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Toward Understanding Movement-evoked pain (MEP) and its Measurement: A Scoping Review

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Abstract

Objective: Individuals with chronic pain conditions often report movement as exacerbating pain. An increasing number of researchers and clinicians have recognized the importance of measuring and distinguishing between movement-evoked pain (MEP) and pain at rest as an outcome. This scoping review maps the literature and describes MEP measurement techniques.

Method: The scoping review utilized six databases to identify original studies that targeted pain or movement-related outcomes. Our search returned 7,322 articles that were screened by title and abstract by two reviewers. The inclusion criteria focused on measurement of MEP before, during and after movement tasks in adults with chronic pain. Studies of children < 18 years of age or with non-human animals, case studies, qualitative studies, book chapters, cancer-related pain, non-English language and abstracts with no full publish text were excluded from the study.

Results: Results from 38 studies revealed great variation in the measurement of MEP, while almost all of the studies did not provide an explicit conceptual or operational definition for MEP. Additionally, studies collectively illuminated differences in MEP compared to rest pain, movement provocation methods, and pain intensity as the primary outcome.

Discussion: These results have clinically significant and research implications. To advance the study of MEP, we offer that consistent terminology, standardized measurement (appropriate for pain type/population), and clear methodological processes be provided in research publications. Based on the findings, we have put forth a preliminary definition MEP which may benefit from continued scholarly dialogue.

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Keywords

Movement-evoked pain; pain; nociception; scoping review; musculoskeletal pain

1. Introduction

Movement is an essential human action that can provoke movement-evoked pain (MEP). MEP can lead to greater functional adversities during common life activities such as coughing, getting dressed, and walking. MEP is experienced during and after active or passive movement and is distinguishable from pain at rest or recalled pain[1,2]. Of importance, MEP is shown to be substantially more intense than pain at rest in surgical patients[3], more severe in Black Americans compared to White Americans with knee osteoarthritis and chronic low back pain[4–6], and associated with central pain mechanisms[7], disability[8], and pain reduction in women with fibromyalgia using transcutaneous electrical nerve stimulation (TENS)[9]. Hence, MEP likely represents a unique type of pain that may require unique measurement and management.

Described as a multi-sensory phenomenon, a key mechanism implicated in MEP is the activation or "turning on" of silent nociceptors in response to joint movement or other movement-related stimuli that normally are not painful[10,11]. This does not suggest that mechanical nociceptors are the only drivers of MEP, rather that complex relationships and interactions likely exist between mechanical, behavioral, and neural mechanisms and other salient factors, such as genetics and environmental issues. Thus, MEP may be an important contributor to understanding the complex relationships between significant factors such as negative psychological beliefs and behaviors (e.g., pain catastrophizing, fear-avoidance, depression), pain outcomes (e.g., functional performance, mobility disability, pain interference), and pain management (e.g., exercise, transcutaneous electrical nerve stimulation [TENS]).

Human movement is dynamic, with fluctuations in the experience of pain that differ from pain measured at rest. However, MEP is an emerging concept that has until recently been understudied apart from general, rest, and breakthrough pain[10]. Changes in pain character and intensity measured with resting pain fail to sufficiently capture the impact of pain on human movement. Thus, it is important to recognize the functional implications of MEP using a standardized measurement and definition. A recent focused review from our lab highlighted the importance of measuring MEP, particularly in conditions associated with movement-induced pain[10]; this review suggested that dynamic assessments of MEP, alongside performance-based measures of function, are critical to comprehensively evaluate and treat chronic pain and persistent pain-related disability. Understanding MEP represents a paradigm shift from static[7] assessments and instruments depending on participant recall. Most studies designating pain as an outcome do not specifically assess MEP, have methodological limitations, and/or implement methods for measuring MEP that limit its clinical applicability as a measurable outcome for translational pain practice. Further challenging measurement of MEP is the absence of a formal definition to guide research inquiry and clinical treatment. The parameters that influence how MEP is conceptualized

and understood may benefit from dialogue focused toward creation of a consensus definition that guides measurement that is more accurate. Only one systematic review has synthesized the evidence on this concept but only in surgical settings[3] (with an updated review planned[7] indicating a need for a broader review). Thus, the outcomes of this scoping review may reveal critically important information about the characteristics of MEP as well as identify essential components that will inform standardized measurement that accurately assesses an individual's MEP.

2. Aim

The purpose of this scoping review is to identify and review the research on the types of studies conducted, MEP measurement techniques, and MEP-related results among adults. Our goal is to advance the existing literature by detailing the multiple approaches taken to evaluate and understand pain with movement in adults presenting with chronic pain. This appraisal will demonstrate how instruments are applied in clinical and research domains.

3. Materials & Methods

The PRISMA extension for Scoping Reviews (PRISMA-ScR) reporting guidelines supported a five stage process[12] (Figure 1). Stage one began with developing a clear research question: "What is the extent to which existing literature provides knowledge on MEP measurement for consistency and transparency of methods?" Stage two followed by identifying content and methodological expertise to capture relevant studies; engaging in an iterative process of selection of refining and reviewing studies (stage three); documenting the variables to extract to answer the research question (stage four); and enabling a descriptive numerical and thematic analysis to identify implications and meanings related to the overall purpose and for future practice, policy and research (stage five)[13,14].

3.1 Literature search

The scoping review team consulted a health scientist librarian specialist to conduct a comprehensive search of medical literature on MEP and methods of pain measurement. The database searched included PubMed, Cochrane, Embase, Web of Science, SportDiscus, and Cumulative Index of Nursing and Allied Health Literature (CINAHL). These databases were searched between September 2019 – January 2020. Relevant controlled vocabulary of each database was used - including MeSH (Medical Subject Headings) for PubMed, Emtree terms for Embase, CINAHL headings for CINAHL, and Thesaurus terms for SportDiscus. Keywords were identified as search terms, with some variation between databases, including: "movement-evoked pain" OR "chronic pain" OR "intractable pain" OR "persistent pain" OR "musculoskeletal pain" OR "movement" OR "motion" OR "motor activity" OR "pain measurement" OR "pain evaluation". For full search strategy, refer to Table 1. Once duplicates were removed, 7322 papers were imported into Rayyan, a mobile and web-based application for data management of systematic reviews, version 0.1.0, Qatar Computing Research Institute[15].

3.2 Inclusion/Exclusion criteria

Development of inclusion criteria focused on measurement of MEP before, during, and/or after movement tasks in adults with chronic pain. Exclusion criteria were studies of children <18 years of age or with non-human animals, case studies, qualitative studies, book chapters, cancer-related pain, non-English language, and abstracts with no full published text.

3.3 Selection process

Within Rayyan, in the first phase of selection, two independent reviewers (D.F and S.M) applied a checklist based on the prespecified inclusion/exclusion criteria to screen the titles and abstracts. The second phase evaluated full-text articles that met the inclusion checklist requirements. A third reviewer (S.A.) resolved disagreements between the original reviewers and scanned the title and abstracts of flagged articles to confirm inclusion or exclusion. Any remaining discrepancies were resolved by a full team discussion. The final selection of articles required a consensus among the scoping review team.

