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Società Italiana di Fisioterapia

CONTENTS

EDITORIAL

About the concept of facilitation in physiotherapy

R. GATTI

San Raffaele Scientific Institute, Milan, Italy

In the last issue of the Italian Journal of Physiotherapy the editorial was dedicated to cognitive facilitations and the question on which it was based was whether it is possible to consider the cognitive facilitations as a new trend in physiotherapy.

With astonishment through some emails that I have received from young colleagues I have realized that little is known of the concept of motor performance facilitation among young physiotherapists. It was not the same for physiotherapists who, like me, already worked in the 80s.

But what does the term facilitation mean in the physiotherapy field? And is the concept or the term that has been overcome?

Since 2007 the MESH term of the Medline database reports the following definition of facilitation: "*Exercises that stretch the muscle fibers with the aim to increase muscle-tendon flexibility, improve range of motion or musculoskeletal function, and prevent injuries. There are various types of stretching techniques including active, passive (relaxed), static, dynamic (gentle), ballistic (forced), isometric, and others*".[1] That is the only definition of facilitation used in physiotherapy catalogued in the scientific literature and it is referred to the *proprioceptive neuromuscular facilitations*. More in general, I think that a facilitation of a motor performance could be defined as the application to patients of approaches based on both sensory and cognitive inputs or movements execution, aimed to improve a motor performance. The rationale of facilitations is connected to the possibility to improve the nervous control of the facilitated motor performance. With this meaningful, Herman Kabat, Maggie Knott and Dorothy Voss in the 50s years were among the beginners who described facilitation techniques. They described their method of proprioceptive neuromuscular facilitation (PNF), a rehabilitation technique based on the stimulation of the neuromuscular system in an effort to excite proprioceptors as, for example, the muscles sensory organs.[2] In the same years Berta and Karel Bobath proposed their method for rehabilitation of subjects with lesions of the central nervous system,[3] especially children or adults survived after a stroke. Even in this case the method included techniques aiming to facilitate or inhibit both movement and posture. In those years also other authors proposed motor facilitations included in the stereotyped rehabilitation methods.[4] In more recent years, together with the decreased use of stereotyped rehabilitation methods, the term facilitation of motor performance has been even more neglected in scientific literature. But its meaning is still actual. Some recent examples of facilitations presented in literature are the use of bimanual training as approach of upper arm recovery in subjects after stroke [5] (motor facilitation), the observation training for decreasing the freezing episodes in subjects with Parkinson disease [6] (cognitive facilitation), the sensory stimulation in order to enhance aspects of motor recovery following a stroke [7] (sensory facilitation), the use of auditory cues for improving the gait kinematics in subjects with different central nervous system disorders [8] (both sensory and cognitive facilitation) and many others.

So, can we conclude that the term facilitation has been overcome and its concept has not?

Only in part. There are at least two important differences between the old and the new concept of facilitations. These differences are an example of how the physiotherapy has been changing over the years.

The first one is connected to the value attributed to the techniques of motor facilitation. In the less scientific approach of some years ago each technique was the consequence of an unchanging neurophysiologic rational. The value of this technique was its coherence with the neurophysiologic model, more than its experimental demonstration. Its application was generalized in many different clinical situations, as it was the derivation of a general concept. In a more scientific approach the value of a facilitation technique is due to the strength of the experimental results that support it. Moreover, the awareness of the huge human variability does not allow to transfer this results in clinical application that have not passed the experimental filter. Consequently, facilitation as a term indicating the possibility to apply the same technique in different clinical situation has even less used.

The second difference is connected to the aim of physiotherapy. The efforts of the first authors were addressed to improve the motor impairment of subjects with central nervous system lesions by the use of facilitations of motor performance. In the rehabilitation planning, less attention was given to the improve of patients' functional autonomy than today. The "intrinsic recovery" was considered more important than the functional use of motor abilities.

Synthetically, it can be said that nowadays physiotherapy has reached the features of a scientific clinical discipline whereas the change in terminology has represented a cultural change of the discipline.

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Influence of high and low frequency anteroposterior mobilization of the talus on ankle dorsiflexion: a double-blind randomized controlled trial

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ABSTRACT

Aim. Anteroposterior mobilization of the talus performed at high frequency (*i.e.,* 1 oscillation every 1-3 seconds) demonstrated to increase ankle dorsiflexion (AD). Some authors proposed a role of the mobilization in elongating connective tissues. This study is aimed at investigating whether the time duration of the talus maintained at the limit of its posterior glide is determinant in increasing AD and the effects of low-frequency mobilization on connective tissue.

Methods. Double-blind randomized controlled trial. Thirty healthy males (age 23.16±2.15) were randomly divided into three groups: low-frequency mobilization (LFM), high-frequency mobilization (HFM) and control (CTRL). The outcome measure was the AD range of motion. LFM consisted of 5 anteroposterior oscillations maintaining the talus at the end of its posterior glide for 20 seconds. HFM consisted of 5 series of 10 anteroposterior oscillations each lasting 2 seconds. CTRL group did not receive any treatment. All the mobilizations were performed by the same physiotherapist, and all the subjects were assessed by the same blinded examiner using a digital inclinometer.

Results. Within-groups comparison found significant increase of AD in both LFM (mean increase 1.64°, CI 95% 1.19° to 2.10°; $P<0.001$) and HFM (mean increase 0.67°, CI 95% 0.33° to 1.01°; $P=0.004$) groups, while CTRL showed no differences ($P<0.468$). Between-groups comparison demonstrated LFM to have greater efficacy than HFM (mean increase difference 0.97°, CI 95% 0.36° to 1.58; $P=0.004$). A significant time by group interaction was found ($P<0.001$).

Conclusion. The time duration of the talus maintained at the end of its posterior glide seems to be determinant in increasing AD. *(It J Physiotherapy 2012;2:3-11)*

Key words. Musculoskeletal manipulations - Ankle joint - Range of motion, articular.

The anteroposterior mobilization of the talus is a common approach used in manual therapy to increase dorsiflexion range of motion (ROM). A recent systematic review provided a level B evidence for this technique in the management of acute ankle inversion sprains.[1] Moreover, previous studies investigating the forces applied during this manoeuvre demonstrated its efficacy even on healthy subjects,[2, 3] but the mechanisms through which this mobilization and in general most of the manual therapy arthrokinematic techniques work have not been fully understood yet.

Different hypotheses have been advanced to explain such effectiveness, some claiming a role in pain modulation,[4, 5] others suggesting an action in repositioning the two articulating bone, respectively.[6] In particular, the greatest effect on

ROM seems to be due to the elongation of connective tissues (CT) such as ligaments, capsula and periarticular fasciae.[7, 8]

Assuming that the dorsiflexion ROM gain largely depends on the elongation of the CT, its mechanical properties should be considered carefully. CT demonstrates viscoelasticity, a property whereby the deformation that results from a load will vary as the loading rate is changed. Therefore, CT that is loaded more quickly will behave more stiffy (will deform less) than the same tissue that is loaded at a slower rate.[8] Findings of previous studies and authors' recommendations suggest that the load should be maintained for 7 up to 60 seconds in order to achieve a plastic elongation of the CT.[7-10]

In all the trials found in the literature a high-frequency mobilization (HFM) was tested, where the technique was made up of 1 anteroposterior oscillations of the talus every 1-3 second.[2-3, 11-14] Although the effectiveness of HFM is demonstrated in ill individuals, where neurophysiological mechanisms play an important role (e.g. pain and related reflexes),[4-5] this technique does not appear to be the most effective to specifically elongate the CT. According to its viscoelastic properties, we may speculate that a low-frequency mobilization (LFM) would be more effective in elongating the CT. Therefore, since no studies have tested such hypothesis so far, the purpose of this work was to evaluate whether the time duration of the talus maintained at the limit of its posterior glide is determinant in increasing ankle dorsiflexion ROM.

Materials and methods

Study design

This study is a monocenter, double-blind, parallel-groups (3 groups), randomized controlled trial. The physiotherapist responsible for measurements was blinded to subject allocation. The physiotherapist who performed all the treatments was a 5-year experienced certified Orthopaedic Manual Therapist. A concealed allocation schedule was randomly generated following simple randomization procedures,[15] obtaining a list of thirty sequential numbers randomly assigned to one of three treatment groups:

— low-frequency mobilization group (LFM);
— high-frequency mobilization group (HFM);
— control group (CTRL), as a term of comparison to verify whether any effect on ankle dorsiflexion might be due to the measurement procedure.

The methodological quality of this study was assessed using the CONSORT standards, except for items 23 and 24.[16]

Population

A convenience sample of thirty subjects was determined for this study. Healthy male volunteers were recruited amongst a population of football players and assessed for eligibility in order to their adherence to the study. Eligible participants were sequentially given an identification number to match the concealed treatment allocation schedule. The study was conducted in August 2010 in the Physical Therapy Outpatient Clinic of the Public Health Service of the "Azienda Provinciale per i Servizi Sanitari", Trento, Italy. Females were not included in the study to avoid the influence of ligamentous laxity variations during the menstrual cycle.[17]

All subjects received verbal information addressing the study aims and procedures before participation and were only included after providing informed written consent in compliance with Italian standards.

For each volunteer, either the right or alternatively the left ankle were tested, whereas the former resulted ineligible due to exclusion criteria.

Exclusion criteria

We excluded subjects that presented one or more of the following conditions for both lower limbs: previous fracture or joint dislocation, history of lower limb surgery, history of ankle or foot injury in the last year, presence of signs or symptoms of ankle instability, ankle or foot tenderness. Moreover we excluded also subjects who were positive to any of the following clinical tests: ankle medial and lateral collateral ligament provocation, tibioperoneal syndesmosis provocation, ankle anterior drawer test; evidence of generalized joint laxity (cut-off: Beighton and Horan Joint Mobility Index [18] Score ≥4).

Outcomes

The only outcome in this study was the ROM as a measure of ankle dorsiflexion. Weight-bearing dorsiflexion has been demonstrated to have excellent inter- and intra-rater reliability, when measured with an analogue inclinometer.[19] Aiming to high reliability, we used a digital inclinometer (Mini-Pro Digital Protractor, Level Developments LTD, Surrey, UK – range 360°, resolution 0.1°).[20]

Procedures

Participants stood with the test foot's second toe, the midline of the heel and the knee maintained in the same plane. They were told to bear their weight on the tested ankle and were allowed to lean the contralateral foot backward and the hands on a table placed ahead in order to easily maintain balance. Then, participants slowly lunged forward into talocrural dorsiflexion and knee slight flexion until no further movement was possible without lifting the heel from the ground. This represented the end of dorsiflexion range, which was therefore measured by placing the digital inclinometer on the midpoint of the anterior border of the tibia (Figure 1), that was previously marked with a felt-tip pen. Cure was taken to ensure that the inclinometer was not positioned over the tibialis anterior muscle belly. The examiner ensured maintenance of heel contact and lower limb alignment via verbal instructions and manual contact with the calcaneum. The position of each subject was carefully recorded by the examiner in order to be precisely reproduced at post-treatment measurement. This procedure was found to be more sensitive in detecting treatment effects than an angular weight-bearing measure and a non-weight-bearing measure.[13]

For the seek of precision, each subject underwent the measurement procedure five consecutive times immediately before (T0) and after (T1) being treated. The arithmetic mean of each series of five measures was calculated and taken as the true value of ankle dorsiflexion.

Figure 1.—Measurement of dorsiflexion ROM. A) Digital inclinometer; B) midpoint of the tibia; C) dorsiflexion angle.

Intervention

For both LFM and HFM groups the mobilization was done with the patient lying on the examination table supine and relaxed, with the ankle positioned just outside the edge, and with a small pillow underneath the knee to keep it slightly bent and reduce the passive resistance of gastrocnemius muscle. The physiotherapist performed a grade III joint mobilization with the ankle in neutral position, holding the interspace between the thumb and the index finger over the talus and wrapping the tarsus with the other fingers (Figure 2). Grade III mobilization consists of oscillatory movements performed after the resistance first felt by the clinician and until the point of maximal resistance that determines the end range of accessory motion. Grade III mobilizations bring the periarticular CTs to their full length, thus promoting viscoelastic adaptation.[8, 10, 21]

Subjects randomized to the LFM group were treated with a low-frequency anteroposterior mobilization of the talus as follows:

Figure 2.—Anteroposterior mobilization of the talus.

— 5 grade III perpendicular tractions, lasting 5 seconds each, in order to permit periarticular tissues adaptation;

— 2 minutes of experimental treatment, during which 5 grade III anteroposterior mobilizations were performed, maintaining the talus at the end of its posterior glide for 20 seconds each oscillation, with 5 seconds interval between each one.

