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Title

Motion detection supported exercise therapy in musculoskeletal disorders: a systematic review

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Conflict of interest

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Abstract

INTRODUCTION: Musculoskeletal disorders (MSDs) are a burden on the healthcare system. Exercise therapy is an important part of MSD rehabilitation. Motion detection systems are developed to support exercise therapy settings. This systematic review aims 1) to investigate which types of motion detection systems have been used as a technological support for exercise therapy, 2) to investigate the characteristics of motion detection supported exercise therapy in relation to its clinical indications, and 3) to evaluate the effectiveness of motion detection supported exercise therapy, in MSD rehabilitation.

EVIDENCE AQCUISITION: A systematic literature search for RCTs was performed in six databases (PubMed, CINAHL, EMBASE, ACM, Cochrane, and IEEE). Studies eligible for inclusion had to evaluate exercise therapy for persons with MSDs, provide a motion detection system capable of as well measuring active movement of the participant during exercise therapy as evaluating the movement in order to provide qualitative feedback, and should present at least one measure of the following ICF function (pain, muscle strength, mobility), activity (disease-related functional disability, balance) or participation (quality of life) level. Two reviewers independently screened articles, appraised study quality, extracted data, and evaluated effectiveness of selected outcome measures. This review was registered in the International prospective register of systematic reviews (Prospero) under registration number CRD42016035273.

EVIDENCE SYNTHESIS: Nine RCTs (n=432 participants) were included. Eight different motion detection technologies were used such as an accelerometer, gyroscope, magnetometer etc. All systems provided visual feedback. Knee disorders were evaluated most frequently, followed by low back pain and shoulder disorders. Therapy consisted of mobility, balance or proprioception exercises. Main outcomes were pain, disability, mobility and muscle strength. Motion detection supported exercise therapy showed similar or enhanced results on all outcomes compared to conventional exercise therapy. However, a limitation of this study was the low methodological quality of the studies.

CONCLUSIONS: To date, a variety of motion detection systems have been developed to support the rehabilitation of MSDs. Results show similar effectiveness of motion detection supported exercise therapy compared to conventional exercise therapy. More research is needed to provide insight in the added value of motion detection systems in musculoskeletal rehabilitation.

Keywords: musculoskeletal, rehabilitation, exercise therapy, technology

Abstract word count: 348

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Introduction

Musculoskeletal disorders (MSDs) involve a variety of highly prevalent pathologies that can have a major impact on a person's health.[1] They are currently the main global cause of work-related illness[2] and chronic physical disability[1] leading to high healthcare costs.[3, 4] During the last decade the prevalence of MSDs has increased with 25%[5] and it is expected that the impact of these disorders will continue to rise in the following years due to increased life expectancy and lifestyle factors such as obesity and physical inactivity. Effective rehabilitation strategies are thus needed to treat MSDs efficiently.

Exercise therapy (ET) has been advocated as an important part of treatment for several chronic MSDs.[6] But, even though ET can improve symptoms and daily functioning of persons with MSDs, therapy outcomes often show limited effect sizes.[7, 8] This can be due to poor therapy adherence.[8-13] To obtain sufficient therapy adherence, retaining the motivation of patients to rehabilitate seems crucial.[13-16] As such, it seems warranted to construct therapy programs that stimulate the motivation of patients to persevere with training sessions and to complete training regimes. However, this can be a challenge because of the repetitiveness of training active movements, which is often considered as boring and unchallenging to patients.[17] Also, compensatory movement patterns can arise through pain avoidance.[18] However, correct and repeated execution of movements is a necessity to induce motor learning and alter movement patterns.[19]

There has been a growing interest in using rehabilitation technology.[20] Virtual environments (i.e. the use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear to be and feel similar to real world objects and events[21]) and serious games (i.e. digital games with a primary goal that goes beyond entertainment, played with a computer or video console in accordance with specific rules, to further government or corporate training, education, health, public policy, and strategic communication objectives."[22]) can be set up to promote physical activity and to train repetitive tasks through exergaming. They can simultaneously entertain the patient, bring an element of fun to the therapy and support therapeutic engagement.[23-26] Lately, technology with the ability to detect body movements (e.g. sensors or cameras) can provide (real-time) augmented feedback concerning quality or quantity of exercise execution or other specific movement-related parameters.[27] Patient specific exercises and training goals can be set with reference to this feedback, resulting in a more client-centered therapy approach.[28] Also, a therapy-aiding system can elongate the therapy session without the constant supervision of an assisting therapist and creates opportunities for patients to train at home while still receiving (sufficient) corrective feedback.[29] Besides, the reduction of need for face-to-face therapy may lead to improved therapy expediency and a decrease of therapy expenses.[30]

In neurological rehabilitation some specific motion detection systems have already been evaluated as a training tool. Nintendo Wii has been proven applicable for the rehabilitation of persons after stroke[31, 32] and with Parkinson disease.[33, 34] Microsoft Kinect has been reviewed in therapeutic settings including stroke, Parkinson, and cerebral palsy.[35-37] Other movement detection systems, such as inertial sensors, have been used in specific neurorehabilitation settings.[38-40] Likewise, motion detection systems have also been effectively used to support therapy of elderly at risk for falls.[35, 41, 42]

To date, the implementation and effectiveness of motion detection systems as a support to exercise therapy for the rehabilitation of person with MSDs has not yet been evaluated in a systematic review. Therefore, this systematic literature review aims 1) to investigate which types of motion detection systems have been used as a technological support for exercise therapy in MSD rehabilitation, 2) to investigate the characteristics of motion detection system supported exercise therapy in relation to its clinical indications in MSD rehabilitation, and 3) to evaluate the effectiveness of motion detection systems as a therapy modality for the improvement on function, activity, and participation level in MSD rehabilitation.

Evidence acquisition

Search strategy

This literature search was performed until the 1st of March 2016 and was registered in the International prospective register of systematic reviews (Prospero), under registration number CRD42016035273. The "Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA)" guidelines were applied. Articles were retrieved through a systematic computerized search in following databases: Pubmed/Medline, CINAHL, EMBASE, ACM, Cochrane and IEEE. Following search terms were used in combination: (musculoskeletal diseases OR musculoskeletal physiological phenomena OR pain OR low back pain OR musculoskeletal) **AND** (rehabilitation OR physical therapy modalities OR home exercises) **AND** (motion detection OR motion analysis OR motion capture OR motion detection OR movement analysis OR motion tracking OR movement tracking OR sensor OR camera OR video OR User-Computer Interface OR serious game OR exergame OR Kinect OR Wii OR virtual reality OR feedback OR biofeedback). The search strategy was modified to the search structure of each database. A detailed search strategy for every database can be found in 'supplementary material 1'. Title and abstract of all retrieved articles were screened for eligibility by two independent reviewers (JV and EK). Reference lists of included articles were scanned for other relevant publications. Eligible articles were read in full text and outcomes were discussed and evaluated until an agreement on in/exclusion was reached. When no agreement was found between EK and JV concerning article in/exclusion, a third reviewer (AT) made the final decision.