3.4 Data extraction

After identifying studies meeting inclusion criteria, two reviewers (D.F. and S.M.) extracted data on the study aims, populations, methodology, and terminology. All data were extracted into an Excel spreadsheet that was further reviewed by the scoping review team. A third reviewer (S.A.) conducted a validation check for discrepancies based on the previous reviewers' data extraction. Discrepant findings and issues were brought to the entire scoping review team for discussion.

3.5 Data Synthesis

Data extraction from the selected studies permitted the categorization of results into themes. Themes were developed by surveying the study design characteristics, MEP measurement techniques, and primary and secondary outcomes across all studies.

4. Results

The database searches returned 7,322 electronic records for review. Titles and abstracts were screened and yielded 71 potentially relevant full-text articles for retrieval. After reviewing full-text articles, 33 studies met the inclusion and exclusion criteria. The PRISMA flow chart in Figure 2 details the literature search and study inclusion. Additionally, 5 studies were retrieved based on the scoping review team's expertise on the literature and from reference lists, resulting in a total of 38 studies analyzed. In brief, data extracted from the included studies are summarized in Table 2. Trends show that the number of publications has steadily increased with the greatest increases observed within the past three years (Figure 3).

4.1 Study design characteristics

The sample of 38 studies was grouped by the aims of each study. Fifteen studies[8,16–28] focused on prediction of future pain (e.g. pain at 6 months after initial MEP measurement) following various MEP tasks. Ten studies[9,29–37] evaluated novel or traditional measurement

tools related to MEP to gauge test effectiveness, reliability and validity. Four studies[38–41] conducted in standardized clinical settings aimed to test MEP for future use in clinical practice.

Four studies[42–45] determined medication efficacy (e.g., gabapentin vs. placebo) in managing MEP. These studies all fall under the post-surgical schema. Two of these studies standardized the effectiveness of medications to alleviate MEP and pain at rest by measuring transitions from seated to standing followed by 120 seconds of rest, measuring peak expirations followed by 120 seconds of rest, and coughing evoked by pain post-anesthesia on the day of surgery[42,45]. The final two studies explored active flexion and extension at the hip[43] and knee[44] post-operatively to determine medication effectiveness in breakthrough pain measures. Two studies[46,47] assessed the course of MEP upon injection of nerve growth factor. Two studies evaluated psychosocial factors and MEP, such as depression, perceived injustice and stigma[48] or fear-avoidance beliefs, pain catastrophizing and negative emotions and cognitions[49]. One study[5] investigated sociocultural constructs and MEP, such as racial/ethnic differences.

Of the 38 studies included, fifteen[8,16,19,21,24,26,28,29,34,36,38,40,41,48,49] were cross-sectional studies. Ten[17,20,22,23,25,27,33,35,37,39] were prospective cohort studies, ranging in duration from two days[37] to eighteen months[33,39]. One[31] was a retrospective cohort study. Nine studies[9,30,42–47,50] were randomized controlled trials, while another one[18] used an experimental case control design. Two studies used secondary data to analyze pooled data from nine randomized controlled trials[32] or from a larger prospective cohort study[5]. Two separate sets of studies shared the same participant cohort[33,39,46,47]. All of the remaining studies utilized their own distinct participant samples.

Nine studies were conducted in the United States; eight studies were conducted in Canada; five studies were conducted in Denmark and Sweden each; two studies were conducted in Australia, China, France, Germany and Switzerland each; one study was conducted in Japan, Spain and the United Kingdom each.

4.2 Sample characteristics

Studies enrolled a variety of participants with a wide spectrum of musculoskeletal conditions and postsurgical pain. Three studies focused on neuropathic pain across a total sample size of 489 participants[9,36,38]. Three studies investigated pain located in the upper extremity across a total sample of 64 participants[35,46,47]. Five studies concentrated on pain in the lower extremity across a total of 7,433 participants[5,33,37,39,40]. Twelve studies evaluated post-surgical pain across a total of 11,236 participants[17,20,22,23,25–27,31,42–45]. Thirteen studies analyzed axial pain across a total of 1,845 participants[8,16,19,21,24,28–30,32,34,41,48,49]. Two studies examined temporomandibular joint (TMJ) pain across a total of 103 participants[18,50]. Pain with movement was measured immediately before, during or after MEP tasks (Table 2) often without mention of measuring change from rest.

4.3 MEP Operationalization

A definition of MEP appeared in two studies conducted by the same research team, in which “pain with movement was defined as pain during walking”[33,39]. The remaining 36 studies

were absent of an explicit definition of MEP. Despite the lack of an overarching definition, these 36 studies operationalized MEP via standardized movement tasks. For example, a task such as “sitting up” describes the study parameters investigating MEP. None of the included studies provided a clear conceptual definition of how MEP encompasses “pain during movement”.

4.5 MEP Instrumentation Measures

Measurement of MEP varied across studies and no standardized methods were noted. While most utilized a numeric rating scale, others incorporated visual analog scales with numeric or descriptive anchors. Eighteen studies used the 11-point numerical rating scale (NRS), where ratings of pain intensity were “no pain” at 0 and “worse imaginable pain” at 10 to measure MEP[8,9,17,20,21,26,27,29,31,34,37,40–42,44,46,47,50]. Five studies preferred either an adapted 21-point NRS[22] or a 101-point NRS[24,48,49,51], which offer similar measures of pain assessment as the 11-point NRS.

The visual analog scale (VAS) uses a 10cm pain rating scale, where 0 indicates “no pain” and 10cm indicates the “worst possible pain.” Ten studies[18,23,28,30,32,35,38,39,43,45] used this scale. One study[36] used the combination of the VAS and the verbal rating scale (VRS), which is a 1–7 pain rating scale indicating 1 as being “no discomfort” at all and 7 being “very severe discomfort.” Another study[33] used a combination of the VAS and the Pain Matcher, which is an instrument for electrical stimulation used preoperatively on participants to assess matched pain (pain corresponding to knee pain with movement) and the thresholds for sensation and pain.

The remainder of the studies utilized other measurement tools, including an 11-point[19] or 101-point[25] numerical pain rating scale (NPRS) known to assess musculoskeletal pain[25] and a light pink to deep red colored visual analogue scale (CAS) with light pink referring to “no pain” and deep red referring to “most pain” generally used for elders with mild to moderate cognitive impairments[16]. The instruments associated with the MEP task characteristics are detailed in Table 2.

4.6 MEP-related Outcomes

The themes identified from all included studies were sorted into three categories: difference in MEP vs. resting pain, movement provocation, and pain intensity. Based on Table 2, the MEP-related results guided the categorization schema based on specific characteristics of extracted results and direct mention of category language (i.e., Meyer-Rosberg et al., 2001 referred explicitly to pain intensity). Two studies measured MEP but did not explicitly report MEP-related results to draw conclusions[16,29].

4.6.1 MEP vs. Rest Pain—Studies were inconsistent in their reporting of MEP intensity vs. resting pain. Only six studies explicitly tested for statistical differences between pain at rest and MEP[18,30,33,36,39,50]. The consensus from these studies is that MEP intensity is higher than resting pain intensity. The remaining thirty-one studies were absent of a measurement comparison between MEP and rest pain intensity. Both resting pain and MEP

may have been included in the study but were more commonly compared across the experimental groups in isolation rather than compared against one another.

