanics, looking at general daily activities,[22, 46] stand-up movement,[35] sit-to-stand,[50] trunk flexion-extension,[45] trunk circumduction,[39] weight lifting,[16, 40, 52] single leg squat,[24] mechanisms of injuries.[44, 53] Two studies focused on creating an evaluation protocol,[47, 48] including a normality dataset.[48] Biomechanical characteristics [15, 23, 29, 32] and the importance of the different models [31] was also studied. Finally, intersegmental spinal motion was considered important.[43]

Table IV.—*Results of papers in healthy individuals.*

2003_Cerveri	Using a biomechanical model it is possible to reconstruct human movements with adequate accuracy
2009_Leardini	All models, both in terms of markers involved and of reference frame definitions, are understood carefully before interpreting the results in clinical decision making.
2010_Preuss	The degree of segmentation of the kinematic model of the spine affect the total trunk motion measured during multi-planar movements. A multi-segmental analysis appears to have several advantages, providing improved insight into the complex, task dependent motions of the trunk, and the often uneven distribution of that motion between spine levels
1995_Gracovetsky	Lumbar skin marker motion patterns in normal subject is consistent and varies little with load; gender have no effect except in initial phase of movement
1995_Vachalathiti	During the movement of the spine no significant gender-specific differences can be observed, but with advancing age there are significant reductions in the ranges of forward and side flexion, but not axial rotation
2009_Kuo	Older adults demonstrate significantly decreased flexion/extension ranges in the cervical, thoracic and lumbar spine.
2015_Inokuchi	Tthree dimensional optoelectronics systems are useful to measure neck range of motion and evaluate the efficacy of interventions, such as surgery or physiotherapeutic exercise
2015_Doungally	A protocol for analyzing kinematics of cervical manipulation in asymptomatic subjects is feasible and there is limited range of axial rotation during cervical spine manipulation.
2002_Sforza	Active head-cervical range of motion reduces between 15 and 45 years of age in men.
2011_Evans	The Aspen collar performs well, particularly at restricting rotation, but it is otherwise comparable to the other collars at restricting motion through functional ranges
2013_Evans	Flexion/extension and rotational movements of the cervical spine are more effectively restricted than lateral bending movements by all collars. The Aspen Vista is the least effective collar at restricting movement in all three planes through physiological ranges.
2014_Oyama	Improper sequencing of the trunk and torso activations alter upper extremity joint loading in ways that may influence injury risk.
1991_Lindbeck	The contribution of the lower extremities and the pelvis to the dynamic effect of the whole body seemed to be quit small.
1998_Klein Breteler	During reaching subjects have a systematic tendency to produce movements in a 60° tilted horizontal plane.
1998_Wang	Kinematic parameters related to the transport component of the arm and the trunk, such as peak velocity and time to peak velocity and the coordination pattern between the arm and trunk was different across conditions.
2005_Ciavarro	A protocol for functional evaluation on all planes to assess both the quality and quantity of lumbar spine movementhas been developed. Two database are created of males and females

TABLE V.—*Results of papers in spinal disorder patients.*

2006_Al-Eisa	There are objective differences in patterns of lumbar movement between asymptomatic subjects and patients with low back pain; anatomic abnormality in the pelvis is associated with altered mechanics in the lumbar spine. Asymmetry of lumbar movement may be a better indicator of functional deficit than the absolute range of movement in low back pain.
2007_Gombatto	Patterns of Lumbar Region Movement during Trunk Lateral Bending in 2 Subgroups of People with Low Back Pain are different; this may be an important factor to consider in specifying the details of the interventions for low back pain problems.
2008_Gombatto	Asymmetry in passive elastic energy of the lumbar region may be related to the low back pain problem
2015_Sanchez-Zuriaga	Reduced maximum ranges of motion and absence of erector spinae flexion-relaxation phenomenon are not useful to identify low back pain patients in the absence of acute pain.
2012_Hidalgo	The kinematic variables are valid, reliable measures and can be used clinically to diagnose chronic non-specific low back pain, manage treatment, and as quantitative outcome measures for clinical trial interventions.
2002_Bouuilland	The maximum vertical effort at the L5/S1 joint is about 1600, 1500 and 1400N for low, medium and high speed, whereas it is lower than 1300N, irrespective of the load, during free lifting. In the context of chronic low back pain rehabilitation, movement strategies used in free lifting could not be relearnt using an isokinetic machine.
2014_Bouriga	Chronic low back pain sufferers exhibit freezing-like behaviors when asked to move their trunk as fast as possible. The use of this parameter may improve the diagnosis of chronic low back pain patients and could be a key indicator for treatment progress and longterm monitoring.
2014_Duc	A wearable inertial system on cervical spine can provide angles and range of motion comparable to those obtained with optoelectronic system and relevant for the cervical assessment after treatment.
2015_Bravo	The flexion–rotation test performed passively can reveal limitations in range of motion toward the side of symptoms in individuals with cervicogenic headaches
2006_Andreoni	The new method (ZooMS) is comparable to the literature and the protocol is validated in term of intraoperator, interoperator and circadian remarking. Low back pain patient has different behavior than normals