Subjects assigned to the HFM group were administered a high-frequency anteroposterior mobilization of the talus:

— as for LFM group, 5 grade III perpendicular tractions, lasting 5 seconds each;

— 2 minutes of experimental treatment, during which 5 series of grade III anteroposterior

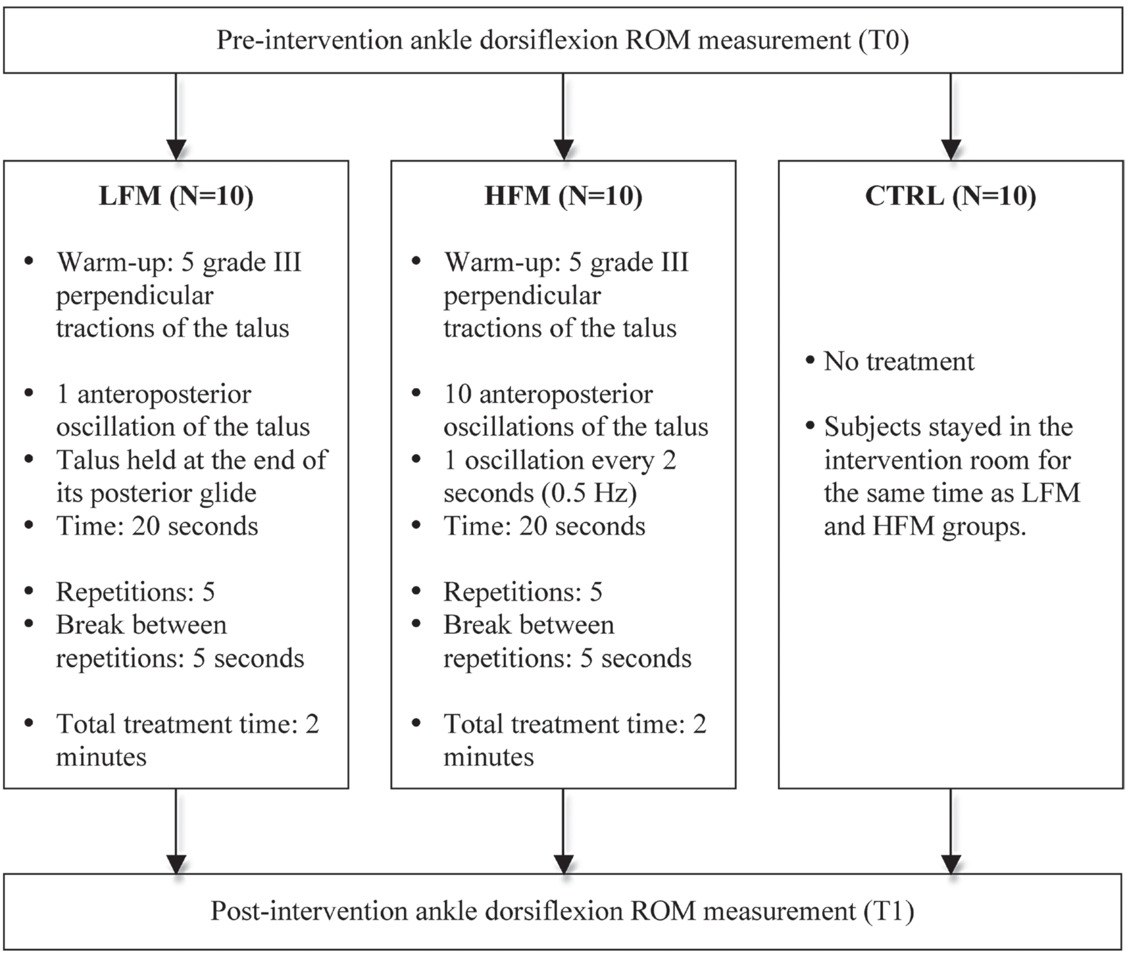

Figure 3.—Schematic representation of the administered interventions.

Table I.—*Sample characteristics (mean ± standard deviation).*

	LFM (N.=10)	HFM (N.=10)	CTRL (N.=10)	P value
Age, yr	22.81±1.85	23.62±1.98	23.04±2.68	0.698[a]
Height, m	1.78±0.06	1.78±0.07	1.79±0.05	0.811[a]
Weight, kg	73.60±5.30	72.20±5.57	74.40±3.78	0.608[a]
ROM T0, degrees	45.46±4.49	45.38±3.30	45.15±5.26	0.987[a]

[a] One-way ANOVA

Table II.—*Within- and between-groups comparisons of pre- and postintervention dorsiflexion changes.*

	LFM		HFM		CTRL		P Value (Time Factor)	P Value (Between Groups)	P Value (Time-by-Group Interaction)
	T0	T1	T0	T1	T0	T1			
Dorsiflexion degrees	45.46±4.49[a]	47.10±3.98[a]	45.38±3.30[a]	46.05±3.27[a]	45.15±5.26[a]	45.09±5.28[a]	< 0.001	0.835	< 0.001

[a]Data are mean±SD.
T0: preintervention; T1: postintervention; LFM: low frequency mobilization; HFM: high frequency mobilization; CTRL: control group

mobilization of the talus were performed at a frequency of 0.5 Hz, that means 10 oscillations for each series, with a 5 seconds interval between each one.

CTRL group subjects did not receive any treatment between the two sets of measurements. A schematic representation of the administered interventions is reported in Figure 3.

Statistical analysis

The five measurements on each subject at T0 and T1 were collected and filed using an Excel 12.0 (Microsoft Corp., Redmond, USA) spreadsheet. Then the means of measurements collected before and after the treatment in each group, the differences occurred in each subject due to the intervention and the mean of all variations for each group were calculated. The accuracy of the dorsiflexion measurement procedure was calculated as the absolute and percentage error of each series of 5 readings. Continuous data were expressed as mean with the relative Confidence Interval (CI).

Baseline characteristics of the sample were initially tested with ANOVA (Table I) to evaluate the between-groups homogeneity.

Data were then analysed using a 2x3 ANOVA for repeated measures with one within-subjects factor (time of assessment: T0 and T1) and one between-subjects factor (group: LFM, HFM and CTRL, Table II). Bonferroni test was used as post hoc analysis in case of significant time x group interaction. Statistical significance was set at P=0.05.

Statistical analysis was performed using MedCalc for Windows, version 11.6.1 (MedCalc Software, Mariakerke, Belgium).

Results

Participant flow is reported in Figure 4.[16] Sample features are shown in table I. In the last column to the right are shown the P values obtained performing an ANOVA on subjects' demographic and anthropometric characteristics. The values obtained allow us to assert that the three samples (LFM, HFM and CTRL) are homogeneous for all considered parameters.

The 2x3 ANOVA for repeated measures demonstrated significant increase of ROM in the LFM (mean increase 1.64°, CI 95% 1.19° to 2.10°; P<0.001) and HFM (mean increase 0.67°, CI 95% 0.33° to 1.01; P=0.004) groups while the CTRL group reported no statistically significant changes. A significant time by group interaction was found (P<0.001, Table II).

The *post hoc* analysis of the two experimental interventions showed a higher statistically significant effect in the LFM group (mean increase difference 0.97°, CI 95% 0.36° to 1.58°; P=0.004, Figure 5).

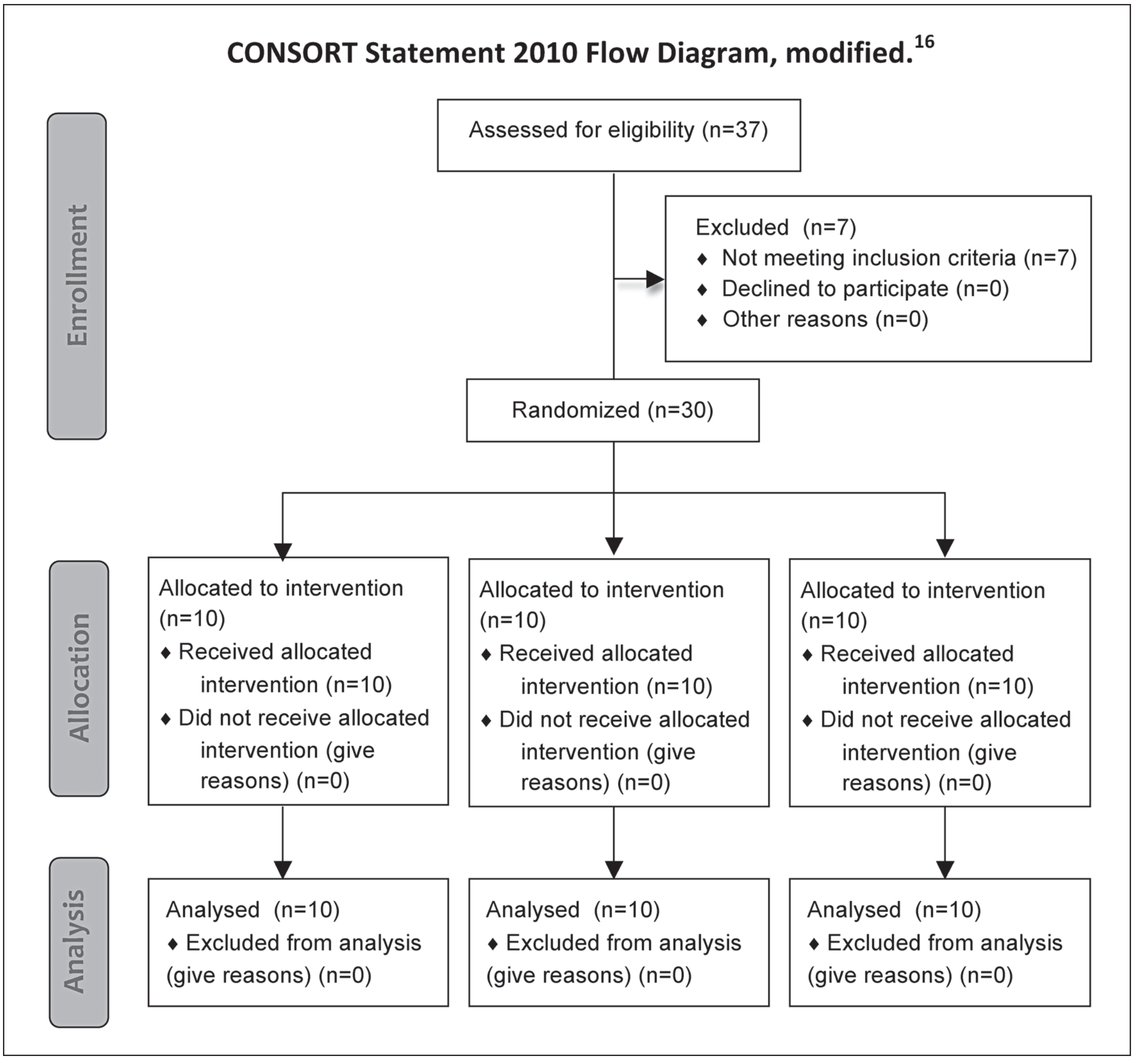

Figure 4.—CONSORT Statement 2010 Flow Diagram of the study, modified.[16]

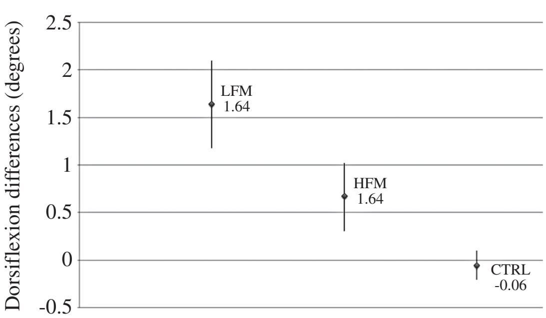

Figure 5.—Comparison between averages variations in degrees of ankle dorsiflexion (with corresponding CI=95%) obtained in three groups (LFM, HFM and CTRL) following the different treatments employed.

The absolute and percentage errors calculated on each series consisting of 5 consecutive measurements reported a maximum value of 0.22° and 0.53%.

Discussion

Similarly to the findings of previous studies,[11-14] and particularly those carried out on healthy subjects by Venturini *et al.*[2] and De Souza *et al.*,[3] our work shows considerable improvement of ankle dorsiflexion ROM after the HFM technique, made up of 5 series of 10 oscillations each lasting 2 seconds. Nevertheless, the main finding of the present study is the greater ROM improvement of the group that was treated with the LFM technique, where the anteroposterior glide of the talus was performed with 5 oscillations of 20 seconds each.

Although we recognise that the amount of ankle dorsiflexion increase in the LFM group is quite small in absolute terms, we wish to point out that this improvement has been obtained after a treatment lasting 2 minutes only. Our results should therefore be considered as purely indicative, whereas applying the same technique in a clinical environment for a longer time might lead to a different, allegedly greater, increment of ROM.

At our knowledge, this is the first study about the efficacy on increasing ROM of two temporal variations of the same mobilization technique. Our primary purpose was, in fact, to evaluate whether a LFM technique that implies to maintain the talus at the end of its posterior glide for a longer time might be more effective than the already known and tested HFM. The hypothesis is based on the assumption that this variation might better act on CT elongation.[7-8] Thus, in order to rule out any other potential condition that might influence the effectiveness of this technique (such as pain),[4, 5] this study was carried out on healthy subjects, recruited after a rigid exclusion criteria selection. Furthermore, global treatment time was the same in both LFM and HFM groups, and the CTRL group verified that the measurement procedure had no effect on dorsiflexion ROM, as it may be expected since it involved stretching of the plantar flexor muscles. For these very important reasons, we may speculate that the greater improvement found in LFM group is the effect of having maintained the talus at the end of its posterior glide for a longer time. In addition, we may assume that the improvement happened in the HFM group also occurred in the LFM group as well, as a result of a warming up action and of a first elongation of the tissues within the toe region, while the remaining greater improvement of the LFM group is the consequence of a plastic CT elongation. Maintaining the talus at the end of its arthrokinematic ROM tightens all those CT structures that limit its posterior glide.[3, 10] These are viscoelastic structures and for this reason require time to adapt and, eventually, elongate.[8, 9] If the stress is held for enough time, the talus can slide further posteriorly, hence allowing for wider dorsiflexion.

It may be argued that LFM intervention should be regarded as capsular stretch instead of mobilization. While we may agree on this assertion, we want to point out that the aim of this study was not that of labelling the different types of intervention administered. Independently from its classification, the LFM seemed to be more effective in increasing dorsiflexion ROM than the HFM, most likely through a specific action on the CT.

Furthermore we are aware that other treatments have been demonstrated to increase ankle dorsiflexion (*e.g.*, calf muscle stretching),[22] but we are not able to state whether the LFM technique, as conceived in this study, is superior or not, as the only way to find it out would be a trial that directly compares these interventions. Moreover, as it is likely that these interventions work on different structures (*i.e.*, muscular versus articular) and therefore involve different mechanisms of action, in our opinion it would be important to understand the specific benefits and the best application modalities of each separate technique.

It is with similar objectives that this trial has been designed, in order to provide significant foundations to effectively act in restoring or increasing ankle dorsiflexion ROM through a specific action on CT. In fact, in presence of a painful ankle in the acute phase after a sprain, anteroposterior HFM of the talus has been shown to be effective in decreasing pain and increasing ROM.[14] According to the recent model proposed by Bialosky *et al.*,[5] it is likely that some neurophysiological mechanisms intervene in this context allowing a greater dorsiflexion, even if it is unclear whether this improvement is consequence of pain decrease or of the mobilization itself. On the other hand, the results of this study are consistent with the importance of considering the biomechanical properties of CT structures,[9] and confirm the recommendations of Kaltenborn,[10] Maitland[21] and Threlkeld;[8] in particular the former suggests to sustain a stretch mobilization for a minimum of 7 seconds, up to a minute or longer to produce a better elongation. Thus, a LFM technique is likely to be useful in a later stage of the management of the same ankle sprain mentioned before, once that the patient no longer experiences pain and CT is in the remodelling phase of healing.