Eligible studies

Articles were included for this review when all of the following criteria were present: 1) the study design was a randomized controlled trial (RCT), 2) the included persons were older than

18 years, 3) exercise therapy[43] was evaluated in persons with MSDs[1], 4) a motion detection system, i.e. a system consisting of minimum one camera and/or sensor with the ability to directly or indirectly measure active movement of (parts of) the body, was used during the execution of the exercise therapy, 5) the motion detection system was able to either qualitatively or quantitatively evaluate the user's performed movements and provide feedback to the user, 6) the control group received active or passive physical therapy with a comparable duration and volume or no therapy at all, 7) one or more of the following outcome measures on the ICF[44] function (pain, muscle strength, mobility), activity (disease-related functional disability, balance) or participation (quality of life) level were evaluated, and 8) articles were written in English, French, Dutch or German.

Articles were excluded for this review when any of the following criteria were present: 1) a motion detection system was solely used for assessment and/or diagnostic purposes, 2) the system evaluated movement by means of heartrate monitoring (ECG), ultrasound imaging or electromyography (EMG).

Methodological assessment

The methodological quality of the selected studies was rated independently by two reviewers (EK and JV) by using van Tulder's Quality Assessment system for RCTs.[45] The van Tulder assessment has a maximum score of 19 and consists of internal validity criteria (score 0-11), descriptive criteria (score 0-6), and statistical criteria (score 0-2). Internal validity criteria refer to characteristics of the study that might be related to selection bias, performance bias, attrition bias, and detection bias. The item 'blinding of the care provider' was not included in the evaluation, as this is inapplicable for exercise therapy settings. Descriptive criteria refer to the external validity of the study. Statistical criteria indicate whether calculations can be made and conclusions can be drawn independently of the opinion of the authors of the original study. Van Tulder considers RCTs to be of high methodological quality when the internal validity is ≥5/10. Before results were discussed, a Cohen's Kappa score was calculated to evaluate agreement correlation. The results of both reviewers were then compared and discussed until an agreement on the checklist score was reached. When no agreement was found, a third reviewer (AT) made the final decision. To minimize publication and selective reporting bias, outcome measures reported in the methodology and results sections of the included studies were screened to note inconsistencies when reporting results. Furthermore, the titles and last author of the included studies were screened for presence on the clinical trials register.

Data extraction

Two reviewers (JV and EK) performed the data extraction independently according to a template that was agreed on in advance. Firstly, an overview table with general study characteristics based on the PICO was set up with reference to participants (number, age, musculoskeletal disorder), interventions (system and technology, intervention exercise therapy program, dropout), comparisons (control group program), and outcomes (outcome measures, results and effect sizes). Secondly, a table was constructed to categorize specific intervention characteristics and system feedback modalities. Subsequently, articles were grouped and evaluated according to the motion detection technology systems characteristics, intervention characteristics (e.g. training volume/frequency, intervention goals), and system feedback characteristics (e.g. feedback modality, quality of feedback). Then, reported outcome measures were extracted and classified according to the International Classification of Functioning, Disability and Health (ICF)[44] to analyze effectiveness of the motion detection supported exercise therapy. Hedges' g was used to calculate the effect sizes of the between group outcomes. Positive values were interpreted in favor of the intervention therapy.

Negative values were interpreted in favor of the control therapy. According to Cohen's classification[46]: an ES of 0.2 is considered as small, 0.5 as medium, 0.8 as large. In cases where means and SDs were not provided in the article, the respective authors of the articles were contacted by e-mail and data were requested. When no data was obtained from these sources, no effect sizes were calculated (displayed as not reported (NR)).

Evidence synthesis

Selection of studies

The database search resulted in 4850 articles. After duplicate removal and title/abstract screening, 154 articles were identified for full text reading. Finally, nine studies were found to be eligible. Figure 1 presents the study selection process in a PRISMA flow diagram.[47]

Methodological assessment

An overview of the Van Tulder quality assessment is shown in table 2. Two reviewers agreed on 145/171 items, resulting in a Cohen's Kappa score of .56 which is considered a moderate agreement. Four studies[48-51] showed high methodological quality (i.e. internal validity score ≥5/10). Overall, the mean internal validity score was 4.3/10 (SD=1.0). The mean descriptive score was 3.9/6 (SD=0.3). All studies had the maximum statistical score of 2/2.

When comparing the outcome measures of each included study described in the methodology to those reported in the results, no inconsistencies were found. However, only Fung *et al.*[49] mentioned clinical trial registration allowing for comparison of the original research protocol to the methodology reported in the publications.

Patient characteristics

A detailed description of patient characteristics is given in Table 3. In total, the results of 432 persons with MSDs with an average age of 62.5 years (SD=12.6) were included. Ayoade & Baillie[51] did not provide mean age and was therefore excluded from this calculation. Five studies[48-52] reported on knee related MSDs (n=304; 70% of total). Two studies[53, 54] reported on low back pain (n=55; 13% of total). Frozen shoulder[55] (n=40; 9% of total) and a variety of lower limb MSDs[56] (n=33; 8% of total) were described in one study each. The average sample size was 50.1 (SD=39.0).

Motion detection technology systems characteristics

An overview of used motion detection technology is shown in table 1. An overview of system characteristics is shown in table 3. Eight different motion detection technologies were used, namely: accelerometer (AM)[48, 50, 51, 53], electronic goniometer (GM)[52], infrared sensor/camera (IF)[48, 53, 55], high-speed red, green, and blue camera (RGB)[55], gyroscope (GY)[50, 51], magnetometer (MM)[51], pneumatic force sensor (FS)[56] and pressure sensor (PS)[48, 49, 54]. The most frequently used technology was an accelerometer (n=4). Five[48, 50, 51, 53, 55] studies used a combination of the latter technologies.

Intervention characteristics

An overview of intervention characteristics is shown in table 4. Apart from the study executed by Ayoade & Baillie[51], all studies consisted of an intervention given at a hospital or rehabilitation center. Motion detection supported exercise therapy was either provided as stand-alone therapy[48, 50-52, 54, 56], combined with additional conventional exercise therapy[49, 53], or combined with passive physiotherapy[55] (e.g. massage, passive mobilization). Six studies[48-50, 54-56] had a control group receiving conventional exercise therapy, one[53] had a control group only receiving passive physiotherapy, and two[51, 52] had a control group receiving no therapy at all.

Intervention volume ranged from 4 to 36 sessions (mean=17.7), except from Fung *et al.*[49], who used a variable total session volume. Intervention frequency varied from once a week up to daily interventions (mean=4.1 sessions/week). Intervention duration ranged from 15 to 60 minutes (mean=38.3). Three studies[51-53] did not provide a clear description of intervention duration. As for the exercise therapy content, mobility exercises[50, 51, 55], balance exercises[48, 49, 53], proprioception exercises[52, 56], and yoga exercises[54] (a combination of balance and mobility) were used. The most stated intervention goals were pain reduction[49, 50, 53, 54, 56] and disability improvement[50-52, 54, 57].

Three studies[50-52] implemented analytical exercises (i.e. addressing localized joint movement not linked to skills), and six studies[48, 49, 53-56] implemented task-oriented exercises (i.e. training of skills and activities aimed at increasing subject's activity and participation[58]).