4.6.2 MEP Provocation—The majority of included studies typically referred to MEP in relation to a standardized movement provocation task. These provocation tasks were conducted under experimental or observational methods for daily activity tasks or repetitive tasks. Twenty studies[8,18,21–23,25–28,30,31,33–35,39,46–50] were deemed MEP studies because of the reporting of pain scores based on movement tasks.

The distribution of MEP provocation tasks varied considerably across the identified MEP studies. Studies investigating upper extremities focused on muscle contraction during either wrist flexion and extension with ulnar deviation[46,47] or elbow flexion tasks during eccentric contraction exercises[35]. Two studies evaluated how participants rated their pre-surgical knee pain with movement (i.e., lower extremity MEP) and used the Pain Matcher electrical stimulation to assess thresholds for first noticeable sensation and matched knee pain with movement during walking[33,39]. Six studies measured post-surgical pain during dynamic movements which included MEP during kneeling, rest and walking in the past 24hrs[31]; during knee active flexion and extension[22]; during postural changes from supine to standing[23]; during shoulder abduction[25]; during activities of daily living such as bathing and getting dressed[27] or coughing, deep breathing, early morning movement and walking[26]. Seven studies explored axial region MEP movements that examined repetitive scapular abduction movements at varying intensities[30]; balanced, chair and walking tests[48]; lifting canisters of varying weights from height-adjusted table[8,34]; the back performance scale for chronic low back pain[49]; forward and backward repetitive bends with brief pauses[21]; lifting crates from the floor during backward and forward bends[28]. Two studies analyzed MEP in relation to TMJ by assessing gum chewing in a position seated freely at rest by performing flexion, extension and laterally flexion movements[18]; and standardized continuous jaw movements at varying intensities (e.g., 3 seconds) and positions with ten minute rest intervals for a total of 20 repeated movements[50].

4.6.3 Pain Intensity as Measurement Outcome—Twelve studies[5,9,17,19–21,24,32,36–38,40] considered the pain intensity as the primary outcome of MEP during activities. The studies in this sample reporting on MEP pain intensity by type of pain or body domain varied slightly in this section. Three studies addressing neuropathic pain explored various dimensions of MEP intensities that involved a neural tension test[38]; assessment of MEP after 4 weeks of active transcutaneous electrical nerve stimulation (TENS) application[9]; and rating the degree of HRQL across four types of pain domains[36]. Three studies examining knee pain captured significantly higher MEP in non-Hispanic Blacks compared to non-Hispanic Whites with or at risk for osteoarthritis[5]; ratings of pain intensities at rest, in last 24 hours and in last eight days[40]; and acceptable symptom states of painful conditions at rest and on movement during the previous 24hrs[37]. Two post-surgical pain studies evaluated the rating of MEP intensity during transition from a lying position to sitting up in bed[17]; and from the edge of the bed[20]. Four studies determined the axial MEP intensity measuring neck pain on movement from six anatomical directions[32]; postural control in four video clip scenarios demonstrating varying lifting techniques[19]; forward and

backward repetitive bends with brief pauses[21]; and sagittal plane mobility during functional tasks of the back performance scale[24].

5. Discussion

Our novel review findings highlight important features of the existing literature addressing MEP. First, existing research lacks a common definition for MEP, which contributes to significant variation in the measurement methods and instrumentation. Second, consistencies and knowledge gaps in the literature were identified through 3 common themes: difference in MEP vs. resting pain intensity, movement provocation, and pain intensity as a primary outcome. It is established that MEP is greater than resting pain for a range of pain conditions[3,18,30,33,36,39]. The types of movement primarily focus on intentional and active range of motion to evoke pain potential. Pain intensity (and/or changes in intensity) is often a primary outcome.

While there is a need for greater conceptual clarity and validation, MEP is likely experientially distinct from spontaneous or breakthrough pain, and remains a significant phenomenon deserving more scientific attention. Recent evidence suggests a complex, reciprocal, and paradoxical relationship between pain and movement[10,51–53], and clinical and basic science investigations thus far have sought to distinguish MEP from other types of pain by understanding its central and peripheral mechanisms. However, the biological transmission and perception of MEP remains largely unknown, but it is believed that the activation of ‘silent’ mechanical nociceptors in the presence of acute tissue injury or inflammation, is a fundamental aspect of a hyperalgesic and perhaps hypervigilant response to innocuous movement[11]. Spontaneous and more frequent discharge of ‘silent nociceptors’ in animal models of arthritis without a mechanical stimulus (joint or muscle movement) have been observed. Also, mechanical and chemical sensitization of C-polymodal and A-delta nociceptors near the incision site is evident in animal models of post-surgical pain. Collectively, this evidence suggests an interaction between nociceptive, nociplastic, and neuropathic pain mechanisms that warrants further examination. While this review did not delve deeply into the biological mechanisms of MEP, we acknowledge that identifying patterns of mechanisms will be critically important to our approaches to measurement and management.

Furthermore, there are considerations on how MEP informs the measurement of high-impact chronic pain, given that it is frequently associated with greater functional interference. High-impact chronic pain is characterized as persistent pain that lasts beyond the time of healing (approximately 3–6 months) and causes significant interference with daily function[55,56]. Thus, to further understand the relationship between MEP and high-impact pain, measurement parameters must be clearly defined such as time(s) of measurement, movement characteristics/quality, type of measurement instrumentation, and pain characteristics (pain intensity, pain duration, pain quality, and interference).

5.1 Recommendations for Research

As demonstrated by our review, measurement was variable and mainly consisted of numeric self-report pain scales to obtain a pain intensity rating. While clinically relevant, other

quantitative measurements that are functionally relevant for different conditions could be reliably obtained which could provide additional insight as to the character and mechanisms of MEP. Corbett and colleagues (2019) suggest that MEP can be acute or persistent (chronic), but other studies also show that MEP can also be considered in terms of breakthrough pain[57]. Specifically, longitudinal studies may show the transitory nature of MEP from acute to chronic pain. One of the prevailing issues identified from this review is the lack of an operational definition provided in the studies and use of varying terminology used in the literature (e.g., movement-evoked, movement-induced, movement-related pain, movement pain, pain with movement, pain-on-movement, functional pain, pain on level of effort, activity-related pain). Additionally, while a standardized approach using a battery of movements that can gauge both pain and performance-based function is important, future research should not exclude developing new and more sensitive MEP techniques. Future research warrants investigation of a possible interaction among cognitive, psychological and social factors that influence the experience of MEP and how pain is measured among individuals. Additional inquiry may reveal critically important information about the populations at risk for MEP as well as illuminate a profile of individuals with MEP. This will ultimately advance our understanding of populations that currently demonstrate greater MEP, such as Black Americans with knee osteoarthritis[5,6], but also multi-modal treatment targets to address specific mechanisms and "secondary pathologies" including fear of movement, anxiety, and mobility disability[45]. Because the study of MEP is developing, future research might explore:

- Psychometric properties of various MEP measures
- Variability in MEP across racial, gender, and age groups
- Variability and feasibility in measurement/assessment of MEP across settings of care and disciplines
- Distinction between MEP and similar concepts such as delayed onset muscle soreness[58], exercise-induced hyperalgesia, increased sensitivity to physical activity (SPA)[59]; repetition-induced summation of activity-related pain (RISP)[8,60], movement-evoked hyperalgesia[61], and pain during level of effort[62]
- Mechanisms of MEP: nociceptive, neuropathic, and nociplastic pain[63] in addition to psychosocial predictors
- Predictive validity of MEP using precision medicine techniques
- Differences in MEP by passive and active (i.e., determined) movements in different planes and/or ranges of motion
- Differences in MEP based on, or due to, varying time sensitive tasks
- Brain activation of MEP through advanced imaging (e.g., functional magnetic resonance imaging and electroencephalogram) studies

5.2 Recommendations for Practice

Patient population, study design, and clinical feasibility determine the choice of pain scale for MEP. The majority of studies (25/38) utilized a verbal rating scale, which may reflect

that in general a verbal pain rating is more compatible and preferred by patients, healthcare providers, and researchers when measuring MEP[8,9,17,19–22,24,25,27,29,31,34,36,37,40–42,44,46–51]. Verbal rating scales can also be administered to cognitively intact, non-English speaking patients[64–66]. Yet, certain populations will continue to require adaptations for valid measurement, such as a colored VAS for patients who are non-verbal or have cognitive impairment[16].

MEP pain was measured by having participants either perform a daily task (e.g. walking, getting dressed) or complete a standardized movement designed to provoke pain associated with their musculoskeletal diagnosis (e.g. supine knee flexion and extension). A benefit of capturing pain during a daily functional activity is clinically meaningful. Yet due to individual variability in movement patterns when completing a daily (functional) task, it may be beneficial to also have participants complete a standardized task to facilitate comparison between patients and over time. Further, isolated joint movement (e.g. knee flexion) may neutralize confounding effects of compensatory movements occurring at other joints (e.g. ankle dorsiflexion or hip flexion) to minimize MEP intensity at the affected joint when completing multiplanar high demand tasks, such as sitting down or a single limb hop landing.

All studies measured MEP during or immediately after completing the movement, which requires clear communication on the aspect of the movement to consider when rating pain. Practically it can be difficult to assess pain during a single motor task, such as supine to sitting, yet in asking participants to rate their pain immediately after the task it has to be clarified if the participant is supposed to rate the pain experienced while they were doing the task (MEP) or at the time when the pain rating is occurring (post-movement pain). In contrast, a repetitive task, such as repetitive forward bending, can have short pauses to allow for pain rating over time during task performance[41]. An additional consideration in test instructions is to clarify if MEP is specific to beginning, mid-range or end-range of joint motion[25], since pain can fluctuate during task performance depending on level of stretch on a tissue and/or type of muscle contraction occurring. Ultimately a more specific definition of MEP can provide greater clarity in driving treatment decisions, greater specificity about the quality and impact of MEP versus spontaneous pain (or something like that), improved communication between physical therapy and nursing personnel by using common terminology, and such as if a referral or continuation of PT is warranted.

5.3 MEP Definition

Further challenging the lack of measurement is the absence of a formal definition of MEP to guide research inquiry and clinical treatment. The majority of studies reviewed operationalized MEP during a standardized movement task but lacked a conceptual definition to define the essential aspects of this outcome. From this review, we also aimed to establish a research-based definition of MEP: “MEP is pain that is acutely provoked and experienced in response to active or passive movement of the involved tissues. Types of active movement can be naturally-occurring or experimentally-standardized to include active range of motion (open-chain or closed-chain), muscle contraction (concentric, eccentric, isometric), any form of physical (or functional) activity, and daily/recreation/sports

activities. Primary afferent inputs may be nociceptive, neuropathic, or nociplastic. Cognitive, psychological and social factors can play an equally important role in the experience of MEP." Researchers pursuing this line of investigation will need to consider that MEP represents a spectrum of experiences of pain provocation with movement, including pain produced during movement, pain produced after movement (e.g., delayed onset muscle soreness), recalled pain experienced with movement, and pain worsened with movement which in some cases may be alleviated within prolonged movement (i.e., consistent exercise)[51]. We expect other scholars in this field of study to build upon this preliminary definition and/or offer other operational definitions to better understand MEP.

5.4 Limitations

We recognize that many clinicians and researchers routinely measure forms of MEP yet were excluded from this review due to a lack of defining the measure as MEP to match the inclusion/exclusion criteria for this study. The restriction of subject search terms to 'movement-evoked pain' may have limited the search results. Alternate terms (e.g., movement induced pain, functional pain, pain with activity, activity-evoked pain) may have identified additional studies. The variability in terminology points toward a greater need for cross-disciplinary consistency. A common definition of MEP and widespread adoption of this terms needs to occur before a more comprehensive literature search can be executed. We propose that the execution of this definition will prompt literature searches that account for different conditions (e.g., knee osteoarthritis vs. elbow arthritis) to allow for more specific measurement accuracy of MEP. Moreover, limiting pain conditions to musculoskeletal also excludes additional studies on cancer-related MEP and animal studies evoking pain. A goal of this publication is to provide an initial definition that distinguishes MEP from other types of pain measurements (resting, worst pain over a period of time), which can facilitate future research to clearly differentiate MEP from other pain measures.

6. Conclusion

Pain during any movement or physical activity (i.e. MEP) is a concept once overlooked apart from general, rest, and breakthrough pain. MEP has emerged as a prominent concept and metric to assess in individuals experiencing different pain conditions. This scoping review has provided researchers and clinicians alike a starting point to advance, identify and measure the phenomenological knowledge of MEP.