Study limitation

This study has some limitations. We enrolled a small number of subjects and did not provide any kind of follow-up measurement to verify whether the dorsiflexion gain could be maintained longer after treatment. It would have also been interesting to provide a study design that allowed the collection of all the information necessary to draw a time versus ROM curve, in order to understand how long it takes to achieve the greatest available ROM increase, that clinically speaking means after how long the mobilization effect should be considered over.

Conclusions

The results of this study suggest that a low-frequency mobilization, where the talus is maintained at the end of its posterior glide, could be more effective than the high-frequency variation in increasing ankle dorsiflexion ROM in healthy subjects, exerting a specific action on CT elongation.

This study provides basic principles to address rehabilitative goals through the application of a more specific and better known manual therapy technique. According to the patient's conditions the physiotherapist will decide which technique of anteroposterior mobilization of the talus to apply, relatively to the ROM insufficiency being either the sequela of pain and inflammation or of CT shortening.

Future studies are needed to confirm these findings also in patients with subacute or chronic ankle sprains and provide stronger evidence on the mechanisms involved. Where possible, we suggest to classify participants into sub-groups, in order to investigate which are the clinical prediction rules that assure the best outcome in the management of ankle dorsiflexion limitation and to contribute to the development of a more and more specific and effective manual therapy science.

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Inter-rater reliability of procedures measuring the passive range of motion of lower extremity joints in healthy and symptomatic subjects. A systematic review

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ABSTRACT

Aim. In daily practice, clinicians base their treatment decision-making on the results of physical examination findings. While passive joint tests for the lower extremity joints are commonly employed during the evaluation of musculoskeletal disorders, evidences regarding inter-rater reliability of these PROM tests are sparse.
The aim of this study is to summarise evidence regarding the inter-rater reliability of PROM measurements of the major joints of lower extremity.

Methods. MEDLINE, CINAHL, EMBASE, PEDro, SCOPUS, and the Cochrane Library were searched from inception to October 2010. All publications reporting inter-rater reliability of PROM measurements in individuals with and without lower extremity disorders were included. The methodological quality was assessed using the QAREL tool. Data were analysed by examining point estimate values (ICC, k) along with estimate of precision (95%CI, SEM, LoA).

Results. Twenty-two studies were included of which 14 provided weak evidence that inter-rater reliability of osteokinematic motion is high (ICC>0.75) among the major joints of lower extremity. In contrast, the scarceness of studies examining the reliability of arthrokinematic tests did not provide definitive results. The overall methodological quality was poor, therefore the results of the studies were affected by biased internal and external validity. Bias affecting the result of the review are underlined.

Conclusion. The majority of the retrieved studies regarded the reliability of osteokinematic motion. Examination findings specific to inter-rater application obtained from goniometer or inclinometer should be implemented in clinical practice with caution, because of the poor methodological quality of the studies. Recommendations for future research are provided. *(It J Physiotherapy 2012;2:12-31)*

Key words: Lower extremity - Range of motion, articular - Reproducibility of results.

In the musculoskeletal field, research affords a useful contribution to the rationale of evaluation and treatment strategy, which are both dependent on the capacity of clinicians to perform valid diagnostic tests.[1, 2] Usually, accuracy and reliability are the main characteristics examined of diagnostic procedures. Diagnostic accuracy refers to the amount of agreement between the results from the index test and those from the reference standard.[3] However, reliability is traditionally considered to be the first step on the development of diagnostic tests [4] because it may affect accuracy diversely.[5] Intra-rater reliability is an useful tool to measure the treatment progression of a single patient. It indicates the extent to which the same results are obtained by a single rater on repeated administrations of the same measure when no change in status has occurred.[6]

For research purpose, however, a measurement needs to be reliable among more than one operator, in order to improve the generalizability of the results.[7] Diagnostic reliability refers to the agreement between two or more observations of the same entity.[8] Along with agreement, inter-rater reliability is a component of reproducibility and it is influenced by the relative measurement error, *e.g.*, the variation among patients as measured by different raters in relation to the total variance of the measures.[6]

Passive joint tests are commonly employed by clinicians during the evaluation of dysfunction of lower extremity. Passive Range of Motion (PROM) can be described in terms of osteokinematic and arthrokinematic component.[9] Osteokinematic motion describes the movement of a bone around an axis; arthrokinematic motion describes the relative motion between joint surfaces.[10] In order to guide the treatment decision-making with physical examination findings, clinicians mainly use devices such as goniometer and inclinometer to evaluate the osteokinematic component of movement [11] while performing manual tests to assess joint's arthrokinematic characteristic (*e.g.*, joint play, end feel).[12] In daily practice, such procedures are directed towards the identification of joint dysfunctions beneath muscoloskeletal disorders.

The inter-rater reliability of arthrokinematic PROM of spine and sacro-iliac joint has been found to be low by several reviews.[6, 13-18] A review on the PROM of upper extremity [19] reported that osteokinematic measurements had higher inter-rater reliability than the estimate of the arthrokinematic component. Overall, the methodological quality of the studies included in the aforementioned reviews was poor.[18, 19] Considering the lower extremity, Van Trijffel *et al.*[20] systematically reviewed the whole lower limb, concluding that the overall inter-rater reliability for the osteokinematic motion measurements was considerably less than in the upper extremity joints. Piriyaprasarth and Morris [21] focused their work on the knee, finding the Intraclass Correlation Coefficients (ICC) of osteokinematic PROM of the knee ranging from 0.43 to 0.99.

Consistent with the Cochrane Collaboration,[22] the purpose of this systematic review was to update the findings of studies about the inter-rater reliability of PROM measurements of the hip, knee, patello-femoral, ankle and subtalar joints.

Materials and methods

Protocol and eligibility criteria

A research protocol was developed before the beginning of the review process.[22]

To be considered for review, the study required a inter-rater design with abstract available written in english, french or italian language; the recruitment of healthy subjects or patients with musculoskeletal disorders; the measurement of the osteokinematic or arthrokinematic component of the joints of lower extremity (hip, knee, patello-femoral, ankle, subtalar) taken with goniometer, inclinometer, or manual tests; and the use of reliability statistic (ICC, k or similar statistic).

Studies were not eligible when anecdotal, spec-

Table I.—*QAREL checklist.*

Item criteria
1. Was the test evaluated in a sample of subjects who were representative of those to whom the authors intended the results to be applied? *
2. Was the test performed by raters who were representative of those to whom the authors intended the results to be applied? *
3. Were raters blinded to the findings of other raters during the study? †
4. Were raters blinded to their own prior findings of the test under evaluation? †
5. Were raters blinded to the subjects' disease status or the results of the accepted reference standard for the target disorder (or variable) being evaluated? †
6. Were raters blinded to clinical information that was not intended to form part of the study design or testing procedure?
7. Were raters blinded to additional cues that are not part of the test? †
8. Was the order of examination varied? †
9. Was the stability (or theoretical stability) of the variable being measured taken into account when determining the suitability of the time interval among repeated measures? †
10. Was the test applied correctly and interpreted appropriately? *
11. Were appropriate statistical measures of agreement used? ‡

QAREL: Quality appraisal of reliability studies; *: external validity; †: internal validity; ‡: statistical methods.

TABLE II.—*Characteristics of included studies on inter-examiner reliability of passive range of motion measurements of lower extremity. (First part, references 40-50).*

Study (year)	Number, Age (years), Sex, Conditions	Number, Profession, Training, Expertise (years)	Outcome, Setting	Position
Aalto *et al.* (2005)[40]	N.=20, Age=18-45, M/F=8/12, Healthy	N.=2 PT Training=Y Expertise=?	OST, PROM (Degree), University Hospital	SUP
				SIT
				SUP
Bennell *et al.* (1998) [41]	N.=13, Age=18.8±2 M/F=8/5 Healthy	N.=4 PT (N.=3), ST (N.=1) Training=Y Expertise=0-19	OST, PROM (Degree), Setting=?	WB
Clapis *et al.* (2008) [42]	N.=42, Age=18-36, M/F=16/26, Healthy	N° = 2, PT, Training = Y, Expertise = 16-21	OST, PROM (Degree) Setting=?	SUP
Dennis *et al.* (2008) [43]	N.=10 Age=? M/F=? Healthy	N.=2 PT Training=Y Expertise=?	OST, PROM (Degree) High Performance Australian Cricket	SUP
Diamond et al. (1988)[44]	N° = 31, Age = 34-77, M/F = 17/14, Diabetes mellitus	N° = 2, PT, Training = Y, Expertise =?	OST, PROM (Degree), Setting =?	PRO
Elveru et al. (1988)[45]	N° = 37, Age = 35.9 ± 15.6, M/F =?, Orthopaedic dysfunction	N° = 14, PT, Training = Y, Expertise = 6.5 ± 3.0	OST, PROM (Degree), Physical Therapy Department	?
Erichsen et al. (2006)[46]	N° = 27, Age = 20-45, M/F = 11/16, Healthy (N° = 12), Ankle sprain (N° = 15)	N° = 2, PT, Training = Y, Expertise =?	ART, PROM (restricted/normal), Setting =?	SUP
Fritz et al. (1998)[47]	N° = 152, Age = 40.0 ± 15.9, M/F =?, Arthroscopic surgery, ACL reconstruction, PFPS, OA, internal derangement, post surgical, non surgical	N° = 33, PT, Training = N, Expertise =?	OST, PROM (Degree), Physical Therapy Department	SUP (Hip 0°)
Gabbe et al. (2004)[48]	N° = 15, Age = 27-36, M/F = 6/9, Healthy	N° = 2, PT (N° = 1), RSC (N° = 1), Training = Y, Expertise = 0-7	OST, PROM (Degree), Setting =?	SUP
Gogia et al. (1987)[49]	N° = 30, Age = 20-60, M/F = 17/13, Healthy	N° = 2, PT, Training = Y, Expertise =?	OST, PROM (Degree), Setting =?	RS
Hayes and Petersen (2001)[50]	N° = 40, Age = 31.8 ± 9.5, M/F = 18/22, Unilateral Knee Pain	N° = 2, PT, Training = Y, Expertise = 18-20	ART, End feel, Setting =?	SUP

(Continues on next page)

Table II.—*(Second part, references 40-50).*

Method	Joint	Movement	Inter-rater reliability (95% CI)			
			ICC	k	SEM	LOA
Masked 2-arm Goniometer	Hip	Flexion (MSLR)	0.929 *			
			0.942 †			
			0.903 ‡			
			0.936 §			
		Extension (MTT)	0.740 *			
			0.827 †			
			0.877 ‡			
			0.860 §			
Masked 2-arm Goniometer	Hip	Internal Rotation	0.748 *			
			0.749 †			
			0.847 ‡			
			0.905 §			
Masked 2-arm Goniometer	Knee	Flexion (MTT)	0.497 *			
			0.602 †			
			0.615 ‡			
			0.617 §			
Inclinometer	Ankle	Dorsiflexion (WB)	0.97 (0.90-0.99)		1.4	
Standard Goniometer	Hip	Extension (MTT)	0.92		1.9	
Gravity Inclinometer	Hip	Extension (MTT)	0.89		2.1	
2-arm Standard Goniometer	Hip	Extension (MTT)	0.27 (0-0.76)		6.6	
		Abduction (MTT)	0.29 (0-0.71)		2.5	
Standard Plastic Goniometer	Ankle	Dorsiflexion	0.87 II		2 II	
			0.74 ¶		3 ¶	
	Sub Talar	Inversion	0.89 II		3 II	
			0.86 ¶		3 ¶	
		Eversion	0.78 II		4 II	
			0.79 ¶		2 ¶	
Small Plastic Goniometer	Ankle	Dorsiflexion	0			
		Plantarflexion	0.74			
		Inversion (NWB)	0.30			
		Eversion (NWB)	0.22			
Manual Test	Ankle	Dorsiflexion		NC		
		Plantarflexion		0.20 (-0.20 – 0.63)		
		Total joint play (UTT)		0.48 (0.20-0.76)		
	Sub Talar	Total joint play (LTT)		0.37 (-0.03 – 0.77)		
Standard Goniometer	Knee	Flexion	0.80 #		3 #	
			0.97 **		3.9 **	
		Extension	0.72 #		1.7 #	
			0.94 **		1.7 **	
Modified Goniometer	Hip	Extension (MTT)	0.92 (0.79 – 0.97)		4	
		Flexion (PSLR)	0.93 (0.80 – 0.97)		4	
Inclinometer	Knee	Flexion (MTT)	0.90 (0.72 – 0.96)		3	
Large Standard Plastic Goniometer	Knee	Flexion Ranging From 0° to 120°	0.99			
Manual Test	Knee	Flexion		-0.01 (-0.36 – 0.35)		
		Extension		0.43 (-0.06 – 0.92)		

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Table II.—*Characteristics of included studies on inter-examiner reliability of passive range of motion measurements of lower extremity. (First part, references 51-61).*