TABLE VI.—*Results of papers in patients with other pathologies.*

2014_Wu	Different kinematic variables may partially reflect motor function before and after treatment to a limited degree in stroke patients. Although the predictive validity was modest, trunk movement may be considered a prognostic determinant of motor function after treatment. A reaching task within arm's length may be a more suitable measure of kinematic performance for describing motor function than a reaching task beyond arm's length.
2014_Massie	The greater trunk rotation during reaching represents a unique segment strategy when using the stroke-affected side
2010_Bartolo	In Parkinson disease patients significant improvements in axial posture and trunk mobility can be obtained through the 4-week rehabilitation program with a parallel improvement in clinical status.
2014_Major	The use of shoulder and trunk movements by prosthesis users as compensatory motions to execute goal-oriented tasks demonstrates the flexibility and adaptability of the motor system.
2003_Chow	The shoulder girdle movement is a key factor in determining field event performance among wheelchair athletes.
1995_Bednarczyk	There was no change in the percentage of the cycle spent in propulsion with 10 kg weight additions in either the adult group or the pediatric group of people with spinal cord injury.
2003_Sibella	There are differences in motion strategy between normal and obese subjects performing sit-to-stand movement: obese subjects rise from the chair limiting trunk flexion and moving their feet backwards from initial position; in addiction they show knee joint torque higher than hip torque.

Quite a number of papers focused on the characteristics of movement of the lumbar spine in healthy and low back pain (LBP) patients. The consistency of movements between genders [12, 21, 47, 48] and in different loading conditions was shown,[21] as were changes with age.[12, 36] Differences were found between normal and LBP patients [13, 40, 41] even if not in all situations:[19] these different patterns,[40, 49] and the asymmetry in passive elastic energy [37] may be important for treatment planning, but also for diagnostic purposes.[41]

Other papers focused on the cervical spine, whose ROM can be used to evaluate the efficacy of treatments [30] and their characteristics.[26] Active ROM reduces with age,[34, 36] and a correlation between passive ROM and cervicogenic headache was found[18]. Differences were shown between different collars in various movements.[20, 33]

The influence of the trunk on reaching has also been studied [14, 25]: in stroke patients [54] the trunk enters a unique segment strategy with the affected upper limb; improper sequencing of trunk activation may increase the risk of upper extremity joint injuries.[27] Finally movements in Parkinson,[42] spinal cord injured patients,[28, 55] prosthesis users,[38] and obese patients [50] have been studied.

Study method

The biomechanical spine models adopted are mainly three-dimensional,[12-15, 17-22, 24-27, 29-35, 37-50, 52-56] although a few studies [23, 28, 31, 36, 51] report bi-dimensional models. 2D models are typically adopted in case of flexion-extension, lateral bending, or almost planar movements: in such cases markers are often placed over the projection of spinous processes. On the contrary, when studying three-dimensional movements, 3D models are necessary.

The most utilized motion analysis systems were the *Vicon* (twelve papers),[17, 24, 26, 27, 30-32, 40, 43, 46, 54, 56] followed by the *Motion Analysis Corporation* (ten) [12, 18, 22, 37-39, 44, 45, 49, 53] and *BTS Bioengineering* (nine).[14, 15, 29, 34, 41, 42, 47, 48, 50] Optoelectronic systems presented 2 to 9 cameras: ten studies [17, 18, 20, 22, 24, 26, 29, 31, 33, 47, 48, 53] presented eight cameras and just one [30] nine.