Systems feedback characteristics

An overview of system feedback characteristics is shown in table 4. Feedback pertained to visual feedback[50-52, 54, 55], or a combination of visual and auditory feedback[56]. Three studies[48, 49, 53] did not state how feedback was provided. The components of feedback were inventoried following a schematic presentation of extrinsic feedback components for motor performance.[59] Knowledge of results (KR) and knowledge of performance (KP) feedback were used in five studies[50-52, 55, 56], always in combination with each other. KP feedback was always given concurrently (real time) and provided qualitative data concerning the participants movement execution. KR feedback was always given as summary feedback after execution of the movement (terminal feedback). Four studies[48, 49, 53, 54] did not describe the type or components of feedback.

Effectiveness of motion detection supported exercise therapy

Because of the heterogeneity of the included studies and overall low study quality, pooling of data was not found appropriate. An overview of Hedges 'g effect sizes on different outcome levels (function, activity and participation) for the individual studies can be found in table 1.

ICF body function level Pain intensity was evaluated in four studies[49, 50, 53, 56]. Kim *et al.*[54] showed improvements on low back pain in a VR-based yoga group compared to conventional exercise therapy. Fung *et al.*[49] and Hershko *et al.*[56] showed comparable improvements in a motion detection supported intervention group and a control exercise therapy program for knee related MSDs. Ji-Hyuk *et al.*[53] also evaluated knee related MSDs and showed improvements in time in the motion detection supported intervention group, however a between group comparison with the passive control group was not executed.

Muscle strength was evaluated in four studies[48, 50, 52, 53]. Piqueras *et al.*[50] showed improved isometric muscle strength of the knee in comparison to conventional therapy, Ji-Hyuk *et al.*[53] and Baltaci *et al.*[48] showed improved isokinetic[53] and functional[48] muscle strength in the motion detection supported intervention group over time, and Lin *et al.*[52] showed improved isokinetic muscle strength through motion detection supported exercise therapy in knee osteoarthritis in comparison to a control group receiving no therapy.

Active range of motion was evaluated in three studies[49-51]. Ayoade & Ballie[51] showed improvements in active knee extension in comparison to standard care. Fung *et al.*[49] and Piqueras *et al.*[50] showed comparable knee flexion and extension ROM increases in a motion detection supported intervention and a control exercise therapy program. Ming-Chun *et al.*[55] evaluated passive shoulder range of motion and showed better improvements in comparison to a conventional exercise therapy program.

ICF activity level Disability was most frequently measured (n=4[49, 51, 52, 54]). Kim *et al.*[54] showed better improvements for motion detection supported exercise therapy in comparison to conventional exercise therapy. The other three studies showed similar improvements between a motion detection supported intervention and a conventional therapy program.

Three studies[48, 49, 53] reported balance. Ji-Hyuk *et al.*[53] showed no improvements in persons with chronic low back pain in a one-legged stance test in the motion detection supported group. Baltaci *et al.*[48] and Fung *et al.*[49] showed similar improvements in persons with knee disorders between motion detection supported exercise therapy interventions and conventional exercise therapy using functional balance scales.

ICF participation level Quality of life was only noted in Ji-Hyuk *et al.*[53]. Improvement was only shown in motion detection supported exercise therapy over time.

Discussion

The first aim of this study was to investigate which types of motion detection systems have been used as a technological support for exercise therapy in musculoskeletal disorder (MSD) rehabilitation. Accelerometers were used the most, solely or in combination with other technology. Accelerometers are small in size, portable and easy to integrate into rehabilitation devices/aids, while also being affordable.[30, 60] Furthermore, they have been shown to be a valid tool for measurement of different kinds of physical motion tracking[61-63], which makes them usable in various rehabilitation setups. On the contrary, newer 'visual based' systems, consisting of cameras and/or vision sensors, such as tracking systems (i.e. systems using a camera that tracks physical body markers or a designated controller) or markerless systems (i.e. systems detecting motion without the patients having to hold, touch or wear any sensors directly on the body) have also emerged as motion detection methods.[64] The latter systems can limit movement restrictions (which are due to accelerometer placing and sensor noise[30]) and are useful for more complicated motion trajectories as they do not produce drift problems like accelerometers.[30] In addition, markerless systems can improve user-friendliness as they do not need any placing of markers before therapeutic use.[30] However, visual based systems often require a more extensive, immovable setup of cameras and specialized data-analysis, and are more dependent on environmental factors such as lighting conditions and background noise.[65] Two studies used a tracking system (i.e. Nintendo Wii), and one[55] a markerless system (i.e. Microsoft Kinect). But, only the latter used a specialized rehabilitation game. The other two used preexisting games that were not optimized for rehabilitation purposes. It is not clear whether those games actually train what they claim to train eg. muscle force, balance, mobility). More research towards construct validity of motion detection systems and their 'game protocols' could aid to investigate whether the patient progress is actually devoted to the gaming element training. Other motion detection technologies such as a gyroscope or pressure sensor were also evaluated, although they were less commonly used and were mainly dependent of accompanying accelerometer data. Their motion analysis was mostly indirect (e.g. Nintendo Wii Balance board estimating movement through ground reaction force analysis) and they were primarily used to quantitatively measure movement. In a rehabilitation context with an emphasis on qualitative movement, these systems are not applicable in their current setups. Importantly, five out of nine systems in this review were relatively inexpensive off-the-shelf products, which can facilitate further clinical implementation and use in hospitals, clinics and even the home setting.[66]

The second aim of this study was to investigate the characteristics of motion detection supported exercise therapy in relation to its clinical indications, in MSD rehabilitation. A variety of MSDs has been evaluated and included in this review. Moreover, MSDs such as chronic musculoskeletal pain[67], patellofemoral pain syndrome[68], shoulder disorders[69], and total hip replacement[70]) have also been studied in non-randomized studies, showing opportunities for broader applicability of motion detection systems in MSD rehabilitation. With the exception of Ayoade & Baillie[51], who provided individual home-based exerces, all included studies consisted of exercise therapy in support of a therapist at a hospital or clinical practice. As home based therapy showed improvements in physical recovery and motivation, and can also support inpatient rehabilitation[71], future research should further investigate the feasibility of implementing motion detection supported exercise therapy in home settings, especially because scientific evaluation of home-based systems in MSDs still seems scares.[29]

Although a task-oriented approach was used more frequently, which has been shown to be important in other populations[72], none of the studies provided client-centered therapy in which the patient had a choice which exercises were performed or how therapy was set up. As client-centered therapy can increase motivation and create the possibility to train on specific individual patient goals[73, 74], motion detection systems should be developed in a more adaptable way. Technology could be of great use in providing a variety of exercises and supporting individual goal setting.[20] At present these components are insufficiently applied. Systems mostly used a standardized program throughout the therapy protocol and were unadaptable to patient demands. Furthermore, characteristics of the training protocol were often unclear. Studies lack information concerning exercise progression, the ability to import or construct new exercises in the software, and the ability to adapt the exercise difficulty by software or therapist. Also, after evaluation of the task oriented exercises, some studies[49, 54] did not translate the task being executed by the patient to a visualization of the same task on a screen, but instead translated this movement into gaming elements (e.g. reaction of an avatar in a unnatural game environment when movement of the patient was detected). The effects of different ways of providing information to the patient and the effects on motor learning have not yet been evaluated in MSD rehabilitation.