Study (year)	Number, Age (years), sex, conditions	Number, Profession, Training, Expertise (years)	Outcome, Setting	Position
Jonson and Gross (1997)[51]	N° = 63, Age = 18-30, M/F = 57/6, Healthy	N° = 2, PT, Training = Y, Expertise = 12-16	OST, PROM (Degree), Setting =?	PRO
Munteanu et al. (2009)[52]	N° = 30, Age = 19-42, M/F = 10/2, Healthy	N° = 4, ST (N° = 1), PD (N° = 3) Training = Y, Expertise = 0-20	OST, PROM (Degree), Setting =?	WB
Murray et al. (2009)[53]	N° = 64, Age = 18-70, M/F = 43/21, Healthy (N° = 36), LBP (N° = 28)	N° = 2, Profession =?, Training =?, Expertise =?	OST, PROM (Degree), 2 Golf Club	PRO
Peeler and Anderson (2007)[54]	N° = 54, Age = 18-45, M/F = 19/38, Healthy	N° = 3, PT, Training = Y, Expertise = more 6	OST, PROM (Degree), University rehabilitation exercise laboratory	SUP (Hip 0°)
Peeler and Anderson (2008)55	N° = 57, Age = 18-45, M/F = ?, Healthy	N° = 3, PT, Training = ?, Expertise = 6-22	OST, PROM (Degree), University rehabilitation exercise laboratory	SUP (Hip 0°)
Piva et al. (2006)56	N° = 30, Age = 29.1 ± 8.4, M/F = 13/17, PFPS	N° = 4, PT, Training = Y, Expertise = 2-10	OST, PROM (Degree), Hospital ART, PROM (Tight/ Normal) Hospital	SUP PRO PRO SUP
Rotsthein et al. (1983)57	N° = 24, Age = ?, M/F = ?, Knee disorder	N° = 12, PT, Training = N, Expertise = 1-4	OST, PROM (Degree), Hospital	PS
Russell et al. (2003)[58]	N° = 1, Age = 24, M/F = 0/1, Healthy	N° = 2, PT, Training = Y, Expertise =?	OST, PROM (Degree), University	SUP
Smith-Oricchio and Harris (1990)[59]	N° = 20, Age = 18-53, M/F =?, Ankle pathology	N° = 3, PT, Training = N, Expertise = 1-2	OST, PROM (Degree), Physical Therapy Department	PRO WB
Sweitzer et al. (2010)[60]	N° = 82, Age = 49, M/F = 43/39, PFPS	N° = 2, PH, Training = Y, Expertise =?	ART, PROM (Restricted/ Normal), Sport Medicine Practice	SUP
Theiler et al. (1996)[61]	N° = 49, Age = 65 ± 14, M/F = 22/27, OA hip/knee	N° = 3, REUM, Training = Y, Expertise =? e	OST, PROM (Degree), Hospital Department of Rheumatology	SUP, LAT SUP

?: unknown; ACL: anterior cruciate ligament; ART: arthokinematic; HL: hamstrings length; ICC: intraclass correlation coefficient; K: cohen's kappa; LAT: lateral; LOA: limits of agreement; LBP: low back pain; LTT: lower twist test, M/F: male/female ratio; MSLR: modified straight leg raise; MTT: modified thomas test; N: no; N°: number; NC: not calculated; NWB: not weight-bearing; OA: osteoarthritis; OST: osteokinematic; PD: podiatrist; PFL: plantar flexors length; PFPS: patello femoral pain syndrome; PRO: Prone; PROM: passive range of motion; PS: physiotherapist's personal

(Continues on next page)

Table II.—*(Second part, references 51-61).*

Method	Joint	Movement	Inter-rater reliability (95% CI)			
			ICC	k	SEM	LOA
Standard Plastic Goniometer	Ankle	Dorsiflexion	0.65			
Digital Inclinometer	Ankle	Dorsiflexion (Knee Extended)	0.95 (0.91 – 0.97)		1.77	-5.7 – 5.7
Clinical Inclinometer	Hip	Internal Rotation	0.94 (0.869 – 0.974)			
		External Rotation	0.83 (0.641 – 0.921)			
Universal Goniometer	Hip	Extension (MTT)	0.60		1	
Universal Goniometer	Knee	Flexion (MTT)	0.50 (0.40 – 0.60)			
Gravity Goniometer	Hip	Flexion (HL)	0.92 (0.82 - 0.96)		4.3	
Gravity Goniometer	Knee	Flexion (QL)	0.91 (0.80 - 0.96)		3.8	
Gravity Goniometer	Ankle	Dorsiflexion (PFL), Gastrocnemius	0.92 (0.83 - 0.96)		1.6	
		Dorsiflexion (PFL), Soleus	0.86 (0.71 - 0.94)		2.2	
Manual test	Patello Femoral	Medio-lateral Translation (TLRS)	0.71 (0.57 - 0.86)			
Large Metal Goniometer	Knee	Flexion	0.99			
		Extension	0.71			
Large Plastic Goniometer	Knee	Flexion	0.92			
		Extension	0.64			
Small Plastic Goniometer	Knee	Flexion	0.91			
		Extension	0.68			
Internet Based Goniometer	Knee	Flexion	1.00			
		Extension	0.96			
Small Plastic Goniometer	Sub talar	Inversion (NWB)	0.42			
		Eversion (NWB)	0.25			
Small Plastic Goniometer	Sub talar	Eversion (WB), Bilateral Stance	0.91			
		Eversion (WB), Unilateral Stance	0.75			
Manual Test	Patello Femoral	Superior – Inferior Translation		0.59 (0.42 – 0.72)		
		Medio – Lateral Translation		0.55 (-0.37 – 0.69)		
Universal Goniometer	Hip	Flexion		0.14 II 0.53 ¶		
		Extension		0.29 II 0.32 ¶		
		Abduction		0.40 II 0.47 ¶		
		Adduction		0.28 II 0.16 ¶		
		Internal Rotation		0.55 II 0.66 ¶		
		External Rotation		0.54 II 0.27 ¶		
Universal Goniometer	Knee	Flexion		0.24 II 0.21 ¶		
		Extension		0.42 II 0.19 ¶		

solution; PSLR: passive straight leg raise; PT: physical therapist; QL: quadriceps length; REUM: rheumatologist; RS: right side; RSC: postgraduate research student with experience in musculoskeletal screening; SEM: standard error of measurement; SIT: sitting; ST: student; SUP: supine; TLRS: tightness of the lateral retinacular structures; UTT: upper twist test; WB: weight-bearing, Y: yes.
*Interday left; † Interday right; ‡ Intraday left; § Intraday right; II Left; ¶ Right; # Uninvolved Side; ** Invoved Side

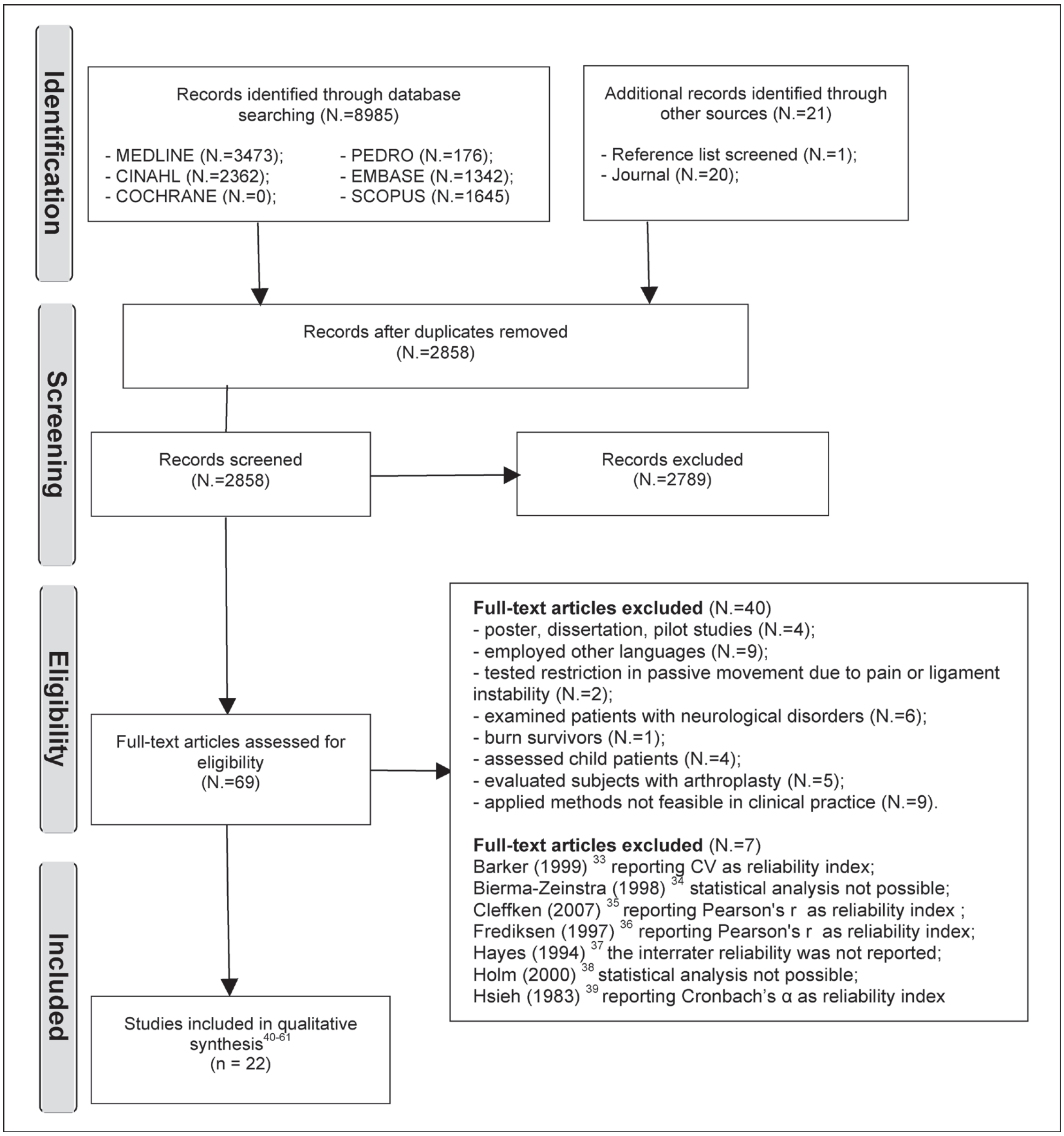

Figure 1.—Flow chart.

ulative or editorial employing different languages, when procedures tested restriction in passive movement due to ligament instability, when participants had neurological disorders. Other non-eligible studies were about joint replacement with arthroplasty, burn survivors, pediatric patients, or when raters applied methods not feasible in clinical practice, considering instruments, costs and amount of training required. To ensure a standardised and comprehensive framework for reporting, the review is written in line with the Preferred Reporting Items for Systematic Reviews and Meta-analyses: PRISMA.[23]

Information sources, search and study selection

An electronic search was developed for original research articles using the following computerised databases from inception to October 2010: MEDLINE, CINAHL, EMBASE, PEDro, SCOPUS, and the Cochrane Library. Subject headings (MeSH), text words and journals screened are reported in Appendix A and Appendix B. The specific search strategy is available upon request. To ensure completeness of the literature search, the reference list of all potentially eligible articles were hand-searched. Two reviewers screened titles and abstracts of identified records for inclusion in eligibility process. If the abstract was relevant, the full article was retrieved and assessed for eligibility.

Data collection process and data items

Data were extracted on participants (number, age, gender, clinical characteristics, study setting), raters (number, profession, training, expertise), assessment procedure (outcome reported, subject position, method of measurement, joint, movement performed, method of blinding, method of randomisation) and inter-rater reliability (point estimates and estimates of precision).

Risk of bias within and across studies

The assessment of risk of bias within studies was performed using the Quality Appraisal of Reliability Studies (QAREL) checklist. This is a recently developed tool for studies of diagnostic reliability [5] and it has not been validated yet. Criteria were rated as *yes, no, not applicable or unknown* when insufficient information was provided. Scoring a criterion as *no* or *unknown* was considered equal to the extent of critical appraisal, indicating high risk of bias. It has been recommended that each item on a quality appraisal tool should be considered separately for its impact on the quality of study.[22, 24, 25] Therefore, studies were not excluded from statistical analysis on the basis of their QAREL score. Thereby, each item of the QAREL checklist was considered singularly to assess the risk of bias affecting both internal and external validity. The former is represented by items 1, 2 and 10. The latter is represented by items 3 to 9. Item 11 refers to the statistical analysis (Table I). In order to gain cumulative evidence the results of the studies with acceptable reliability were weighted considering the presence of risk of bias in each study. A funnel plot was planned to evaluate the presence of publication bias.

Assessment of Inter-reviewer agreement

The inter-reviewer agreements were calculated on the screening (AP, GR), eligibility (AP, GR), data extraction (AP, GR), and methodological assessment processes (GR, TG). The disagreements were resolved by consensus. If discrepancies persisted after discussion, a third reviewer (MT) made the final decision. The agreement rate prior to amending any such discrepancies was assessed using the weighted kappa (k_w) statistic [26] with linear weights.[27] Kappa values were analysed using the labels assigned by Landis and Koch,[28] which are described below.

Data synthesis and analysis

The quantitative analysis of estimates of inter-rater reliability was performed by examining ICC and Cohen's Kappa [*k*]. The cut-off values of these reliability scores are advocated by many authors with different thresholds for each coefficient. In this article, ICC's above 0.75 were considered acceptable.[29] Regarding *k*, the corresponding classification labels typically assigned by Landis and Koch [28] are: poor (<0.00); slight (0.00-0.20); fair (0.21-0.40); moderate (0.41-0.60); substantial (0.61-0.80) and almost perfect reliability (0.81-1.00). We considered *k* acceptable when labelled substantial or almost perfect.[30]

In order to assess the estimate of precision of the aforementioned measures, we considered the width of confidence limit (95% CI). Further, Standard Error of Measurement (SEM) [31] and Limits of Agreement (LoA) [32] were considered to represent the degree to which repeated measurements vary for individuals. Since these were expressed in the actual units of measurement, their values were rated more acceptable when closer to zero.

Results

Study selection and characteristic

A total of 2858 articles were identified, after the removal of duplicates. During the screening process, 2789 studies were discarded on the basis of their titles and abstracts. There were 13 disagreements on screening of studies, solved with consensus, with an inter-reviewer agreement of 99.5% and an almost perfect inter-reviewer reliability (k_w =0.91, 95% CI:0.88-0.95). Therefore, 69 articles were selected as potentially eligible. Following the eligibility process, 40 articles were discarded on the basis of exclusion criteria and seven because the statistical analysis was neither possible nor involved appropriate coefficients.[33-39] In total, 22 studies [40-61] fulfilled the inclusion criteria (Figure 1). There were no disagreements between reviewer on eligibility and data extraction processes. The included studies are summarised in Table II. A meta-analysis of estimates of reliability was not conducted because of clinical and methodological heterogeneity among studies.