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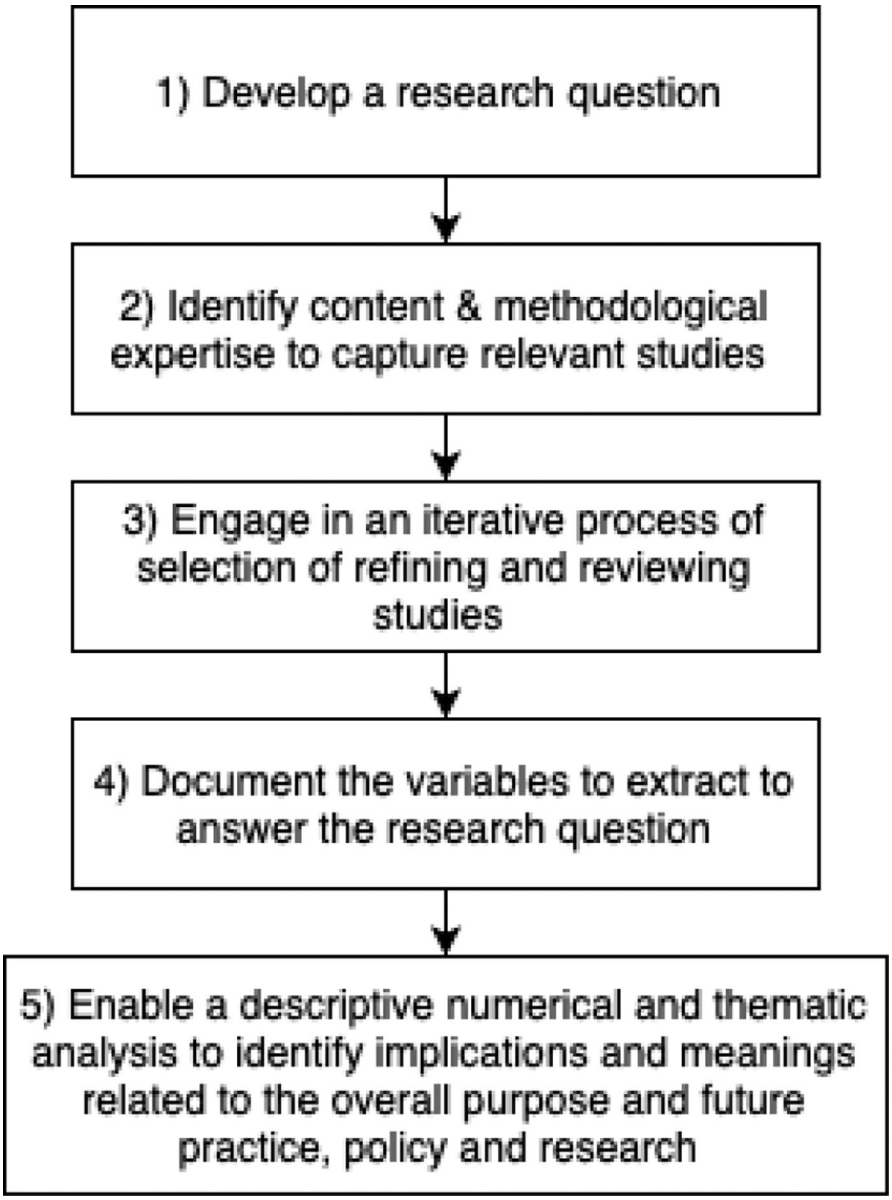