All motion detection systems were used to provide feedback during or after the exercise therapy. Providing feedback can help improve the low therapy compliance seen in rehabilitation[10], as it supports patients with regard to exercise instructions and feedback on performance, and provides a motivational nudge in order to comply with the optimal exercise regime.[10, 11] Through providing augmented feedback, the attention of the patient is directed on an external focus, which can improve performance and retention of motor tasks.[75, 76] However, general guidelines concerning the use of external feedback in musculoskeletal disorders are scarce and should be further investigated.[75] Apart from Hershko et al.[56], who used a combination of auditory and visual feedback, all studies solely used visual feedback to rate movement performance. Visual feedback has been supported the most for delivering feedback, but other modalities such as audio or haptic feedback are being investigated and seem increasingly valuable.[77] A combination of feedback delivery methods might improve the outcomes more, certainly when complex tasks are being executed.[77] Although the motion detection systems always provided feedback, feedback characteristics were described inaccurately. Depending on the outcome of the therapy e.g. enhancing motivation or facilitating skill improvement, different sorts of feedback (e.g. knowledge of performance during an exercise or knowledge of results after an exercise) should be given[59] and systems need to be set up to support a specific purpose. On top of that, feedback may also need to change during different stages of rehabilitation. To improve the use of motion detection systems, it is thus crucial to inventory feedback characteristics and optimize the way they can aid rehabilitation.

The third aim of this study was to evaluate the effectiveness of motion detection supported exercise therapy, in MSD rehabilitation. All studies showed that movement detection system supported exercise therapy in MSD rehabilitation was more effective than passive therapy or a control group without exercise therapy, and at least equally as effective as conventional exercise therapy. Furthermore, on the ICF function level and activity level, motion detection system supported exercise therapy seemed to be able to improve some outcomes such as pain intensity, range of motion and disability more than conventional exercise therapy. These positive outcomes were however not reproduced in all studies. It should be mentioned that methodological quality was low in five out of nine included studies. All studies lacked or gave unclear information concerning patient and assessor blinding. Furthermore, lack of concealment of allocation, low therapy compliance rates and/or lack of information concerning compliance rates were noted in almost all studies. Hence, these issues could have a considerable effect on the displayed results of this review. Also, the improvements, or lack thereof, found in motion detection supported exercise therapy, could have been due to several causal factors (e.g. the addition of an interactive environment, increased effectiveness of exercises execution, the provision of continuous feedback, improved satisfaction with the therapy, …). The included studies insufficiently answered the possible influence of these factors.

Limitations & future perspectives

Firstly, because of the limited number of high quality RCTs, the heterogeneity in MSK populations, and the small amount of homogeneous data concerning specific outcome measures, it proved difficult to summarize motion detection systems on their effectiveness in comparison with conventional therapy settings. Further, the observed low therapy compliance in some studies (>20% dropout) can have an impact on the reviewed results. However, this is a generic problem in MSD rehabilitation[10] and no differences were noted between motion detection supported and convention exercise therapy groups. To improve the use of motion detection systems in MSD rehabilitation, more RCTs with high methodological quality should be set up. These RCTs should clearly evaluate the added effect of the motion detection system compared to the conventional therapy in various MSDs. Secondly, future studies should provide more information concerning intervention characteristics and system feedback, as offering individualized exercises, home therapy, and providing feedback according to the proficiency level of the user is stated to be important. Lastly, the causes for therapy success when using motion detection supported therapy should be investigated as these can bring forward specific guidelines for setting up new systems.

Conclusions

To date, motion detection systems have been used to support the rehabilitation of a selection of MSDs such as knee disorders and low back pain. Motion detection supported exercise therapy seems at least as effective as conventional therapy, but it does not show superiority to other exercise therapy modalities. Technology consisting of an accelerometer has been used most frequently for motion detection. In this review, methodological quality of the included studies was relatively low and meaningful effect size comparison was partly obstructed due to heterogeneity of study designs. Therefore, more research is needed to justify the usability and effectiveness of motion detection supported exercise therapy in MSD rehabilitation.

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Conflicts of interest

The authors report no conflicts of interest.

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Figure 1. – PRISMA flow chart of the article selection process.

Table 1.

Overview of the used motion detection technologies.

Study	Accelerometer	Electronic goniometer	Infrared sensor/camera	(hghspeed or RGB) Camera	Gyroscoop	Magnetometer	Pneumatic force sensor	Pressure sensor
Ayoade (2014) [51]	x				x	x		
Ji-Hyuk (2013) [53]	x		x					
Huang (2014) [52]				x				
Baltaci (2013) [48]	x		x					
Fung (2011) [49]								x
Hershko (2008) [54]							x	
Kim (2014) [55]								x
Lin (2007) [59]		x						
Piqueras (2013) [50]	x				x			
Total	4	1	2	1	2	1	1	2

Table 2.

Van Tulder methodological quality assessment of the included studies.

Study	Internal validity											Descriptive quality						Statistical validity		Final scoring
	B1	B2	E	F	G	H	I	J	L	N	P	A	C	D	K	M1	M2	O	Q	Quality
Ayoade (2014) [51]	1	0	Na	0	1	0	0	1	1	1	0	1	1	0	0	1	0	1	1	High
Ji-Hyuk (2013) [53]	0	0	Na	1	1	0	0	1	0	1	0	1	1	1	0	1	0	1	1	Low
Huang (2014) [52]	0	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	Low
Baltaci (2013) [48]	1	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	High
Fung (2011) [49]	1	0	Na	1	0	0	1	1	1	0	0	1	1	1	0	1	0	1	1	High
Hershko (2008) [54]	0	0	Na	1	0	0	0	1	0	1	0	1	1	1	0	1	0	1	1	Low
Kim (2014) [55]	0	0	Na	1	0	0	0	1	0	1	0	1	1	1	0	1	0	1	1	Low
Lin (2007) [59]	0	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	Low
Piqueras (2013) [50]	1	1	Na	1	0	0	0	1	1	1	0	1	0	1	0	1	1	1	1	High

Abbreviations: A: Were the eligibility criteria specified?; B1: Was a method of randomization performed?; B2: Was the treatment allocation concealed?; C: Were the groups similar at baseline regarding the most important prognostic indicators?; D: Were the index and control interventions explicitly described?; E: Was the care provider blinded for the intervention?; F: Were co-interventions avoided or comparable?; G: Was the compliance acceptable in all groups?; H: Was the patient blinded to the intervention?; I: Was the outcome assessor blinded to the interventions?; J: Were the outcome measures relevant?; K: Were adverse effects described?; L: Was the withdrawal/dropout rate described and acceptable?; M1: Was a short-term follow-up measurement performed?; M2: Was a long-term follow-up measurement performed?; N: Was the timing of the outcome assessment in both groups comparable?; O: Was the sample size for each group described?; P: Did the analysis include an intention-to-treat analysis?; Q: Were point estimates and measures of variability presented for the primary outcome measures?; Na: not applicable.

Table 3.

Overview of study characteristics.