Risk of bias within studies

The methodological assessment is presented in Table III. Overall, all the studies were seriously harmed by the risk of bias affecting items representing statistical methods, internal validity and external validity. Regarding the latter, a selection bias could have occurred when clear details about participants population were not provided in the studies enrolling patients.[44-47, 50, 57, 59, 61] Furthermore, a spectrum bias could be present when studies did not specify the setting.[44, 46, 50, 59] Considering internal validity, studies lacking of inter-rater [51, 53] and intra-rater blinding [41] could have biased estimates as well as those studies in which raters were not blinded to the disease status [46, 53] and to additional clinical information.[46, 50, 53, 60] A clinical review bias could have affected the studies in which raters were not blinded to clinical information.[44, 47, 56, 57, 61] All of the studies apart from Rothstein *et al.*[57] did not apply randomisation procedures on both subjects and raters, thus leading to a potential systematic error of measurement or a raters recall bias, respectively. A graphic representation summarising the items not affected by risk of bias in each study is provided in Figure 2.

In 72 items out of a total 242 there was disagreement on the critical appraisal. This was resolved with a consensus meeting, with an agreement of 83.6% and a substantial inter-reviewer reliability (k_w =0.67, 95% CI:0.60-0.75).

Inter-rater reliability by joint

The studies with acceptable reliability for joint movements, in healthy and symptomatic subjects, are represented in Table IV.

Hip joint

Regarding healthy subjects, ICC's were considered unacceptable in the studies by Dennis *et al.*[43] and Peeler and Anderson [54] as they scored below the required 0.75 level. In the study by Aalto *et al.*,[40] two trained physical therapists (PTs) assessed three hip movements in intraday and inter-day sessions with a goniometer. The reported values were acceptable for flexion, whilst extension and internal rotation were reliable mainly in the intraday sessions. Further, the study by Gabbe *et al.*[48] demonstrated that the goniometer in modified Thomas Test position for flexion and extension is reliable. In the clinical study by Clapis *et al.*,[42] two very experienced PT's measured extension in the same position. After a Power analysis (0.80), a non-systematic sample was recruited and results showed high reliability for both goniometer and inclinometer. Further, SEM values were lower than those found by Gabbe *et al.*[48]

When a clinical inclinometer was used both on patients with low back pain (LBP) and on those without LBP, Murray *et al.*[53] demonstrated reliability value was acceptable for hip internal rotation. However, this value was calculated without distinguishing between the two groups. Piva *et al.*[56] reported that measures taken by goniometer had acceptable reproducibility for hip flexion in subjects with patello-femoral pain syndrome (PFPS) examined by trained and experienced PTs in a primary care setting. In Theiler

Table III.—*QAREL scores for each of the included studies.*

Study (Year)	Item										
	EV			IV							SM
	1. Participant Sample	2. Raters Sample	10. Test Application and Interpretation	3. Inter-rater Blinding	4. Intra-rater Blinding	5. Disease Status Blinding	6. Clinical Information Blinding	7. Additional Cues Blinding	8. Randomization	9. Stability of Variable	11. Statistical Method
Aalto *et al.* (2005)[40]	Y	U	Y	Y	NA	NA	N	U	Y	Y	N
Bennell *et al.* (1998)[41]	U	U	Y	N	NA	NA	U	U	Y	Y	Y
Clapis *et al.* (2008)[42]	U	U	Y	NA	NA	NA	N	U	Y	Y	Y
Dennis *et al.* (2008)[43]	U	Y	Y	Y	NA	NA	N	U	Y	Y	Y
Diamond *et al.* (1988)[44]	U	U	Y	NA	N	U	U	U	Y	Y	Y
Elveru *et al.* (1988)[45]	U	Y	Y	NA	U	U	U	U	Y	U	N
Erichsen *et al.* (2006)[46]	U	U	Y	Y	Y	Y	Y	U	Y	Y	Y
Fritz *et al.* (1998)[47]	U	U	Y	NA	N	N	U	U	Y	U	Y
Gabbe *et al.* (2004)[48]	U	U	Y	Y	NA	NA	N	U	Y	Y	Y
Gogia *et al.* (1987)[49]	U	U	Y	NA	NA	NA	U	U	Y	Y	N
Hayes and Petersen (2001)[50]	U	U	Y	Y	N	Y	U	U	Y	Y	Y
Jonson and Gross (1997)[51]	U	U	U	NA	NA	NA	U	U	Y	Y	N
Munteanu *et al.* (2009)[52]	U	U	Y	Y	NA	NA	U	U	Y	Y	Y
Murray *et al.* (2009)[53]	Y	U	U	NA	Y	Y	N	U	Y	Y	Y
Peeler and Anderson (2007)[54]	Y	Y	Y	Y	NA	NA	U	U	Y	Y	Y
Peeler and Anderson (2008)[55]	Y	Y	Y	Y	NA	NA	U	U	Y	Y	Y
Piva *et al.* (2006)[56]	Y	Y	Y	NA	U	N	N	U	Y	Y	Y
Rotsthein *et al.* (1983)[57]	U	Y	Y	NA	N	N	U	Y	Y	U	N
Russell *et al.* (2003)[58]	U	U	Y	Y	NA	NA	U	N	Y	Y	Y
Smith-Oricchio and Harris (1990)[59]	U	U	Y	NA	N	N	N	U	Y	Y	N
Sweitzer *et al.* (2010)[60]	Y	U	Y	NA	N	Y	U	U	Y	Y	Y
Theiler *et al.* (1996)[61]	U	U	Y	NA	U	U	N	U	Y	N	N

EV: external validity; IV: internal validity; SM: statistical method; N: no; NA: not acceptable; U: unclear; Y: yes; QAREL: Quality appraisal of reliability studies.

et al.'s study,[61] two rheumatologists examined patients with osteoarthritis in a hospital setting. The reliability ranged from slight to substantial for all of the hip movements.

Knee joint

Measuring knee flexion in the Thomas Test position with an inclinometer was relatively acceptable in the study by Gabbe *et al.*[48] In fact, despite the ICCs point estimate was 0.90, the lower value of corresponding estimate of precision (95% CI) was 0.72. However, the difference between averages of raters was small (SEM=3°) and the same procedure was not reliable using a goniometer in the studies by Aalto *et al.*[40] and Peeler and Anderson.[55] Conversely, goniometric measurement was shown to be reliable by Gogia *et al.*[49] when two PTs evaluated positions chosen arbitrarily by an assistant in a range of knee flexion between 0° and 120°. Russell *et al.*[58]

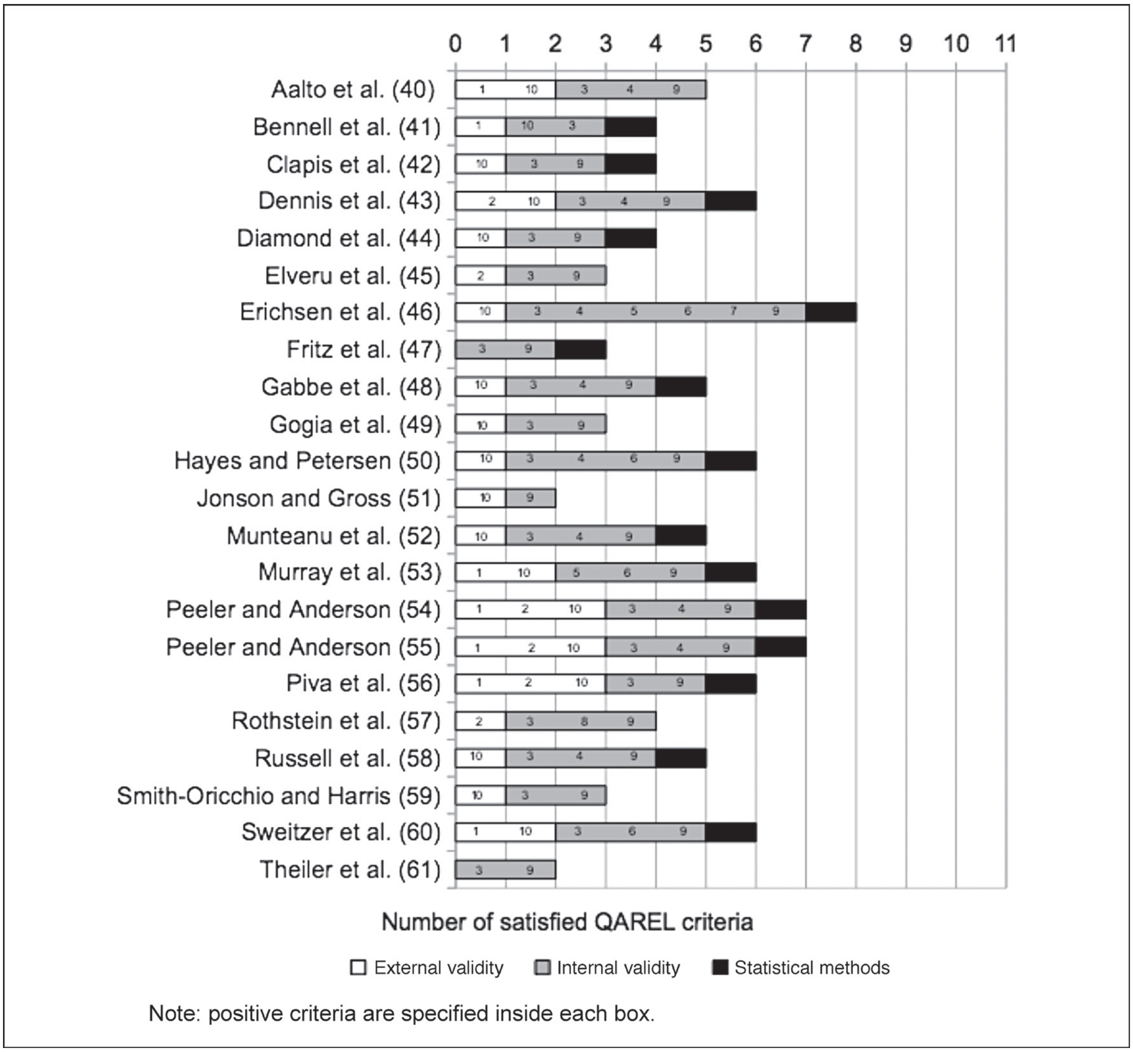

Figure 2.—Risk of bias within studies.

incorporated an internet-based goniometer into a low-cost tele-medical application for the delivery of physiotherapy intervention to the home. Knee flexion and extension measured with this application were highly reliable, however the sample size consisted of only one healthy subject.

Five studies enrolled subjects with various musculoskeletal disorders. Manual assessment of knee flexion and extension performed by two trained and very experienced PT's in patients with unilateral knee pain had poor to moderate reliability in the study by Hayes and Petersen.[50] Four studies about the reliability of goniometer have investigated knee flexion and extension. Fritz *et al.*[47] found acceptable values for the involved side in a range of knee pathologies including PFPS, osteoarthritis and internal derangement. The raters enrolled were not trained as well as in the study by Rothstein *et al.*[57] In this study, twelve PTs evaluated knee disorders employing three different goniometers and acceptable values for flexion rather than extension were reported.[57] In contrast, a slight to moderate reliability between two trained rheumatologists was

TABLE IV.-*Summary of studies with acceptable reliability along joint movement and physical status.*

		Healthy	Ankle Pathology	Diabetes	Knee Pain	LBP	OA	PFPS
Hip	Flexion	Aalto *et al.*[40] Gabbe *et al.*[48]						Piva *et al.*[68*]
	Estension	Aalto *et al.*[40****] Gabbe *et al.*[42] Gabbe *et al.*[48]						
	Internal rotation	Clapis *et al.*[43]				Murray *et al.*[53***]	Theiler *et al.*[61]	
Knee	Flexion	Aalto *et al.*[40****] Russel *et al.*[58**]			Fritz *et al.*[47] Rothstein *et al.*[57]			Piva *et al.*[56*]
	Estension	Russel *et al.*[58**]			Fritz *et al.*[47]			
Ankle	Dorsal Flexion	Bennell Bennell (WB) Munteanu *et al.*[52] (WB)		Diamond *et al.*[44]				Piva *et al.*[56]
Subtolar	Inversion			Diamond *et al.*[44]				
	Eversion		Smith-Oricchio and Harris [59] (WB)	Diamond *et al.*[44]				

Key: LBP (Low Back Pain). OA (Osteoarthritis), PFPS (Patello-femoral Pain Syndrome), WB (Weight-Bearing),
* = Gravity goniometer, ** = Internet based gonbiometer, *** = LBP and Healthy subjects together, **** = Intraday session.
Cells color: ☐ Goniometer; ☐ Inclinometer.

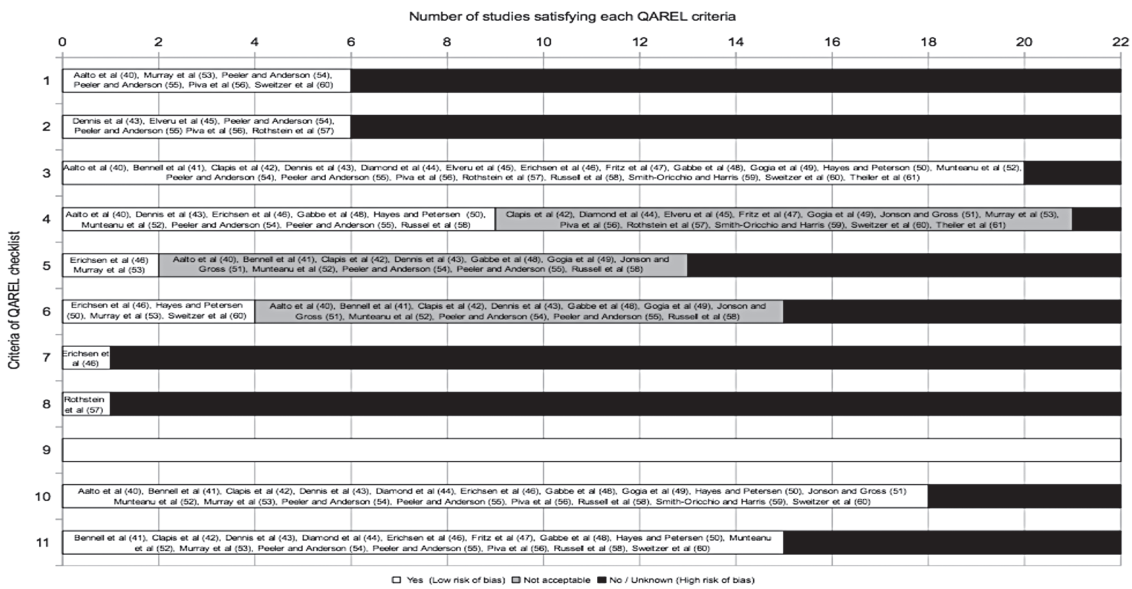

Figure 3.—Risk of bias across the studies.

recorded by Theiler *et al.*[61] in patients with osteoarthritis during flexion and extension measurements. Finally, Piva *et al.*[56] showed high reliability among four trained PTs measuring knee flexion with a goniometer in patients with PFPS.