Figure 1.
Five Stage PRISMA-ScR Process

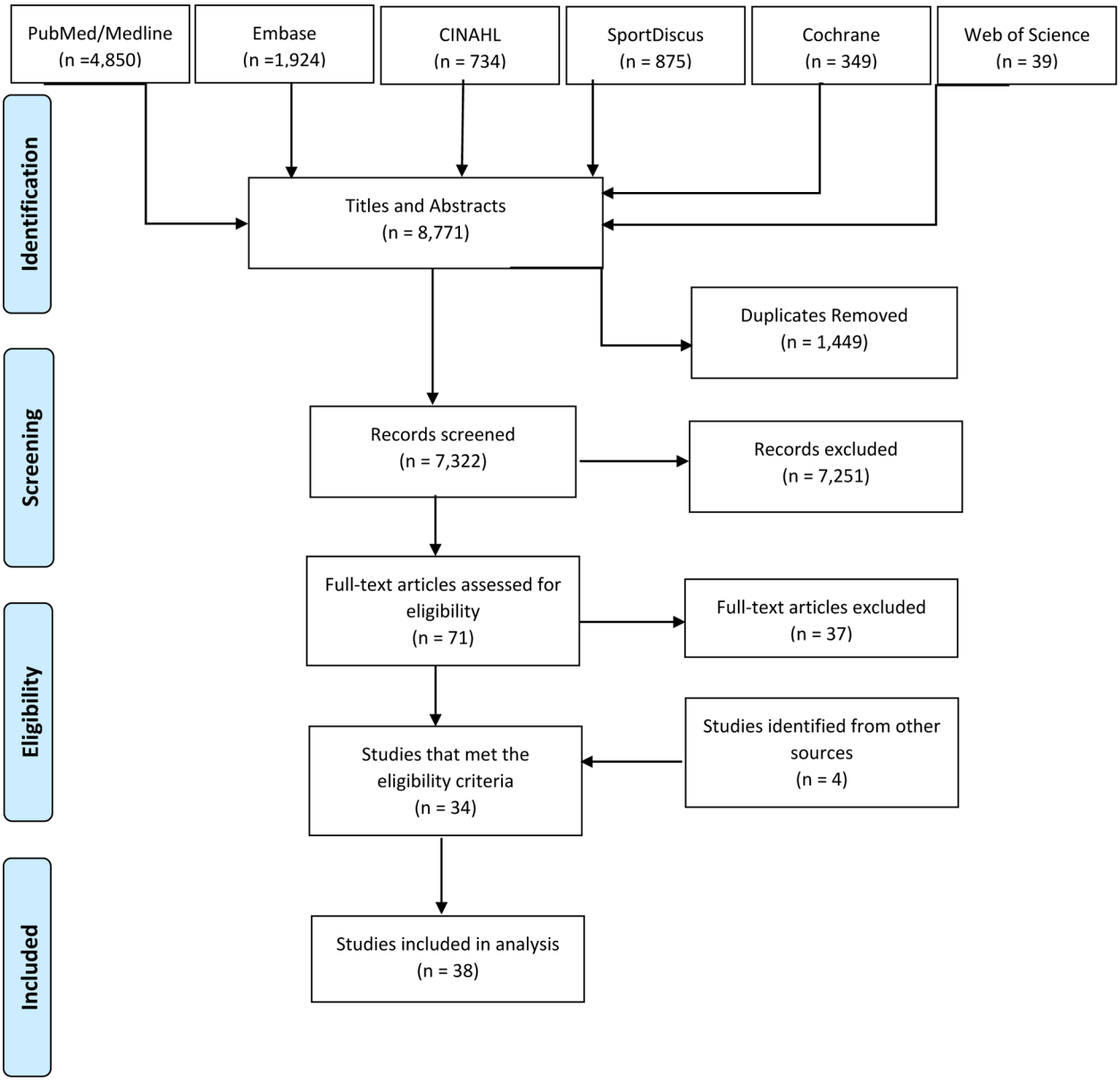

Figure 2.
PRISMA Flow Diagram

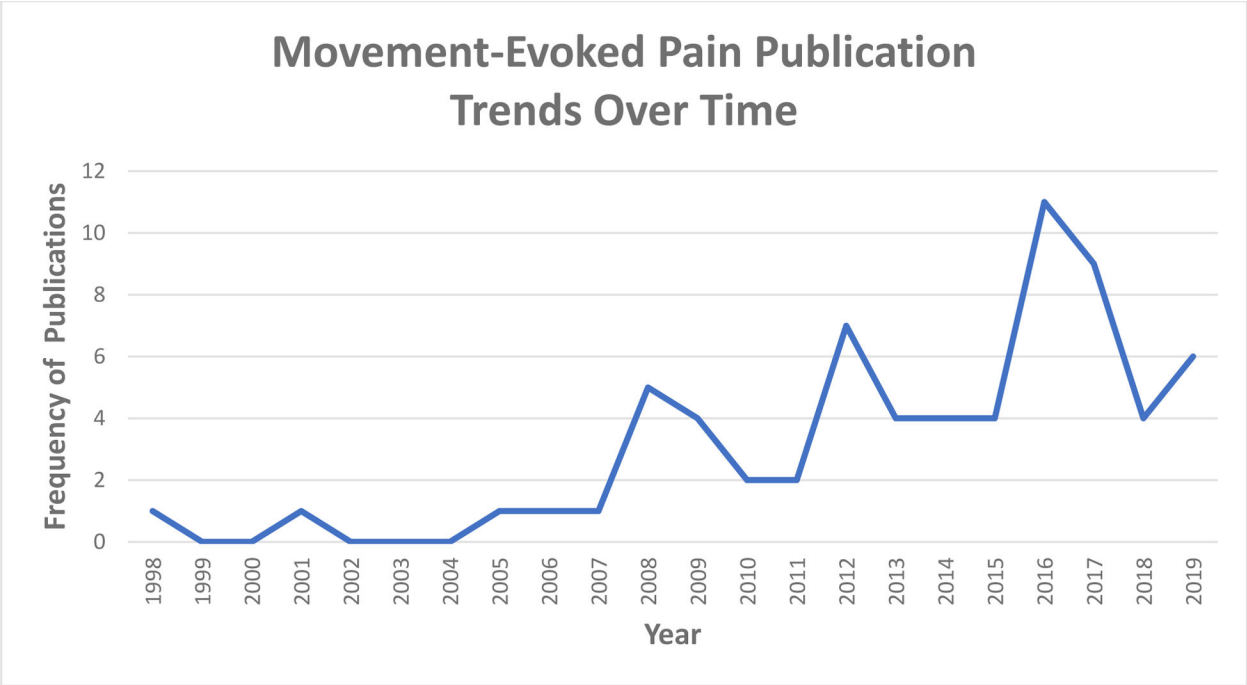

Figure 3.
Number of Peer-Reviewed Publications by Year Assessed for Eligibility

Table 1.

Search Strategy

	Pain	Movement	Pain Measurement
PubMed	"Chronic Pain"[Mesh] OR "Pain, Intractable" [Mesh] OR "movement evoked pain"[tiab] OR "chronic pain"[tiab] OR "intractable pain" [tiab] OR "persistent pain"[tiab] OR "musculoskeletal pain"[tiab]	"Movement"[Mesh] OR "Motion" [Mesh] OR "motor activity"[tiab] OR "motion"[tiab] OR "movement"[tiab]	"Pain Measurement"[Mesh] OR "pain evaluation"[tiab] OR "pain measurement"[tiab] OR "pain assessment"[tiab]
SportDiscus	(DE "CHRONIC pain") OR (TX "chronic pain" OR TX "intractable pain" OR TX "movement evoked pain" OR TX "persistent pain" OR TX "musculoskeletal pain")	(DE "MOTION") OR (TX movement OR TX motion OR TX "motor activity")	(DE "PAIN measurement") OR (TX "pain measurement" OR TX "pain evaluation" OR TX "pain assessment")
Embase	'chronic pain'/exp OR 'chronic intractable pain':ti,ab OR 'chronic pain':ti,ab OR 'pain, chronic':ti,ab OR 'MEP':ti,ab OR 'pain'/exp OR 'pain':ti,ab OR 'persistent pain':exp OR 'persistent pain':ti,ab	'movement (physiology)'/exp OR 'movement':ti,ab OR 'movement (physiology)':ti,ab OR 'motion'/exp OR 'motion':ti,ab OR 'movement (physical phenomena)':ti,ab OR 'motor activity':ti,ab	'pain measurement'/exp OR 'pain evaluation':ti,ab OR 'pain measurement':ti,ab OR 'pain assessment':ti,ab
CINAHL	(MH "Chronic Pain") OR (MH "Pain") OR (TX "chronic pain" OR TX "intractable pain" OR TX "movement evoked pain" OR TX "persistent pain" OR TX "musculoskeletal pain")	(MH "Motor Activity") OR (MH "Movement") OR (MH "Motion") OR (TX movement OR TX motion OR TX "motor activity")	(MH "Pain Measurement") OR (TX "pain measurement" OR TX "pain evaluation" OR TX "pain assessment")
Web of Science	"movement evoked pain" OR "chronic pain" OR "intractable pain" OR "persistent pain" OR "musculoskeletal pain"	"motor activity" OR "movement" OR "motion"	"pain measurement" OR "pain evaluation" OR "pain assessment"
Cochrane	"movement evoked pain" OR "chronic pain" OR "intractable pain" OR "persistent pain" OR "musculoskeletal pain"	"motor activity" OR "movement" OR "motion"	"pain measurement" OR "pain evaluation" OR "pain assessment"

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Table 2.

Table of Evidence

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
Neuropathic						
Beneciuk, 2010	To investigate whether the Fear-Avoidance Model of Musculoskeletal Pain (FAM) factors with known influence on pain sensitivity in experimental settings and outcomes in clinical settings also have an influence on a commonly used neurodynamic testing procedure	• Sample size: 62 • Participants: healthy individuals • Comparison: n.a. • Age range, years: 18–50 years • Age, mean (SD) years: 23.7 (3.9) • Gender, n (%) F: 74 • Body region: neck or dominant upper-extremity symptoms • Timing: during test • Country: USA	• Primary: pain-intensity • Secondary: movement avoidance behavior	• 10 cm visual analogue scale (VAS)	• Step 1: passive scapular depression • Step 2: combined shoulder abduction and external rotation; combined forearm supination, wrist extension, and finger extension • Step 3: elbow extension	• Elbow range of motion (ROM) was not strongly associated with pain intensity or non-painful sensation intensity • Healthy subjects pain intensity is positively associated with non-painful sensation intensity, but not elbow ROM during a neurodynamic test for the median nerve
Dailey, 2020	To test the effectiveness of repeated Transcutaneous Electrical Nerve Stimulation (TENS) on movement-evoked pain in women with fibromyalgia (FM) following random assignment to 3 groups: active TENS, placebo TENS, or no TENS. Secondary aims were to test the effects of TENS on fatigue, function, and other patient-reported outcomes	• Sample size: 301 randomized, 238 used for analysis • Participants: females with FM • Comparison: TENS vs placebo control; TENS vs no TENS • Age range, years: 18–70	• Primary: movement-evoked pain • Secondary: resting pain, fatigue, function, disease impact, quality of life, fear of movement, and other psychological factors	• 11-point numeric rating scale (NRS)	• 6-minute walk test and 5 time sit to stand test	• After 4 weeks of active TENS use, within-group movement-evoked pain during a 6-minute walk test was significantly reduced by 1.8 points compared to pre-TENS treatment on visit 2, and the reduction was greater compared to