Study	System	Participants	Intervention	Outcome measures	Results	Effect sizes [CI 95%]	Dropout
Ayoade (2014) [51]	Interactive rehabilitation visualisation system (AM, GY, MM)	TKR (n=21).	(I) Home exercise program with RVS (n=11) (C) no treatment (n=10)	*Function* AROM flexion AROM extension *activity* OKS	NS in I compared to C significant ↑ in I compared to C (p=0.002) NS in I compared to C	NR NR NR	described: 3 non described: 3 total: 6
Ji-Hyuk (2013) [53]	Nintendo Wii (AM, IR)	Chronic LBP (n=24).	(I) Nintendo Wii exercise program plus usual care (n=8) (C1) stabilization exercises program plus usual care (n=8) (C2) passive therapy (hot pack, interferential current, ultrasound) (n=8)	*Function* Pain VAS Muscle strength *activity* OLST *participation* RAND-36 physical functioning mental functioning	Significant ↓ in I compared to PRE (p<0.05) Significant ↑ in I compared to PRE NS in I compared to PRE NS in I compared to PRE NS in I compared to PRE	NR NR NR NR NR	no description
Huang (2014) [52]	Microsoft Kinect (IR, RGB)	Frozen shoulder (n=40).	(I) usual care with VR-based real-time quantified feedback and VR game based training (n=20) (C1) usual care (rehabilitation exercise training, hot pack, ultrasonic treatment) (n=20)	*Function* PROM flexion, abduction, external rotation, internal rotation	Significant ↑ between I and C in flexion (p<0;05), abduction (p<0.05), external rotation (p<0.05), internal rotation (p<0.01)	NR	no dropout
Baltaci (2013) [48]	Nintendo Wii (AM, IR) Nintendo Wii Balance Board (PS)	ACL recon-struction (n=30).	(I) Nintendo Wii Fit exercise program (n=15) (C) conventional rehabilitation exercise program (n=15)	*Function* Muscle strength *Activity* SEBT	NS in I compared to C NS in I compared to C	NR 0.43 [-0.29, 1.16]	no description
Fung (2011) [49]	Nintendo Wii Balance Board (PS)	Full lower extremity weight baring TKR (n=50).	(I) Wii Fit gaming activity plus usual care (n=27) (C) extra lower extremity exercises plus usual care (n=23)	*Function* AROM knee flexion AROM knee extension NPRS *Activity* LEFS ABCS	NS in I compared to C NS in I compared to C NS in I compared to C NS in I compared to C NS in I compared to C	NR	no dropout

Hershko (2008) [54]	Smartstep Gait System (FS)	PWB after fracture or surgery (n=33).	(I) (C)	same therapy as the control group with addition of a biofeedback system (n=15) weight-bearing walking, transfer training and strengthening exercises for the injured limb (n=18)	*Function* Pain VAS	NS in I compared to C	NR	no description
Kim (2014) [55]	Nintendo Wii Balance Board (PS)	Chronic LBP (n=30).	(I) (C)	VR-based yoga program using the Wii fit activities. trunk stabilization exercises and normal physiotherapy	*Function* Pain VAS *activity* ODI RMDQ	Significant ↓ in I compared to C (p<0.01) Significant ↓ in I compared to C (p<0.05) Significant ↓ in I compared to C (p<0.05)	1.47 [-0.67, 2.28] 1.11 [-1.88, -0.34] 0.88 [-0.13, -1.63]	no description
Lin (2007) [56]	custom-built apparatus (EG)	Bilateral KO (n=89).	(I) (C1) (C2)	a game to be played by the trained foot of the subject (n=29) 10 sets of 10 repetitions of resisted knee flexion and extension (n=26) no therapy	*Function* Muscle strength knee extension Muscle strength knee flexion *activity* physical function subscales of WOMAC	Significant ↑ in I compared to C2 (p=0.0083), NS in I compared to C1 Significant ↑ in I compared to C2 (p=0.0083), NS in I compared to C1 Significant ↓ in I compared to C2 (p=0.0083), NS in I compared to C1	NR	described: 8 total: 8
Piqueras (2013) [50]	interactive virtual tele-rehabilitation system (AM, GY)	TKA (n=142).	(I) (C)	IVT sessions of rehabilitation standard clinical physical therapy protocol for TKA	*Function* AROM flexion AROM extension pain VAS Quadriceps muscle strength Hamstrings muscle strength	NS in I compared to C NS in I compared to C NS in I compared to C Significant ↑ in I compared to C (p<0.01) NS in I compared to C	0.12 [-0.21, 0.45] -0.21 [-0.54, 0.12] 0.05 [-0.28, 0.38] 0.46 [0.13, 0.79] 0.20 [-0.13, 0.53]	described: 39 non described: 9 total: 48

Abbreviations: OM: outcome measures; ES: effect size; CI: confidence interval; NA: not applicable; AM: accelerometer; GY: gyroscope; MM: magnetometer; TKR: total knee replacement; RVS: rehabilitation visualization system; AROM: active range of motion; IMI: intrinsic motivation inventory; OKS: Oxford Knee Score; IR; infrared sensor/camera; LBP: low back pain; VAS: visual analogue scale; OLST: one-legged stance test; QOL: quality of life; RGB: RGB camera; VR: virtual reality; PS: pressure sensor; ACL: anterior cruciate ligament; SEBT: star excursion balance test; TKR: total knee replacement; NPRS: numeric pain rating scale; LEFS: lower extremity functional scale; ABCS: activity-specific balance confidence scale; FS: force sensor; PWB: partial weight-bearing; NSLBP: nonspecific low back pain; MCI: motor control impairment; AF: augmented feedback; PT: physiotherapy; ODI: oswestry disability index; PSFS: patient specific functional scale; RMDQ: Roland–Morris disability questionnaire; EG; electronic goniometer; KO: knee osteoarthritis; WOMAC: Western Ontario & McMaster Universities Arthritis Index; IVT: interactive virtual rehabilitation; TKA: total knee arthroplasty.

Table 4.

Intervention characteristics of the included studies.

Study	Intervention location	Intervention content	Intervention volume	Intervention frequency	Program length	Session duration (min)	Exercise therapy content	Intervention goals	Control group type	Therapy approach	Exercise database display	Exercise database quantity	Feedback modality	Quality of feedback	Real time feedback	Feedback on patient progress
Ayoade (2014) [51]	H	MDT	UC	daily	6 w	UC	Mobility exercises	Mobility, disability	NT	A	N	UC	visual	KP & KR	Y	yes
Ji-Hyuk (2013) [53]	C	MDT + CET	24	3	8 w	UC	Balance exercises	Pain, muscle strength, balance, QOL	C1: SSET C2: PAT	TO	N	UC	UC	UC	Y	UC
Huang (2014) [52]	C	MDT + PAT	8	2	4 w	20	Mobility exercises	Mobility	CET	TO	Y	6	Visual	KP & KR	Y	yes
Baltaci (2013) [48]	C	MDT	36	3	12 w	60	Balance exercises	Balance, muscle strength	CET	TO	Y	4	UC	UC	UC	UC
Fung (2011) [49]	C	MDT + CET	var	2	var	15	Balance exercises	Mobility, pain, disability, balance	CET	TO	Y	9	UC	UC	UC	UC
Hershko (2008) [54]	C	MDT	10	daily	10 d	45	Proprioception exercises	pain	CET	TO	Y	1	Visual and auditory	KP & KR	Y	UC
Kim (2014) [55]	C	MDT	12	3	4 w	30	Yoga	Pain, disability	CET	TO	N	UC	visual	UC	UC	UC
Lin (2007) [56]	C	MDT	24	3	8 w	UC	Proprioception exercises	Disability, muscle strength	C1: SSET C2: NT	A	Y	1	Visual	KP & KR	Y	UC
Piqueras (2013) [50]	C	MDT	10	daily	10 d	60	Mobility exercises	Mobility, muscle strength, pain, disability	CET	A	N	UC	Visual	KP & KR	UC	Yes