PATELLO-FEMORAL JOINT

The patellar mobility was examined with manual tests in two studies performed in primary care settings. In patients with pain greater than four weeks and located in the patellar region, Sweitzer *et al.*[60] found a moderate reliability of the medio-lateral and superior-inferior translation of the patella assessed by two trained physicians. In contrast, Piva *et al.*[56] reported the medio-lateral translation was substantial in patients with PFPS evaluated by four PTs. However, this value is not acceptable because the lower value of the 95% CI went beyond the threshold of substantial reliability.

Ankle joint

Two studies by Bennell *et al.*[41] and Munteanu *et al.*[52] enrolled healthy subjects and assessed the dorsiflexion of the ankle with the inclinometer by trained raters. Acceptable values were found with the knee either in neutral [41] or extended position,[52] respectively. In these studies, each sample of raters was composed by four examiners of which one was a student. The goniometric assessment of ankle dorsiflexion was not found to be reliable by Jonson and Gross [51] in healthy subjects. This is consistent with other studies in patients with orthopedic disorders in dorsiflexion and plantar-flexion movement measured by two trained and experienced PT's in the study by Elveru.[45] However, reliability was found to be acceptable when trained PTs assessed dorsiflexion in patients with diabetes in the study by Diamond *et al.*[44] or PFPS in the study by Piva *et al.*[56] Erichsen *et al.*[46] found the manual test performed in both healthy subjects and patients with ankle disorders having poor reliability for plantar-flexion and moderate reliability for ankle joint-play. In this study the agreement between the two trained and experienced PTs was calculated merging the values of both groups.

Subtalar joint

The overall ICC for eversion resulted in lower scores than for inversion. Symptomatic subjects were enrolled in all retrieved articles. Among those investigating the goniometer, Diamond *et al.*[44] found acceptable reliability between two trained PTs measuring inversion and eversion in patients with diabetes. In contrast, poor values were reported in patients with orthopedic disorders by Elveru *et al.*[45] and in subjects recovering from ankle sprain or fracture by Smith-Oricchio and Harris.[59] However, when eversion was measured in a weight-bearing position the reliability was shown to be high.[59] The raters were three untrained and inexperienced PTs. Manual tests were reported to be fair for inversion and eversion in patients with a diagnosis of ankle disorders assessed by two trained and experienced PTs in the study by Erichsen *et al.*[46]

Risk of bias across studies

A graphic representation of how much bias is in each item across all the included articles is presented in Figure 4. Overall, the risk of bias affected seriously all the items regarding both internal and external validity. Therefore, evidences arising from this review are consequently weak. The assessment of publication bias was done by plotting the point estimates of the effect against the sample size, because not all of the retrieved studies (12/22) reported estimates of precision. The use of sample size or log sample size is troublesome because the expected shape of the plot in the absence of bias is unpredictable,[62] thus not so useful to evaluate possible presence of publication bias. Therefore, a funnel plot was not reported because of its limited usefulness.

Discussion

Summary of evidence

In this systematic review, we retrieved 22 articles investigating inter-rater reliability of PROM measurements of lower extremity. The inter-rater reliability of goniometer's varied from 0 for ankle dorsiflexion in orthopaedic conditions [45] to 1,00 for knee flexion in laboratory setting.[58] However, the ICC's have been found acceptable at the hip and knee joint in healthy subjects.[40, 42, 48, 49, 58] Regarding disease status, reliability was high for knee movements in patients with knee disorders [47, 57] for hip internal rotation in patients with osteoarthritis,[61] for ankle and subtalar joint movement in subjects affected by diabetes,[44] and ankle pathology,[59] and in flexion of the hip, knee and ankle joints in subjects suffering of PFPS.[56] In five studies using the inclinometer, the reliability has been shown to have high ICCs for hip extension [42] and ankle dorsal flexion [41, 52] in healthy subjects, and during internal rotation of the hip in patients with LBP.[53] However, these evidences are necessarily weak because of poor methodological quality and scarce within joints and conditions. In contrast, none of the four articles studying manual tests in patients with unilateral knee pain,[50] PFPS [56, 60] and ankle disorders [46] reported acceptable reliability. The methodological quality of these studies was somewhat stronger considering external [56] and internal validity.[46, 50] However, it is premature to gather an evidence-based recommendation about the low reliability of manual tests because of the few publications.

Regarding external validity, several studies with acceptable reliability had limited generalizability due to the presence of selection bias.[44, 47, 57, 59, 61] Further, a spectrum bias occurred in two studies.[44, 59] Consequently, their results could not be applicable among different clinical settings. In fact, it is well established that the accuracy of a diagnostic test changes moving from primary to tertiary care and vice versa.[63] The same phenomenon could happen for the estimates of diagnostic reliability. Furthermore, none of the studies specified methods for raters recruitment or screened raters for eligibility criteria, thus creating a biased sample of raters and, again, a poor generalizability. Finally, studies not describing the measurement procedures [47, 57, 61] do not allow the reproducibility of the test in clinical practice.

Different types of blinding and randomisation could affect the internal validity of the studies in several ways. Firstly, the lack of inter-rater blinding reduces the validity the study's results,[53] whilst the lack of intra-rater blinding [41] could have biased values regarding inter-rater reliability studies. In diagnostic accuracy studies, availability of clinical information from participants to examiners before executing the test has been shown to increase sensitivity.[64] The studies lacking of this criteria could have a clinical review bias and, therefore, increased reliability estimates.[44, 47, 56, 57, 61] In addition, none of the studies blinded raters to any additional cues, thus reliability estimates may be inflated.

Except Rothstein *et al.*,[57] all the retrieved articles had the criterion on randomisation methods scored as unknown because subjects and raters were not randomised together. In fact, varying the order in which subjects were examined could avoid potential raters' recall bias due to the fixed order in which raters perform their measurements. This distortion obviously lead to increase reliability. Furthermore, being the measured parameters susceptible to adaptation or pain aggravation, it is important to vary the order in which raters examine subjects to avoid potential systematic error.[5] Regarding statistical analysis, seven studies [40, 45, 49, 51, 57, 59, 61] were scored as no because not reporting estimate of precision (*e.g.* 95% CI, SEM, LoA), thereby the reliability values of these studies cannot be considered significant. Moreover, in two studies data were analysed without distinguishing between healthy subjects and patients.[46, 53] Although the results shown by Murray et al[53] were acceptable, we have already discussed a possible explanation of biased reliability of this study. Therefore, we could think that the results found by Erichsen *et al.*[46] could have been weakened by biased data analysis.

Either ICC (95% CI) or both SEM and LOA have several problems when used separately [65, 66] and many authors underlined that the best choice is to present all the three reliability scores.[66-68] In the present review only Munteanu *et al.*[52] reported the three measures together affirming with more certainty the reported evidence.

Our results confirm what was previously found in studies examining similar tests in the upper limb.[19] Thus, the inter-rater reliability of PROM measurements of the extremities may seem to be higher than that of the spine and SIJ.[17, 18]

Seffinger *et al.*[15] attributes these differences in reliability to the dimension of articular surfaces. In contrast, Van de Pol *et al.*[19] suggests these differences would be related more to the total range of motion. However, a third explanation could be put forward. Such a discrepancy could be related more to the component of PROM assessed (*e.g.*, osteokinematic/arthrokinematic). Therefore, the problem may lie in the different methods employed to measure each PROM component. Generally speaking, osteokinematic motion is usually measured with devices such as goniometer or inclinometer. Our results suggest that the use of goniometer and inclinometer to measure the osteokinematic motion of the joints of the lower extremity is reliable, *e.g.*, hip,[40, 42, 48, 53, 56, 61] knee,[47-49, 56-58] ankle,[41, 44, 52, 56] and subtalar joint [44, 59] either in healthy subjects or in patients. Furthermore, we did not note an association between high reliability and raters' training and expertise.

In contrast, the arthrokinematic motion is usually assessed with manual tests. In this review, these tests had low reliability values.[46, 50, 56, 60] The same scenario reflects what previously found in the upper extremity, *e.g.*, shoulder,[50, 69, 70] elbow,[71] carpal joint,[72] and in the spine and SIJ.[6, 13-18]

The low reliability of manual tests seems to be dependent on the inter-rater differences in setting force intensity and direction, in perception of accessory motion, in patient positioning, and on employed classification system.[73]

Hence, we state that overall inter-rater reliability of osteokinematic component is more reliable because obtained with goniometer and inclinometer. In contrast, assessment of arthrokinematic motion might be less reliable because evaluated with manual tests.

However, results arising from this systematic review disagree with those found by Van Trijffel *et al.*[20] There are several differences in this manuscript that might have led to different results: 1) a more extensive research encompassing 5 databases; 2) the inclusion of studies regarding patello-femoral joint; 3) the exclusion of studies estimating ROM measures through vision; 4) the use of QAREL,[5] a tool specifically developed for the critical appraisal of studies with reliability design; 5) the inclusion of only those studies with a proper reliability statistic, such as SEM and LOA index, and the exclusion of studies reporting reliability index prone to systematic bias, such as Pearson's r,[35] or reliability coefficient not properly calculated.[76]

Here we accepted studies examining both healthy subjects and patients. It is interesting to note that significant results arising from healthy subjects[40,41,42,48,49,57] do not apply in clinical situations. Nevertheless, it is appropriate to use healthy volunteers to detect normative data.[5]

As suggested by Fritz and Wainner,[4] the usefulness of reliability data is best appreciated when considered in conjunction with data examining diagnostic accuracy. For instance, in a well-conducted study by Sweitzer *et al.*,[60] reliability of manual tests evaluating patients with patellar pain was moderate. However, when used as a cluster of tests, their specificity was high [60] and allowed to rule in subjects with PFPS. In a similar sample, Piva *et al.*[56] reported a moderate to almost perfect reliability of manual assessment of medio-lateral patellar translation. Thereby, the use of PROM manual tests may be implemented in the diagnosis of subjects with PFPS.

The measurement of hip internal rotation in patients with osteoarthritis of the hip [61] or LBP [53] has been found to have substantial and high reliability, respectively. Previous studies have incorporated this procedure in clusters of tests to identify those patients, suffering of the aforementioned conditions, likely to benefit from manipulation of the hip [74] or of the spine.[75] However, the high risk of bias within the study by Theiler *et al.*[61] and the lack of inter-rater blinding in the study by Murray *et al.*[53] seriously harms the employment of hip internal rotation PROM test to diagnose such conditions.

Moreover, two studies reported good reliability of knee PROM measurements in patients with a range of knee disorders.[47, 57] This is in line with previous findings.[21] Also the reliability of ankle PROM measurements in patient with diabetes [44] or recent ankle pathology [59] was high. However, the inconsistency of external validity of these studies limits their applicability in clinical practice.

Limitations of systematic review

In this review there are several methodological issues that should be explicated. Evidence regarding the evaluation of osteokinematic PROM by mean of devices could appear to be weak because of the small number of publication encompassing a single joint that were retrieved and included in this review. Similarly, articles deeming arthrokinematic manual test reliability were scarcely indexed in the screened databases and the use of key words with high specificity could have produced a potentially more restrictive research within this review (source selection bias).

Despite the extensive search based on six databases and the bibliographic screening of the included articles, studies not indexed were possibly missed (publication bias). Furthermore, a language bias should be considered because of the language restriction applied in the research strategy. The critical appraisal of the retrieved papers has been made utilising a checklist recently developed (QAREL). Although not yet validated, the QAREL tool was applied because more appropriate for the assessment of inter-rater study. Preliminary data of this review reported an acceptable overall inter-rater agreement (methodological assessment bias).

A large number of districts of the lower quadrant were analyzed in the retrieved studies. These included heterogeneous samples of healthy subjects and patients with musculoskeletal disorders, tested by different measurement devices (structure bias). Although aware of this methodological limitation, it was decided to use this strategy to extract a set of evidence satisfying the variability and the measurements devices commonly available in physiotherapist daily clinical practice.

Conclusions

Implication for practice

Measurements of the osteokinematic component obtained with goniometer or inclinometer seem to have high reliability. However, these results may be inflated by biased internal validity and have poor generalizability. The evaluation of arthrokinematic motion of patellar mobility with manual tests may be considered as an helpful additional element during the diagnosis of PFPS within a consistent clinical reasoning process. Clinicians should be cautious when using the hip internal rotation test to guide clinical decision-making process in conditions such as osteoarthritis and LBP.

Implication for research

Future research needs to examine a sample of subjects with musculoskeletal disorders of all the joints of the lower limb (hip, knee, patellofemoral, ankle, subtalar and tarsal joint). Moreover, further inter-examiner reliability research should develop higher methodological quality studies based on QAREL tool or similar. In addition, researchers should focus on the interrater reliability of the arthrokinematic motion. Finally, there is a need to validate the QAREL as a tool of methodological appraisal in reliability studies.