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Gender, n (%) F: 100 • Body region: generalized • Timing: during task • Country: USA				movement-evoked pain observed in the placebo TENS group and the no TENS group
Meyer-Rosberg, 2001	To develop new outcome measures for the evaluation of new and existing health-related quality of life (HRQoL) treatments	• Sample size: 126 • Participants: neuropathic pain diagnosis • Comparison: n.a. • Age range, years: 24–82 • Age, median years: 54 • Gender, n (%) F: 55.6 • Body region: peripheral neuropathy pain (PNP) • Timing: at rest and during test • Country: Sweden	• HRQoL treatments with respect to peripheral and neuropathic pain	• 100 mm VAS • Seven-point verbal rating scale (VRS) graded from “No discomfort at all” (=1) to “Very severe discomfort” (=7)	• Frequency: Rated pain in response to “Have you been bothered by pain during the past week?” • Rated the degree to which they were troubled by four types of pain (at rest, evoked by movement, touch, and cold) on a seven-point VRS	• The median VAS score for current pain intensity was highest (53) for movement-evoked pain followed by pain at rest and cold- and touch-evoked pain (medians 40, 41, and 34 respectively) • 43% percent of patients scored their highest pain as evoked by movement
Upper Extremity						
Bergin, 2015	To investigate the time course of pain and hyperalgesia induced by injection of nerve growth factor (NGF) into a wrist extensor muscle, and whether movement and muscle contraction provoke pain in the NGF-induced hyperalgesic muscle	• Sample size: 26 • Participants: healthy individuals • Comparison: NGF injection vs. isotonic saline (ISO) control • Age, mean (SD) years: 25.8 (5.4)	• The nature and time course of pain induced by NGF injection	• 11-point numeric rating scale (NRS)	• Muscle contraction tasks: wrist extension & gripping • Stretching tasks: wrist flexion & ulnar deviation	• Participants reported greater pain provocation during maximal wrist extension contraction for the limb injected with NGF than the limb injected in the ISO

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Gender, n (%) F: 27 • Body region: arm • Timing: immediately after contraction and stretching tasks • Country: Denmark				group and the contralateral limbs in either group • Participants reported greater provocation of pain after wrist flexion for the injected limb of the NGF group than the injected side of the ISO group and the contralateral limb in either group
Matusda, 2015	To examine whether Delayed-Onset Muscle Soreness (DOMS) is a suitable model for the study of movement-evoked pain and to identify brain regions specifically involved in pain evoked by active and dynamic movement	• Sample size: 12 • Participants: healthy, right-handed individuals • Comparison: n.a. • Age range, years: 23–48 • Gender, n (%) F: 25 • Body region: dominant arm • Timing: before (0 days) and during (for 7 days) DOMS induction, then 30 days after • Country: Japan	• Assessment of pain intensity during rest and repeated elbow flexion • Assessment of range of motion • fMRI scans to identify involved brain regions	• 100 cm visual analogue scale (VAS)	• To induce DOMS: elbow flexion torque measurement and eccentric contraction exercise	• Maximum VAS ratings for movement-evoked pain after DOMS induction were recorded on day 2 • Movement-evoked pain clearly decreased by day 7, and it completely disappeared in all subjects by day 30 • No subject reported pain at • rest on day 2 or day 30
Mista, 2016	To compare changes of direction and variation of multidirectional (task-related and tangential) forces: 1) in the presence of	• Sample size: 26 • Participants: healthy individuals	• Effects of saline-induced pain • Effects of injection of	• 11-point numeric rating scale (NRS)	• Day 1: force-matched wrist extensions (motor task) before and after NGF injection	• Participants injected with NGF reported greater NRS pain scores when performing

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Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
	acute experimental pain, 2) after experimental movement-evoked pain had been sustained for several days, and 3) with the combined effect of additional acute pain on a background of persistent movement-evoked pain	• Comparison: nerve growth factor (NGF) injection vs. saline control • Age, mean (SD) years: 26 (5) • Gender, n (%) F: 27 • Body region: right arm • Timing: during tasks • Country: Denmark	NGF and isotonic saline • Effects of saline-induced pain during persistent movement-evoked pain		• Day 2: acute muscle pain was induced by injection of hypertonic saline • Day 4: 1 trial of the motor task without any injection	“repeated arm movements” on day 2 and day 4 than those injected with isotonic saline • NGF group also reported greater “maximum pain experienced over the past 48 hours” on day 2 and day 4 than day 0, and the highest “maximum pain experienced over the past 48 hours” was reported on day 2
Lower Extremity						
Booker, 2019	To 1) identify ethnic/race group differences in persons with knee osteoarthritis (OA) pain specific to movement-evoked pain (MEP), physical performance, and perceived stress measures, and 2) determine if perceived stress explains the relationship between MEP and function in Non-Hispanic Blacks (NHBs) and Non-Hispanic Whites (NHWs)	• Sample size: 162 • Participants: unilateral or bilateral knee pain and screened positive for clinical knee OA • Comparison: n.a. • Age range, years: 45–85 • Age, mean (SD) years: NHBs - 58.04 (563); NHWs - 61.46 (7.63) • Gender, n (%) F: 61	• Perceived stress • Physical function • Movement-evoked pain • Pain and function	• 101-point NRS	• Weight-bearing knee flexion • Maximal isometric strength testing of the knee extensor muscles, extension of the leg with maximum force while a handheld dynamometer was placed just above the ankle to resist participant movement • Tests were performed three times on each leg while	• There were significant racial/ethnic differences in all measures of MEP in both the crude unadjusted and fully adjusted models such that NHBs reported greater MEP than NHWs • NHBs were more likely to report the maximum intensity of pain (pain intensity = 100) for MEP, while more NHWs were likely to report

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Body region: knee • Timing: after each movement • Country: USA			the participant was in a sitting position with knee extended 75° from the horizontal position	no MEP (pain intensity = 0) • There was not a significant main effect for the association of perceived stress with any measure of MEP
Lundblad, 2008	To 1) test whether separate assessments of pain at rest and on movement preoperatively could be of value in predicting the effect on pain of the intervention and 2) establish the usefulness of the Pain Matcher as a tool for measuring different aspects of pain in osteoarthritis (OA) and its value in predicting pain relief	• Sample size: 69 • Control size: 24 • Participants: patients scheduled for (total knee replacement (TKR) for OA • Comparison: knee OA vs control • Age range, years: 40–80 • Age, mean years: 68 • Gender, n (%) F: 50.7 • Body region: knee OA • Timing: during movement, before TKA • Country: Sweden	• Pain at rest and with movement before total knee arthroplasty (TKA) operation and 18 months post-operation	• 100 mm visual analogue scale (VAS) • The Pain Matcher: an instrument for electrical stimulation, used preoperatively on all patients to assess matched pain (the pain corresponding to the knee pain with movement) and the thresholds for sensation and pain	• Participants were asked to rate their pain with movement upon walking (VAS) the day before surgery • Step 1) Participants were told to press a button on the Pain Matcher at the first noticeable sensation, the sensation threshold • Step 2) Participants were instructed to press the button when the perceived signal was painful, the pain threshold • Step 3) Participants were asked to press the button when the intensity of pain was the same as that from their knee on movement,	• VAS: Pain at rest was significantly less than that with movement • Pain Matcher: the matched pain with movement was 1.42 times higher than the pain threshold • Comparisons of pain with movement according to the VAS, and the matched pain with movement according to the Pain Matcher, showed no significant relationship