Abbreviations: H: Home based program; C: therapy in a clinical setting; UC: unclear; var: variable; w: week; d: days; MDT: motion detection therapy; CET: conventional exercise therapy; PAT: passive modalities therapy; NT: no treatment; CET: conventional exercise therapy; SSET: study specific exercise therapy program; F: function level; TO: task-oriented; N: no; Y: yes; KP: Knowledge of performance; KR: knowledge of results; NI: no information.

Appendix 1

Search strategies.

Database 1: PubMed

Search strategy 1

((((((((("Musculoskeletal Diseases"[MeSH]) OR "Musculoskeletal Physiological Phenomena"[MeSH]) OR "pain"[MeSH]) OR "low back pain"[keyword]) OR "musculoskeletal"[keyword]) OR "musculoskeletal system"[MesH])) AND ((((rehabilitation[MeSH:noexp]) OR physical therapy modalities[MeSH Terms]) OR "home exercises")) AND ((((((((((((((((("motion detection") OR "motion analysis") OR "motion capture") OR "motion detection") OR "movement analysis") OR "motion tracking") OR "movement tracking") OR "sensor") OR "camera") OR "video") OR User-Computer Interface[MeSH Terms]) OR "serious game") OR "exergame") OR "kinect") OR "wii") OR "virtual reality" OR "feedback") OR "biofeedback"))))

Search strategy 2

(("low back pain" OR "arthritis" OR "osteoarthritis" OR "osteoporosis") AND (("therapy" OR "rehabilitation") AND ("virtual reality" OR "feedback" OR "sensor" OR "camera" OR "game"))

Database 2: ACM

((musculoskeletal AND (therapy OR rehabilitation)) AND (("motion" OR movement OR detection OR capture OR analysis OR tracking OR "sensor" OR "camera" OR "video" OR "serious game" OR "kinect" OR "exergame" OR "wii" OR "virtual reality" OR "feedback"))

Database 3: Cinahl

((MH "Musculoskeletal System Physiology") OR (MH "Musculoskeletal System+") OR (MH "Musculoskeletal Diseases+") OR (MH "Musculoskeletal Abnormalities+") OR (MH "Diagnosis, Musculoskeletal+")) AND ((MH "Physical Therapy+") OR (MM "Research, Physical Therapy") OR (MM "Physical Therapy Practice, Research-Based") OR (MM "Physical Therapy Practice, Evidence-Based") OR (MM "Physical Therapy Practice") OR (MM "Rehabilitation")) AND ((MM "Motion Analysis Systems" OR "sensor" OR (MM "Videorecording") OR (MM "Virtual Reality") OR "kinect" OR "wii" OR "camera" OR "feedback" OR (MM "Video Games") OR (MM "User-Computer Interface"))

Database 4: Cochrane

(("Musculoskeletal") AND ("Rehabilitation" OR "Physical Therapy") AND ("motion" OR movement OR detection OR capture OR analysis OR tracking OR "sensor" OR "camera" OR "video" OR "serious game" OR "kinect" OR "exergame" OR "wii" OR "virtual reality" OR feedback))

Database 5: Embase

(Musculoskeletal Diseases OR musculoskeletal pain OR low back pain (all fields)) AND (rehabilitation OR physical therapy modalities (all fields)) AND (motion detection OR motion analysis OR motion capture OR motion detection OR movement analysis OR motion tracking OR movement tracking OR sensor OR camera OR video OR User-Computer Interface OR serious game OR exergame OR kinect OR wii OR virtual reality OR feedback (all fields))

Database 6: IEEE

"Physical therapy" + "motion
"Physical therapy" + "movement
"Physical therapy" + "Kinect
"Physical therapy" + "sensor
"Physical therapy" + "camera
"Physical therapy" + "video
"Physical therapy" + "wii
"Physical therapy" + "virtual reality"
"Physical therapy" + "game
"exercise therapy" + "motion
"exercise therapy" + "movement
"exercise therapy" + "Kinect
"exercise therapy" + "sensor
"exercise therapy" + "camera
"exercise therapy" + "video
"exercise therapy" + "wii
"exercise therapy" + "virtual reality"
"exercise therapy" + "game
"Musculoskeletal" + "rehabilitation" + "motion"
"Musculoskeletal" + "rehabilitation" + "movement"
"Musculoskeletal" + "rehabilitation" + "Kinect"
"Musculoskeletal" + "rehabilitation" + "sensor"
"Musculoskeletal" + "rehabilitation" + "camera"
"Musculoskeletal" + "rehabilitation" + video"
"Musculoskeletal" + "rehabilitation" + "wii"
"Musculoskeletal" + "rehabilitation" + "virtual reality"
"Musculoskeletal" + "rehabilitation" + "game"
"Pain" + "rehabilitation" + "motion"
"Pain" + "rehabilitation" + "movement"
"Pain" + "rehabilitation" + "Kinect"
"Pain" + "rehabilitation" + "sensor"
"Pain" + "rehabilitation" + "camera"
"Pain" + "rehabilitation" + "video"
"Pain" + "rehabilitation" + "wii"
"Pain" + "rehabilitation" + "virtual reality"
"Pain" + "rehabilitation" + "game"
"Wii" + "rehabilitation"
"Kinect" + "rehabilitation"
"Wii + therapy"
"Kinect" + "therapy"
"physical therapy" + "feedback"
"Exercise therapy" + "feedback"
"Musculoskeletal" + "rehabilitation" + "feedback"
"Pain" + "rehabilitation" + "feedback"

Database 7: Medline

("Musculoskeletal Diseases" OR "musculoskeletal pain" OR "back pain" OR "neck pain") AND (rehabilitation OR "physical therapy" OR "exercise therapy") AND ("motion detection" OR "motion analysis" OR "motion capture" OR "motion detection" OR "movement analysis" OR "motion tracking" OR "movement tracking" OR sensor OR camera OR video OR "User-Computer Interface" OR "serious game" OR exergame OR kinect OR wii OR "virtual reality" OR feedback)

Table 1.

Van Tulder methodological quality assessment of the included studies.