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Appendix 1

Terms of research used in the databases

Field of research	Terms	MeSH
Joint	"Hip"; "Knee"; "Patellofemoral"; "Ankle"; "Subtalar"	"Hip"[Mesh]; "Hip Joint"[Mesh]; "Knee Joint"[Mesh], "Knee"[Mesh]; "Ankle Joint"[Mesh], "Ankle"[Mesh]; "Subtalar Joint"[Mesh]
Parameters	"End Feel", "End-Feel"; "Accessory Motion", "Joint Play", "Joint-Play"; "Glide", "Slide", "Translation", "Traction"; "PROM", "Passive Rom", "Passive Range Of Motion"; "Goniometry", "Goniometric Measurement", "Inclinometer", "Goniometer";	"Arthrometry, Articular"[Mesh]; "Range of Motion, Articular"[Mesh]; "Traction" [Mesh]; "Physical examination"[Mesh]
Reliability	"Reliability"; "Reproducibility of Results", "Reproducibility", "Concordance", "Repeatability", "Agreement", "Variation*", "Variabilit*", "Interexaminer", "Interobserver", "Interrater", "Intertester", "Observer Variation", "Examiner*", "Rater*", "Observer*", "Tester*", "Exam", "Examination", "Assessment", "Evaluation";	"Reproducibility of Results"[Mesh]; "Observer variation"[Mesh]; "Physician's practice patterns"[Mesh]

Appendix 2

E-journals screened during search

E-journals	Years	Score (Number)
Journal of manual and manipulative therapy	1993-2010	1
Journal of manipulative and physiological therapeutics	1987-2010	0
Advanced in physiotherapy	1999-2010	1
Physiotherapy research international	2000-2010	1
Physiotherapy theory and practice	1999-2010	1
Physical therapy	1980-2010	11
Manual therapy	1995-2010	1
Physical therapy in sport	2000-2010	4
Physical therapy reviews	2003-2010	0

The mirror neuron system as a main target in rehabilitation

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ABSTRACT

Experimental evidence collected in the last two decades has radically changed the view on the cortical motor system. The discovery of mirror neurons in monkeys and mirror neuron system (MNS) in humans has extended the role of the motor system that is now recognized to be engaged not only in planning and executing actions but also in cognitive functions such as understanding observed actions and intentions behind them. The resonant behavior of mirror neurons seems to be a more general mechanism of the brain involving also sensory and emotion systems. These concepts open new perspectives also in the clinical domain offering a novel basis for grounding new strategies in the rehabilitation field. The present review focuses on rehabilitation approaches which possibly have the MNS as a main target. Among these, mirror therapy, motor imagery as a rehabilitation strategy and the action observation treatment are all examples of treatments aimed at exploiting the MNS for restoring function, since it may account for our capacity to perform motor imagery and to learn through imitation. *(It J Physiotherapy 2012;2:31-8)*

Key words: Rehabilitation - Mirror neurons - Exercise therapy.

In the last three decades our view of the cortical motor system has radically changed. Traditionally three main motor areas were described, namely the primary motor area (M1) devoted to control movement execution, the premotor region and the supplementary motor area (SMA) involved in motor preparation. More recently new functional and neuroanatomical data have been collected that give a different picture of the cortical organization of the motor system on the basis of cytoarchitectural and functional data. The premotor cortex has been shown to be subdivided in several sub-areas that, according to Matelli *et al.*,[1] are labeled with the letter F followed by Arabic numbers (F2-F7). Each subarea of this mosaic is characterized by a specific pattern of connections with other parietal and prefrontal areas and also with subcortical structures, in particular the spinal cord. The F1-F5 areas are mainly connected with parietal areas while F6-F7 are mainly connected with the prefrontal cortex. Parietal-related areas send projections to the spinal cord but this is not true for prefrontal-related areas. In addition, several distinct body parts are represented in each subdivision of the premotor cortex.[2] Summing up, at the core of the cortical motor system is now placed a series of parallel parieto-frontal circuits connecting specific areas of the frontal and parietal cortex which are devoted to code specific sensorimotor transformations necessary to interact with objects and other individuals. These parieto-frontal circuits are influenced by attentive and motivational factors, possibly fed up by the prefrontal cortex.

The functional properties of a particular class of premotor neurons, the mirror neurons, first discovered in the ventral premotor cortex of the monkey (area F5) by the group of Rizzolatti, have further and substantially widened the role of the cortical motor system. It is indeed widely accepted that it is involved in cognitive functions as the comprehension of others' motor behavior.[3]

The mirror neuron system

Mirror neurons are a set of visuomotor neurons that are active not only when the monkey performs a given goal-directed action but also when it observes a conspecific or an experimenter performing the same or a similar action.[4, 5] Basically, they allow the mapping of the observed action onto the same neural population which controls the execution of that action. Since, subsequently, mirror neurons have been described also in other brain areas such as the inferior parietal lobule, it is more appropriated to refer to a mirror neuron system (MNS). From a motor perspective mirror neurons are generally active during the execution of different goal directed actions such as reaching-grasping of objects, hand holding, hand manipulation, mouth movements related to feeding behavior and so on.

It has been proposed that MNS is involved in coding the scope of an action. Since the observed action is mapped onto the neural substrates controlling the execution of the same action and since the observer knows the meaning and the consequences of performing actions belonging to his own motor repertoire, eventually this knowledge can be transferred to the observed action. This notion is corroborated by the results of an experiment where F5 mirror neuron activity has been investigated in two different experimental conditions.[6] In one case the monkey could observe the entire sequence of an action like, for instance, a hand grasping an object. In the other case the monkey was prevented from observing the last part of the sequence by means of a panel. The animal knew that an object was hidden behind the panel but could not observe the experimenter's hand grasping it. More than half of recorded mirror neurons kept on firing even when the last part of the action was obscured by the panel. This has been taken to indicate that mirror neurons are able to complement missing information, namely to simulate the last part of the action and then through the simulation to infer its goal.

The mirror neurons' ability to match perceived actions with executed actions is not limited to the visual domain. Koehler *et al.*[7] investigated the neuronal responses when monkeys were exposed to audio-visual, visual only and audio only stimuli. They showed that during the condition of listening to the typical sound of an action, like peanut cracking, without observing the action a significant number of recorded neurons presented a response similar to that recorded when the animal could either observe and listen to the action. These neurons were labeled as audio-visual mirror neurons. This finding indicates that mirror neurons are able to code the same action regardless of the sensory modality involved in its perception and eventually to code an abstract representation of actions.

More recently the mouth-related mirror neurons have been investigated in detail by Ferrari and colleagues.[8] They are abundant in the lateral part of area F5 and respond during the performance of ingestion actions by the monkey. According to their visual properties they can instead be subdivided into two classes. The more representative class responds during observation of ingestion actions such as mouth grasping of food, chewing, sucking and so on (ingestion mirror neurons) while the other class responds during the observation of mouth actions with communicative functions like lip smacking (communicative mirror neurons). The latter class shows then only a broad congruence between observed and executed action, since the observed action is communicative while the executed one is related to food ingestion. It has been proposed that communicative mirror neurons play an important role in language evolution since they are phylogenetically the first neurons with communicative functions appearing in the lateral convexity of the brain hemisphere.

In order to address whether mirror neurons contribute to encoding the perspective from which the motor acts of others are seen, Caggiano *et al.*[9] recorded the visual responses of mirror neurons of monkey area F5 by using a novel experimental paradigm based on the presentation of movies showing grasping actions from different visual perspectives. They found that the majority of the tested mirror neurons (74%) exhibited view-dependent activity with responses tuned to specific points of view. A minority of the tested mirror neurons (26%) exhibited view-independent responses. They propose that view-independent mirror neurons encode action goals irrespective of the details of the observed motor acts, whereas the view-dependent ones might either form an intermediate step in the formation of view independent or contribute to a modulation of view-dependent representations in higher-level visual areas, potentially linking the goals of observed motor acts with their pictorial aspects.

The mirror neuron system in humans

By means of non-invasive techniques it has been possible to investigate also the human brain and many studies have been carried out that confirm the existence of mirror properties also in specific regions of the human cortex. In a pivotal study Fadiga *et al.*[10] applied transcranial magnetic stimulation (TMS) pulses over hand motor cortex showing that the excitability of this region is enhanced when subjects observed hand actions with respect to a control condition. Later evidence in favour of a motor resonance system has been collected using different techniques spanning from EEG to brain imaging (functional MRI, PET) and others. Hari and *et al.*,[11] using magnetoencephalography (MEG) found a suppression of 15-25 Hz oscillatory activity, known to originate from the precentral motor cortex, during the execution and, to a less extent, during the observation of object manipulation. Cochin *et al.*[12], for instance, demonstrated clear similarities between observation and execution of movement by quantified electroencephalography. A functional MRI (fMRI) study [13] investigated which brain areas are active during the observation of actions performed with different body effectors. The results indicated that different premotor regions are activated according to the effector involved in the observed action. The MNS in humans shows then somatotopic organization that resembles the motor homunculus. In another fMRI study Buccino *et al.*[14] were interested in investigating whether the human MNS is activated by the observation of actions performed by different species. Participants to the study were presented with mouth actions related either to food ingestion or to communication. These actions were performed by a human being, a monkey and a dog. The results showed that ingestion actions' observation activates the premotor cortex regardless of the observed species while communicative actions' observation was effective only when participants observed a conspecific (human being moving the lips as during speaking) but not when they observed a communicative gesture performed by the monkey (lip smacking) or the dog (barking). This finding has been interpreted as the proof that the human MNS can match the observed actions on the executed ones only if the observed action belongs to the motor repertoire of the observer. This is a prerequisite in order to operate a motor simulation of what is observed that, in turn, allows inferring the scope of perceived actions. Similarly, the motor expertise of the observer affects the motor resonance system. Expert dancers resonate more strongly when they observe another dancer performing exactly the same kind of dance they practice with respect to the condition in which they have to look at a different type of dance.[15]

Intentions, emotions and the mirror neuron system

Action understanding involves different levels. The data briefly revised above tell us that the MNS, being an observation/execution matching system permits the motor recognition of perceived actions and the inferring of the scope of those actions. So when observing, for instance, the observation of a hand grasping an object allows the observer to realize that the observed action is aimed at taking possession of a given object. In addition to this capability to capture the immediate scope of the observed action, recent data suggest that the MNS is involved also in more refined aspects of action understanding. Traditionally, the ability to understand the intentions subtending actions is a task that is presumed to be achieved by means of logical-deductive reasoning. The ensemble of mental processing devoted to this purpose is called Theory of Mind (ToM). The MNS offers an alternative either non-exclusive explanation about how one person can capture the intentions of the actions others perform close to him. The same simulation model put forward to comprehend the immediate scope of an action can serve also the decoding of broader aspects of intention.

In a recent fMRI study by Iacoboni *et al.*[16] participants were presented with the same action embedded in two different contexts. In one case they observed an actor grasping a cup lying on a table set for breakfast while in the other case they observed the grasping of a cup lying on the same table at the end of breakfast. One group of participants had to just observe the actions while another group was required to explicitly state the different intentions subtending the same action of grasping performed by the actor in the two different contexts. Results showed that there was no differential activation of brain areas between the two groups of participants, suggesting that the brain automatically extracts the intentions of observed actions together with the processing of motor aspects of those same actions and of the context in which the actions take place. In fact, the activated brain regions in the two groups were those typically belonging to the MNS.

To investigate the neural basis of the capacity of understanding when actions done by others do or do not reflect their intentions, in another fMRI study by Buccino *et al.*[17] volunteers were presented with video-clips showing actions that did reflect the intention of the agent (intended actions) and actions that did not (non-intended actions). Observation of both types of actions activated a common set of areas including the inferior parietal lobule, the lateral premotor cortex and mesial premotor areas. When directly comparing brain areas activated for non-intended and those activated for intended actions three regions specifically emerged: the right temporo-parietal junction, left supramarginal gyrus, and mesial prefrontal cortex. The converse comparison did not show any activation. The authors concluded that our capacity to understand non intended actions is based on the activation of areas signaling unexpected events in spatial and temporal domains, in addition to the activity of the mirror neuron system. The concomitant activation of mesial prefrontal areas, known to be involved in self-referential processing, might reflect how deeply participants are involved in the observed scenes.

By studying the properties of monkey parietal mirror neurons Fogassi *et al.*[18] have shed light on the possible neural mechanism subtending the coding and decoding of intentions. Parietal mirror neurons' activity was recorded during execution and observation of different sequences of actions. A typical sequence comprised for instance the reaching-grasping of an object by the hand and the subsequent action of either bringing it to the mouth or placing it into a container located close to the mouth. The two different sequences, namely grasp to eat and grasp to place, were very similar from a kinematic point of view but had different scopes. A set of mirror neurons discharged during the reaching-grasping action regardless the following action were bringing to the mouth or placing in a container but, interestingly, another set of mirror neurons discharged during the grasping action only when the following action was of a particular type, either bringing to the mouth or placing but not both. The authors have proposed that the mirror neurons ability of decoding intention could rely on the activation of specific chains of neurons representing specific sequences of actions committed to the achievement of a particular scope.

Action observation can give us important clues not only about the intentions that drive a specific action but also about the accompanying emotions. Recently, researchers have investigated the brain structures possibly involved in emotion decoding, postulating that a mirror mechanism should play an important role.[19] Brain imaging studies [20] showed that a resonance mechanism similar to that described for mirror neurons in the motor cortex is at work in cortical areas controlling the visceral motor responses that accompany emotions. When someone feels pain or disgust and when she/he observes in other people the emotional responses elicited by painful or disgusting stimuli two main cortical structures are activated: the cingulate region and the insula.[21] This finding clearly indicates that either perceiving and observing someone else perceiving emotions activate the same neural substrate.

Mirror neuron system and clinical implications

The mirror mechanism and the cognitive functions attributed to the cortical motor system open new scenarios also in the clinical domain offering a novel basis for grounding new strategies in the rehabilitation field. The mirror therapy,[22] motor imagery as a rehabilitation strategy and the action observation treatment (AOT) are all examples of rehabilitation approaches which possibly have as a main target the MNS. This especially because the mirror neuron system may account for our capacity to perform motor imagery and to learn through imitation.

Mirror neuron system and motor imagery

Motor imagery refers to the ability of mentally run movement or action motor plans without actually performing any movement.[23] It has been shown how motor imagery may help learning new motor strategies as much as the execution of the same motor strategies does. When speaking of motor imagery it is useful a distinction between two different types of imagery. In one case a person can visually imagine a movement as if she/he were really observing someone else moving (third person perspective) while, alternatively, she/he can internally simulate a movement and elicit the kinesthesic sensations related to the simulated movement (first person perspective). The former case should be labeled visual imagery while the latter is a true motor imagery. Since motor imagery is closer to motor execution than visual imagery, it has been established a strict relationship between motor imagery and motor preparation, imitation and motor learning.[24-31] Brain imaging studies contributed in defining the set of brain areas activated by a motor imagery task. These areas comprise the supplementary motor area, the superior and inferior parietal lobules, the dorsal and ventral premotor cortices, the inferior frontal gyrus, prefrontal areas, the superior temporal gyrus, the primary motor cortex, the supplementary somatosensory area, the insula, the cingulate cortex, the basal ganglia and the cerebellum. It appears then that during motor imagery the same areas are active as during movement observation and execution, namely motor imagery shares the same neural substrates with the motor resonance system.