Few studies considered the whole trunk,[12, 13, 15, 21, 22, 29, 31, 32, 36, 37, 39, 41, 43-46, 49, 53] although none of them focused on each vertebra independently; in fact, in those papers the trunk was divided into three segments. Two studies focusing on the lumbar spine evaluated all metamers with a triplet of markers.[47, 48]

Marker position

Marker numbers and location were investigated in all selected papers: only nine studies [15, 20, 22, 27, 32, 39, 43, 44, 52] included more than 20 markers on the overall body, while twenty-two studies [12, 13, 15, 17, 19-21, 23, 24, 26, 30-32, 34-36, 47, 48, 50, 53-55] located at least one marker on the spine. Among these last studies, one [32] located 30 markers on the back, two [47, 48] used 28 markers, one [43] used 20 markers on that zone, two [21, 44] 11 markers, while a number varying from 1 to 6, was considered in the others.

Not all markers were placed on the spine; some of them were positioned on the muscles close to it; indeed, only one article [21] analyzed 11 vertebrae, three examined 8,[43, 47, 48] and two articles [31, 32] marked 6.

The spinous process of the seventh cervical vertebra was the preferred spinal landmark to set a marker on; seventeen articles [15, 21, 24, 30-32, 38, 39, 41-44, 46, 50, 52, 53, 56] used this reference point, primarily because of its easy localization through palpation, but also because cervical vertebra dynamics is independent of the thoracic vertebra. Another reference point widely adopted was the spinous process of the fifth lumbar vertebra, easy to find too, used in 8 studies,[12, 13, 19, 21, 31, 32, 39, 46] while in 8 articles [12, 19, 21, 32, 41, 43, 45, 53] markers were applied to the spinous process of the 12th thoracic vertebra.

Discussion

This study has shown that the literature on trunk motion analysis today is relatively scarce. In clinical terms, results are sparse, and till now papers have focused primarily on biomechanical analysis. The only wholly representative group of papers studied low back pain patients, but the reduced number of individuals evaluated make their conclusions questionable.

In recent decades optoelectronic motion analysis has become a common tool for researchers in the assessment of the neuro-physiological and biomechanical basis of human posture and movement,[7, 10] thanks to the technical and procedural improvements that have made it possible to reduce measurement errors, and to the development of appropriate biomechanical models. Considering spinal movements, we found that different tools are available, based on similar principles. Nevertheless, only one standard protocol for possible use in clinics has been proposed so far, and exclusively for the lumbar spine.[47, 48] Marker positioning and their number, and the segment of the spine to analyze differ across the studies. A precise analysis would probably need the use of a marker for each vertebra (if not three), and possibly a comprehensive overview of the whole spine. Also an evaluation of all possible movements of the spine should be considered.[10, 47, 48] According to the reported data, some common features in marker position exist, with C7, T12 and L5 being the most used point of reference.

From a clinical perspective, the need for a global versus a partial analysis can differ according to each single case. For example, in patients complaining of pain, the painful area could be enough in most cases, even if a global approach to the sagittal alignment of the spine is becoming more and more relevant and desirable.[57, 58] In case of patients with complex spinal disorders, like scoliosis or kyphosis, a more global approach is needed.[59, 60]

Even if described decades ago [61-63] spinal functional instability remains a specific need of spinal disorders literature: even today the diagnosis of functional instability still remains clinical, and there are no specific diagnostic tests.[3] Motion analysis instruments could offer an interesting perspective in this specific diagnostic area, and this could be an important research domain.

Optoelectronic systems are considered extremely precise, but this relates to the signal acquisition. Unfortunately, the markers are not positioned directly on bones. This makes their anatomical reliability questionable. Only one study in the present review tried to address this point by comparing radiographies and optoelectronic systems.[27] The authors report that the difference between real anatomic parts and marker positions is insignificant. Actually it's hard to state that this result can be generalised to the usual clinical practice, that can include for example obese patients, but further studies would be very useful to better determine this.

Conclusions

The use of optoelectronic systems in the evaluation of spine movement is a growing research area. Nevertheless, no standard protocols have been developed so far, making its clinical application hard at present time. Future research is needed with the aim of defining a precise protocol in terms of number and position of markers along the spine and movements and tasks to be evaluated.

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