Study	Internal validity											Descriptive quality						Statistical validity		Final scoring	
	B1	B2	E	F	G	H	I	J	L	N	P	A	C	D	K	M1	M2	O	Q	Total	Quality
Ayoade (2014)	1	0	Na	0	1	0	0	1	1	1	0	1	1	0	0	1	0	1	1	10	High
Ji-Hyuk (2013)	0	0	Na	1	1	0	0	1	0	1	0	1	1	1	0	1	0	1	1	10	Low
Huang (2014)	0	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	10	Low
Baltaci (2013)	1	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	11	High
Fung (2011)	1	0	Na	1	0	0	1	1	1	0	0	1	1	1	0	1	0	1	1	11	High
Hershko (2008)	0	0	Na	1	0	0	0	1	0	1	0	1	1	1	0	1	0	1	1	9	Low
Kim (2014)	0	0	Na	1	0	0	0	1	0	1	0	1	1	1	0	1	0	1	1	9	Low
Lin (2007)	0	0	Na	1	0	0	0	1	1	1	0	1	1	1	0	1	0	1	1	10	Low
Piqueras (2013)	1	1	Na	1	0	0	0	1	1	1	0	1	0	1	0	1	1	1	1	13	High

Abbreviations: A: Were the eligibility criteria specified?; B1: Was a method of randomization performed?; B2: Was the treatment allocation concealed?; C: Were the groups similar at baseline regarding the most important prognostic indicators?; D: Were the index and control interventions explicitly described?; E: Was the care provider blinded for the intervention?; F: Were co-interventions avoided or comparable?; G: Was the compliance acceptable in all groups?; H: Was the patient blinded to the intervention?; I: Was the outcome assessor blinded to the interventions?; J: Were the outcome measures relevant?; K: Were adverse effects described?; L: Was the withdrawal/dropout rate described and acceptable?; M1: Was a short-term follow-up measurement performed?; M2: Was a long-term follow-up measurement performed?; N: Was the timing of the outcome assessment in both groups comparable?; O: Was the sample size for each group described?; P: Did the analysis include an intention-to-treat analysis?; Q: Were point estimates and measures of variability presented for the primary outcome measures?; Na: not applicable.

Table 2.

Overview of study characteristics.

Study	System	Participants	Intervention	Outcome measures	Results	Effect sizes [CI 95%]	Dropout
Ayoade (2014)	Interactive rehabilitation visualisation system (AM, GY, MM)	TKR (n=21).	(I) Home exercise program with RVS (n=11) (C) no treatment (n=10)	*Function* AROM flexion AROM extension *activity* OKS	 trend towards significant ↑ in I compared to C (p=0.06) significant ↑ in I compared to C (p=0.002) NS in I compared to C	 NR NR NR	described: 3 non described: 3 total: 6
Ji-Hyuk (2013)	Nintendo Wii (AM, IR)	Chronic LBP (n=24).	(I) Nintendo Wii exercise program plus usual care (n=8) (C1) stabilization exercises program plus usual care (n=8) (C2) passive therapy (hot pack, interferential current, ultrasound) (n=8)	*Function* Pain VAS Muscle strength *activity* OLST *participation* RAND-36 physical functioning mental functioning	 Significant ↓ in I compared to PRE (p<0.05) Significant ↑ in I compared to PRE NS in I compared to PRE NS in I compared to PRE NS in I compared to PRE	 NR NR NR NR NR	no description
Huang (2014)	Microsoft Kinect (IR, RGB)	Frozen shoulder (n=40).	(I) usual care with VR-based real-time quantified feedback and VR game based training (n=20) (C1) usual care (rehabilitation exercise training, hot pack, ultrasonic treatment) (n=20)	*Function* PROM flexion, abduction, external rotation, internal rotation	 Significant ↑ between I and C in flexion (p<0;05), abduction (p<0.05), external rotation (p<0.05), internal rotation (p<0.01)	 NR	no dropout
Baltaci (2013)	Nintendo Wii (AM, IR) Nintendo Wii Balance Board (PS)	ACL recon-struction (n=30).	(I) Nintendo Wii Fit exercise program (n=15) (C) conventional rehabilitation exercise program (n=15)	*Function* Muscle strength *Activity* SEBT	 NS in I compared to C NS in I compared to C	 NR 0.43 [-0.29, 1.16]	no description
Fung (2011)	Nintendo Wii Balance Board (PS)	Full lower extremity weight baring TKR (n=50).	(I) Wii Fit gaming activity plus usual care (n=27) (C) extra lower extremity exercises plus usual care (n=23)	*Function* AROM knee flexion AROM knee extension NPRS *Activity* LEFS ABCS	 NS in I compared to C NS in I compared to C NS in I compared to C NS in I compared to C NS in I compared to C	 NR	no dropout

Hershko (2008)	Smartstep Gait System (FS)	PWB after fracture or surgery (n=33).	(I) (C)	same therapy as the control group with addition of a biofeedback system (n=15) weight-bearing walking, transfer training and strengthening exercises for the injured limb (n=18)	*Function* Pain VAS	NS in I compared to C	NR	no description
Kim (2014)	Nintendo Wii Balance Board (PS)	Chronic LBP (n=30).	(I) (C)	VR-based yoga program using the Wii fit activities. trunk stabilization exercises and normal physiotherapy	*Function* Pain VAS *activity* ODI RMDQ	Significant ↓ in I compared to C (p<0.01) Significant ↓ in I compared to C (p<0.05) Significant ↓ in I compared to C (p<0.05)	1.47 [-0.67, 2.28] 1.11 [-1.88, -0.34] 0.88 [-0.13, -1.63]	no description
Lin (2007)	custom-built apparatus (EG)	Bilateral KO (n=89).	(I) (C1) (C2)	a game to be played by the trained foot of the subject (n=29) 10 sets of 10 repetitions of resisted knee flexion and extension (n=26) no therapy	*Function* Muscle strength knee extension Muscle strength knee flexion *activity* physical function subscales of WOMAC	Significant ↑ in I compared to C2 (p=0.0083), NS in I compared to C1 Significant ↑ in I compared to C2 (p=0.0083), NS in I compared to C1 Significant ↓ in I compared to C2 (p=0.0083), NS in I compared to C1	NR	described: 8 total: 8
Piqueras (2013)	interactive virtual tele-rehabilitation system (AM, GY)	TKA (n=142).	(I) (C)	IVT sessions of rehabilitation standard clinical physical therapy protocol for TKA	*Function* AROM flexion AROM extension pain VAS Quadriceps muscle strength Hamstrings muscle strength	NS in I compared to C NS in I compared to C NS in I compared to C Significant ↑ in I compared to C (p<0.01) NS in I compared to C	0.12 [-0.21, 0.45] -0.21 [-0.54, 0.12] 0.05 [-0.28, 0.38] 0.46 [0.13, 0.79] 0.20 [-0.13, 0.53]	described: 39 non described: 9 total: 48