Mirror neuron system and imitation

It is normally assumed that imitation is a typical human ability and intrinsically related to language and culture acquisition. Imitating refers to the ability of observing and recognizing actions performed by conspecifics, but also requires motor imagery and the ability of actively performing actions. Imitation may refer to the mere replay of a movement of one's own motor repertoire or to the learning of new motor sequences, as in the case of people learning to play guitar (true motor learning by imitation). According to Schmidt,[32] learning new motor tasks involves three distinct and subsequent phases. During the cognitive phase people recognize the rules and constraints that apply to the execution of a specific action (for instance, before riding a bike one has to know that hands must rest on the handlebars and the back must be kept straight and so on). During the associative phase people decompose an action into more basic motor acts that are easily performed. This step also permits to identify which elements of an action are essential for its execution from what constitutes irrelevant information. The last phase, the automatic phase, is characterized by the ability of effortlessly perform the acquired motor task. This approach assumes that during learning of new motor skills people move from a cognitive-declarative type of knowledge of the task to perform to a fully acquired procedural knowledge that permits the effortless execution of the new action.

Recent neuroimaging studies have demonstrated the MNS involvement in imitation. Iacoboni *et al.*[33] in order to test if imitation may be based on a mechanism directly matching the observed action onto an internal motor representation of that action asked human participants to observe and imitate a finger movement and to perform the same movement after spatial or symbolic cues. Brain activity was measured with fMRI. If the direct matching hypothesis is correct, there should be areas that become active during finger movement, regardless of how it is evoked, and their activation should increase when the same movement is elicited by the observation of an identical movement made by another individual. Two areas with these properties were found in the left inferior frontal cortex (opercular region, a part of Broca's area) and the rostral-most region of the right superior parietal lobule. Broca's area involvement in imitation, especially during imitation of goal directed movement, has been confirmed also by other studies.[34, 35] Nishitani and Hari,[36] by means of magnetoencephalography (MEG), investigated the cortical dynamics in subjects who could observe still pictures of lip forms, on-line imitate them, or make similar forms in a self-paced manner. Cortical activation progressed from the occipital cortex to the superior temporal region, the inferior parietal lobule, and the inferior frontal lobe (Broca's area), and finally, to the primary motor cortex. The signals of Broca's area and motor cortex were significantly stronger during imitation than other conditions. These results demonstrate that still pictures, only implying motion, activate the human MNS in a well-defined temporal order. Summing up, these experiments suggest that those areas that activate in motor imitation tasks are also active during the observation of the same actions to imitate. A major role in imitation is played by the left inferior frontal gyrus (pars opercularis of Broca's area). MNS has also been studied during the imitation of movements that are outside one's own motor repertoire. In a fMRI paper,[37] musically naive participants were scanned during four events: 1) observation of guitar chords played by a guitarist (model); 2) a pause following model observation; 3) execution of the observed chords; and 4) rest. The results showed that the basic circuit underlying imitation learning consists of the inferior parietal lobule and the posterior part of the inferior frontal gyrus plus the adjacent premotor cortex (mirror neuron circuit). This circuit starts to be active during the observation of the guitar chords. During pause, the middle frontal gyrus (area 46) plus structures involved in motor preparation (dorsal premotor cortex, superior parietal lobule, rostral mesial areas) also become active. The most likely interpretation for the MNS activation found in the present experiment is that during imitation and learning of new motor schemes observed actions are decomposed in their constitutive elements that activate and resonate in the MNS. Once activated, these elementary representations are recombined in order to adapt to the model. This recombination of motor plans already acquired by the observer's motor system, in order to create new motor schemes, would be orchestrated by area 46.

Action observation treatment and rehabilitation

The experimental evidence presented above indicates that the role of the motor system is not limited to mere executive functions. The motor system in fact, is provided with the ability to resonate when actions, that are already or could become an integral part of our motor repertoire, are observed. This resonance mechanism allows for understanding actions made by other people and for capturing the emotions and the intentions of the agent. It has then been shown that the motor system, and in particular the MNS, is involved in the tasks of motor imagery and learning new motor skills. Since several years, motor imagery is used in the rehabilitation practice and sports.[38] The recruitment of motor representations, driven by motor imagery, can improve the quality of motor performance, even in the absence of an actual performance of action. Based on this evidence, a few years ago [39] it was proposed that the careful observation of actions, made in an ecological situation, would become, similarly to motor imagery, a valid approach in rehabilitation (action observation treatment, AOT), since even action observation has proven to be effective in recruiting motor representations of observed actions.

In AOT patients who had a reduction of motor skills are required to carefully and systematically observe, during a rehabilitation treatment that lasts 3-4 weeks, a series of movies that display everyday actions (drink coffee, read the newspaper, clean the table). Actions are chosen on the basis of their ecological value. Every action is divided into 3-4 motor segments. For example, the action to take the coffee can be decomposed into the following motion segments: pouring coffee into the cup, adding sugar, turning the spoon and then bringing the coffee to the mouth. Each motion segment is presented for 3 minutes through the movie (observation phase). At the observation end the patients are required to perform the observed action. All items needed to perform a contextualized action in are placed at their disposal (execution phase).

A typical AOT session takes about half an hour. A few minutes are needed by the physiotherapist to explain the task to the patient (carefully looking at the movie, paying attention also to the details of presented actions) and to motivate him to the task, then 12 minutes of observation (3 minutes for each of the motion segments in which the action is divided) and finally 8 minutes of imitation (2 minutes for each motion segment). The patient, during the imitation phase, has to perform the observed motor segment at the best of his ability. Anyway he/she is informed that the focus of treatment is the observation of action, not its execution.

So far, AOT has been employed in the rehabilitation of patients suffering from chronic ischemic stroke (at least 6 months after the acute event), Parkinson disease and also in non-neurologic patients such as those undergone orthopedic surgery of hip or knee. Recently, it has been conducted a case-control study on the efficacy of AOT in children affected by cerebral palsy (personal communication).

In a study of patients with chronic stroke,[40] patients undergoing AOT significantly improved in all functional scales used to quantify changes in motor abilities as compared to controls. In this study the Stroke Impact Scale (SIS), the Wolf Motor Function Test and the Frenchay Arm Test (FAT) were used as functional scales. Similar results were obtained more recently by Franceschini *et al.* (2011).[41]

In a recent randomized case-control study Buccino *et al.*[42] investigated the efficacy of AOT in Parkinson disease. Rehabilitation treatment is known to complement the pharmacologic approach in this class of patients. While the cases followed AOT procedure, the controls observed movies devoid of specific motor content. The functional evaluation scales employed were the Unified Parkinson's Disease Rating Scale (UPDRS) and the Functional Independence Measure (FIM). In both scales cases reached significantly different scores, even if these results need be confirmed in a broader sample of patients.

To assess whether AOT may also improve motor recovery in postsurgical orthopedic patients, Bellelli *et al.*[43] conducted a randomized controlled trial where all participants underwent conventional physiotherapy. In addition, patients in the case group were asked to observe video clips showing daily actions and to imitate them afterward. Patients in the control group were asked to observe video clips with no motor content and to execute the same actions as patients in the case group afterward. Participants were scored on functional scales (FIM and Tinetti Scale) at baseline and after treatment by a physician blinded to group assignment. At baseline, groups did not differ in clinical and functional scale scores. After treatment, patients in the case group scored better than patients in the control group. The present findings shows that, in addition to conventional physiotherapy, AOT is effective in the rehabilitation of postsurgical orthopedic patients.

Conclusions

In conclusion, our present knowledge on the motor system on one side extends the role of the motor system to domains classically considered of cognitive nature; on the other it provides with new strategies to be applied in the field of rehabilitation.

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LETTER TO THE EDITOR

Wiihabilitation

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Dear Editor,

We would like to draw readers' attention to the promising alternatives that virtual rehabilitation (VR) can offer to traditional techniques and exercises. The world of VR is exciting, and a new generation of affordable commercial video game consoles (VGCs) with a motion-sensing controller that allows players to perform real-life physical movements has been making inroads into the rehabilitation arena.[1] The objective is to make therapeutic exercise fun and contextual, encouraging patients to improve through repetition their performance.

Presently, the worldwide best selling VGC is the Nintendo Wii (Nintendo of Europe GmbH, Grossostheim, Ger), and the term *Wiihabilitation* has been coined to indicate its use in rehabilitation.[1] The Wii has received increasing attention from researchers and clinicians, and has been recently integrated into rehabilitation programs to assist in treating impairments of various different origins, e.g. neurological, respiratory, balance and orthopedic. However, there are currently few studies evaluating its therapeutic effects that meet evidence-based criteria.[2]

In this letter, we will seek to answer the following questions: what are the potential advantages of and the risks arising from Wii use? And what are the best movement-based interfaces and games for patients?

The Wii may offer a cost-effective, widely available means to utilize VR as an adjunct in the rehabilitation of injured patients. It could represent a solution to current limits on health care resources by increasing patients' independence in carrying out their rehabilitation, while engaging and motivating the individual involved to continue therapy for a longer period of time.[3] Increased motivation in those patients who are often unmotivated to carry out the very repetitive limb movements that are common in rehabilitation has been reported with use of the Wii, minimizing the problems with compliance encountered with more traditional therapeutic strategies. Some patients reported also that as their focus turned to the game, there was a less negative focus on the affected limb.[4] Finally, it may offer an opportunity for socialization and occupational therapy, for example if patients use it in pairs or in a group supervised by the therapist.[5]

While the Wii does have benefits, the games are not designed specifically for rehabilitation, leading to some limitations concerning its use in this context: it cannot accurately monitor and track patient's progress, games may be too difficult for patients (who could become frustrated with high-challenging tasks), and there is a lack of appropriate feedback for patients.[1] Overexertion is another aspect to consider when using Wii with individuals who have the risk of harming themselves from either too much use or through exaggerated move-

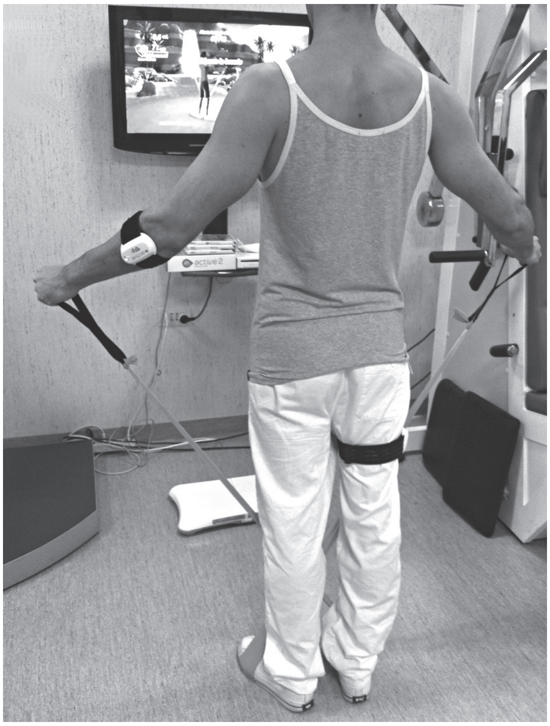

Figure 1.—A subject playing with Wii "Sports Active 2": note the two wireless sensors for motion capture on his right thigh and left forearm. The exercise is performed by using an external resistance (Theraband) and feedback for proper technique is provided by the virtual trainer on the screen.

ments within a short time. Very little exists in the medical literature regarding the type and distribution of Wii related injuries, but it is realistic to think that they are much more common than reported, especially for hand trauma.

Nintendo Wii detects the user's movement and acceleration in 3 dimensions using a wireless handheld pointing controller (Wiimote) housing a gyroscope and an accelerometer. This system provides also multi-sensorial feedback such as auditory, haptic and visual components - and gives high goal-attainment motivation to the patient. Further innovation has led to the development of the Wii Balance Board, a platform containing multiple pressure sensors that allow the calculation of the user's center of balance. Players employ active body movements as the mode of interaction with the video game, e.g. swinging a virtual tennis racket or throwing a virtual basket ball. Thus, the selection of the most appropriate software title is targeted to specific activities or muscles to be trained: those most suitable for rehabilitation purposes are fitness (Wii Fit Plus, Wii Fit), sports (Wii Sports Resort, Wii Sports) and occupational (Cooking Mama, Brico Party) games.

One of the principal Wiihabilitation's drawbacks is the fact that participants can use different movement strategies to play games, particularly when interacting with the handheld controller.[5] The strategies can differ according to the participants' motivation, range of movement restriction, pain, or weakness in the involved muscle groups. For example, a patient with shoulder complaints playing the Wii basket free throws can obtain high scores even by moving only the wrist, without properly elevating the upper limb. Whatever the cause of this wrong pattern of movement, the device does not give proper feedback on the actual movement being performed, making the Wii less effective for rehabilitation purposes. A possible solution could be offered by the recently released title "Sports Active 2" by EA Software. This game uses a more accurate motion capture system composed of two sensors placed on the body: one on the right thigh, the other on the left forearm (Figure 1). It also offers the possibility to monitor heart rate and to customize exercise protocols by choosing the area (upper limb, lower limb, trunk), type (strengthening, cardiac, stretching, balance & coordination, burn up) and degree of difficulty (low, medium, hard). The exercises can be performed free-body or with the use of additional devices (Theraband, step, bouncer, dumbbell, barbell, Wii Balance board, etc.). A virtual trainer shows the correct movements to be performed, their velocity and amplitude, and allows the patient to correct himself. The scores can be saved and improvements are shown in a trend curve, representing the goal-motivation feedback.

At present Wiihabilitation cannot be a substitute for conventional rehabilitation, but it can add a dimension of entertainment and offer promising alternatives to traditional exercises. However, it suffers from drawbacks that prevent its widespread adoption. The first requirement is to produce evidence supporting its therapeutic use, so that therapists can understand what type of patient and what conditions can benefit from its use. It will be also important to validate the game outcomes as indicators of improved range of movement, balance or function. Partnership between physiotherapists, engineering, software developers and industry would be a useful strategy to bring together the necessary expertise to examine the therapeutic benefits of VR and further develop it and related technologies for clinical purposes.[4]

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