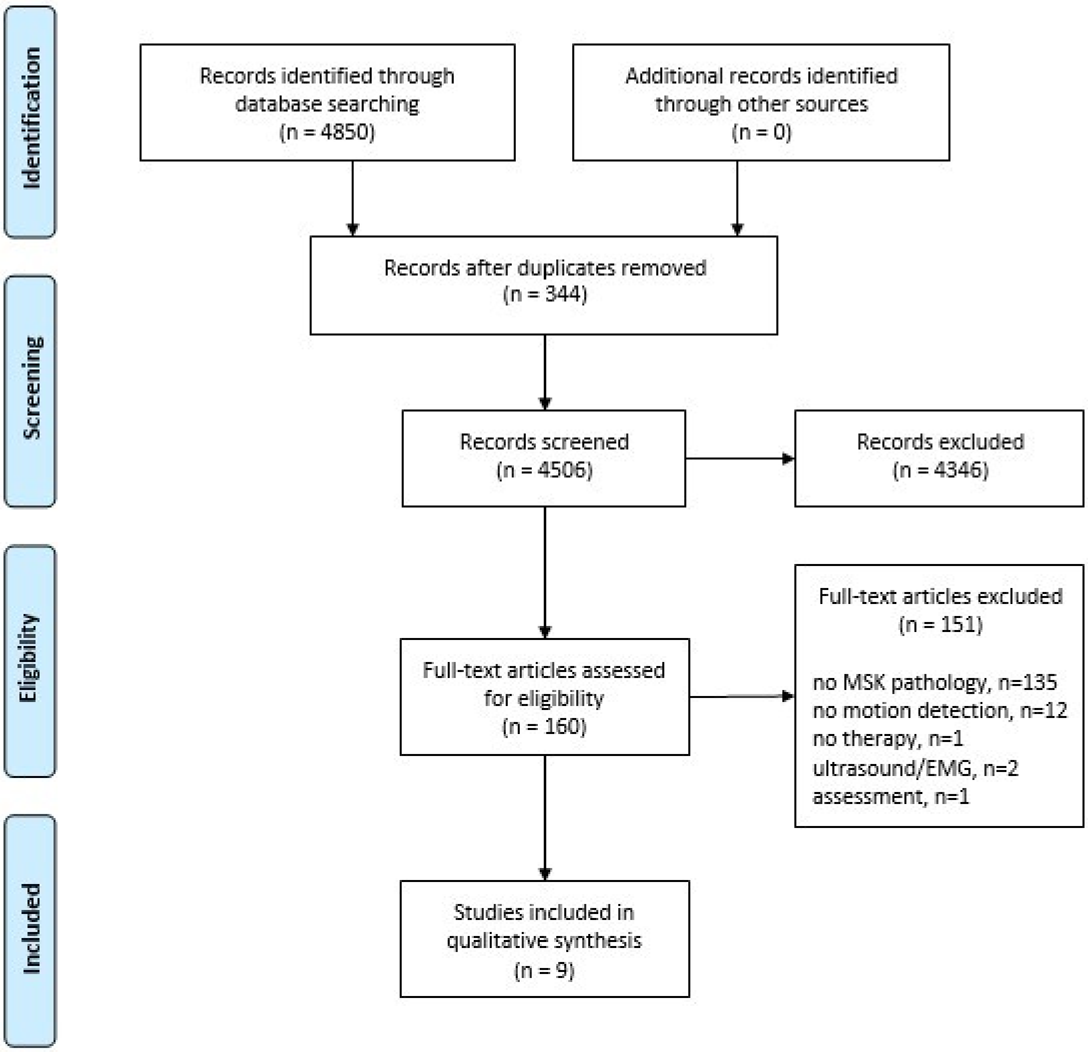
Abbreviations: OM: outcome measures; ES: effect size; CI: confidence interval; NA: not applicable; AM: accelerometer; GY: gyroscope; MM: magnetometer; TKR: total knee replacement; RVS: rehabilitation visualization system; AROM: active range of motion; IMI: intrinsic motivation inventory; OKS: Oxford Knee Score; IR; infrared sensor/camera; LBP: low back pain; VAS: visual analogue scale; OLST: one-legged stance test; QOL: quality of life; RGB: RGB camera; VR: virtual reality; PS: pressure sensor; ACL: anterior cruciate ligament; SEBT: star excursion balance test; TKR: total knee replacement; NPRS: numeric pain rating scale; LEFS: lower extremity functional scale; ABCS: activity-specific balance confidence scale; FS: force sensor; PWB: partial weight-bearing; NSLBP: nonspecific low back pain; MCI: motor control impairment; AF: augmented feedback; PT: physiotherapy; ODI: oswestry disability index; PSFS: patient specific functional scale; RMDQ: Roland–Morris disability questionnaire; EG; electronic goniometer; KO: knee osteoarthritis; WOMAC: Western Ontario & McMaster Universities Arthritis Index; IVT: interactive virtual rehabilitation; TKA: total knee arthroplasty.

Table 3.

Intervention characteristics of the included studies.

Study	Intervention location	Weekly session (amount)	Program length	Total sessions (amount)	Session duration (min)	Exercise sorts	intervention goals	Session content	Control group type	Therapy approach	Exercise database display	Exercise database quantity (amount)	Sensory type of feedback	Quality of feedback	Real time feedback	Feedback on patient progress
Ayoade (2014)	H	daily	6 w	UC	UC	Mobility	Mobility, disability	MDT	NT	A	N	UC	visual	KP & KR	Y	yes
Ji-Hyuk (2013)	C	3	8 w	24	UC	Balance	Pain, muscle strength, balance, QOL	MDT + CET	C1: SSET C2: PAT	TO	N	UC	UC	UC	Y	UC
Huang (2014)	C	2	4 w	8	20	Mobility	Mobility	MDT + PAT	CET	TO	Y	6	Visual	KP & KR	Y	yes
Baltaci (2013)	C	3	12 w	36	60	Balance	Balance, muscle strength	MDT	CET	TO	Y	4	UC	UC	UC	UC
Fung (2011)	C	2	variable	variable	15	Balance	Mobility, pain, disability, balance	MDT + CET	CET	TO	Y	9	UC	UC	UC	UC
Hershko (2008)	C	daily	10 d	10	45	Proprioception	pain	MDT	CET	TO	Y	1	Visual and auditory	KP & KR	Y	UC
Kim (2014)	C	3	4 w	12	30	Yoga	Pain, disability	MDT	CET	TO	N	UC	visual	UC	UC	UC
Lin (2007)	C	3	8 w	24	UC	Proprioception	Disability, muscle strength	MDT	C1: SSET C2: PAT	A	Y	1	Visual	KP & KR	Y	UC
Piqueras (2013)	C	daily	10 d	10	60	Mobility	Mobility, muscle strength, pain, disability	MDT	CET	A	N	UC	Visual	KP & KR	UC	Yes

Abbreviations: H: Home based program; C: therapy in a clinical setting; UC: unclear; va: variable; w: week; d: days; MDT: motion detection therapy; CET: conventional exercise therapy; PAT: passive modalities therapy; NT: no treatment; CET: conventional exercise therapy; SSET: study specific exercise therapy program; F: function level; TO: task-oriented; N: no; Y: yes; KP: Knowledge of performance; KR: knowledge of results; NI: no information.


Identification
Screening
Eligibility
Included
Records identified through database searching (n = 4850)
Additional records identified through other sources (n = 0)
Records after duplicates removed (n = 344)
Records screened (n = 4506)
Records excluded (n = 4346)
Full-text articles assessed for eligibility (n = 160)
Full-text articles excluded (n = 151)
no MSK pathology, n=135
no motion detection, n=12
no therapy, n=1
ultrasound/EMG, n=2
assessment, n=1
Studies included in qualitative synthesis (n = 9)