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
					the matched pain	
Lundblad, 2012	To assess the degree of radiographic osteoarthritis (OA) and histological inflammation in relation to pain at rest and with movement before and 18 months after total knee arthroplasty (TKA)	• Sample size: 69 • Participants: patients scheduled for (total knee replacement (TKR) for OA • Comparison: n.a. • Age range, years: 40–80 • Age, mean years: 68 • Gender, n (%) F: 50.7 • Body region: knee OA • Timing: during movement, before TKA • Country: Sweden	• Pain at rest and with movement before TKA operation and 18 months post-operation	• 100 mm VAS	• Participants were asked to rate their pain with movement upon walking (VAS) the day before surgery	• 94% of participants scored 5 or higher for pain with movement (VAS) • The mean change in pain score in relative terms was -64% (SD 32%) for pain with movement
Perrot, 2009	To examine the clinical and demographic correlates of pain intensity in patients with hip and knee osteoarthritis (OA)	• Sample size: 4719 • Participants: patients with painful hip or knee OA • Comparison: n.a. • Age, mean (SD) years: 67 (9) • Gender, n (%) F: 58 • Body region: knee & hip OA • Timing: during movement	• Joint pain and factors associated with joint pain severity by demographic and clinical variables in a large cohort of outpatients with hip and knee OA	• 11-point numeric rating scale (NRS)	• Patients were asked to rate pain intensities as per the following 3 ratings: (1) pain at rest; (2) pain during movement in the last 24 hours; and (3) average pain in the last 8 days.	• Mean pain intensity on movement during the last 24 hour and during the last 8 days showed a positive correlation (r = 0.78) • Mean pain intensity at rest and on movement during the last 24 hours showed a positive correlation (r = 0.57)

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Country: France				• Patients with both hip and knee OA reported significantly higher mean pain intensity than those with only one affected joint • Mean pain intensity increased with duration of OA in 5-year period
Perrot, 2013	To determine the cutoff points for patient acceptable symptom state (PASS) and minimal clinically important improvement (MCII) in real life, and to compare these values between patients with painful knee osteoarthritis (KOA) and hip osteoarthritis (HOA), after 7 days of usual care (with or without drugs) delivered by general practitioners	• Sample size: 2414 • Participants: patients with painful KOA or HOA • Comparison: n.a. • Age, mean (SD) years: 67.3 (8.7) • Gender, n (%) F: 49.8 • Body region: knee & hip • Timing: during movement • Country: France	• Assess the daily management of chronic painful conditions	• 11-point NRS	• At Day 0, pain intensity at rest and on movement during the previous 24 hours was assessed on an NRS • At Day 7, pain at rest and on movement during the previous 24 hours was again assessed and the patients' opinions of their state was assessed	• Mean (SD) pain intensity 7.0 (1.4) on movement • 89.6% of patients considered their pain at day 7 to have improved since baseline, pain intensity of 4.4 (1.9) on movement
Post-Surgical						
Gilron, 2005	To evaluate the safety and analgesic efficacy of a rofecoxib–gabapentin combination in comparison with either single agent following surgery	• Sample size: 103 • Participants: receiving abdominal hysterectomy • Comparison: placebo control vs. gabapentin	• Primary: pain intensity, at rest and with movement, during the first and second postoperative days	• 100 mm visual analogue scale (VAS)	• Pain at rest • Pain evoked by sitting, in a standardized fashion, from the supine position, followed by a	• The combination treatment was superior to placebo for all pain measures on days 1 and 2

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		vs. rofecoxib vs. combination • Age, mean years: 44.4 • Gender, n (%) F: 100 • Body region: abdomen • Timing: during first and second postoperative days • Country: Canada			120 s rest period • Pain evoked by peak expiration using a peak flow meter followed by a 120 s rest period • Pain evoked by cough. • During postanesthetic recovery on the day of surgery, rest pain only was rated verbally	• Gabapentin was superior to placebo on day 1 for pain evoked by sitting • Rofecoxib was superior to placebo on day 2 for pain evoked by cough and at almost all times for pain at rest, evoked by sitting, and evoked by peak expiration
Gilron, 2009	To test the hypothesis that a meloxicam-gabapentin combination has superior efficacy versus either drug alone in ambulatory patients after laparoscopic cholecystecomy	• Sample size: 89 • Participants: patients after laparoscopic cholecystectomy • Comparison: gabapentin vs. meloxicam vs. combination • Age range, years: 21–81 • Age, mean years: 46 • Gender, n (%) F: 71.9 • Body region: abdomen • Timing: day of surgery, post-operative days 1, 2, and 30 • Country: Canada	• Pain intensity at rest and with movement on day of surgery	• 11-point numeric rating scale (NRS)	• Pain at rest • Pain evoked by sitting, in a standardized fashion, from the supine position, followed by a 60s rest period • Pain evoked by peak expiration using a peak flow meter followed by a 120 s rest period • Pain evoked by cough.	• Pain intensity decreased from 60 to 120 min for pain evoked by peak expiration, sitting and coughing • Cough pain at 60 minutes for gabapentin was lower than that for meloxicam • On postoperative days 1, 2, and 30, there were no significant effects of treatment group on spontaneous or movement-evoked pain measures

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
Isaac, 2019	To test whether suprapatteller (SP) approach would result in lower knee pain than infrapatellar (IP) nailing in patients with at least 1 year of follow-up	• Sample size: 262 • Participants: patients treated with reamed intramedullary nailing of the tibia • Comparison: SP vs. IP • Age, mean years: 40.5 • Gender, n (%) F: 26.7 • Body region: knee • Timing: during tests • Country: USA	• Primary: knee pain during kneeling • Secondary: knee pain during resting, walking, and the past 24 hours.	• 11-point NRS	• Recorded knee pain during kneeling, resting, walking, and the past 24 hours	• No differences were detected between the 2 groups for knee pain during kneeling • There was no association detected between follow-up time and kneeling pain (P = 0.59) or with any of the secondary knee pain scores
Katz, 2009	To determine the extent to which (1) pre-operative pain intensity, pain disability, and post-traumatic stress symptoms (PTSS) predict post-thoracotomy pain disability 6 and 12 months later; and (2) if these variables, assessed at 6 months, predict 12-month pain disability	• Sample size: 47 • Participants: patients scheduled to undergo postero-lateral thoracotomy • Comparison: n.a. • Age range, years: 18–60 • Gender, n (%) F: 48.9 • Body region: chest • Timing: 24 and 48 hours after surgery • Country: Canada	• Pain disability	• 11-point numeric rating scale (NRS)	• Had the patient sit up in bed from a lying position and then provide a pain rating. • Average and worst pain at the 6 month and 12-month follow-ups	• Pre-operative factors and acute movement-evoked pain intensity on days 1 and 2 after surgery did not significantly predict 6 or 12-month pain disability

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
Koroglu, 2008	To study the effect of preoperative 3-in-1 block for total hip athroplasty (THA) surgery on intraoperative analgesic requirements and postoperative pain and tramadol consumption during patient-controlled analgesia	• Sample size: 30 • Participants: patients undergoing THA • Comparison: bupivacaine vs. placebo control • Age, mean years: 55.2 • Gender, n (%) F: 70 • Body region: hip • Timing: immediately after surgery and up to 48 hours • Country: Germany	• Intraoperative analgesic and postoperative pain	• 10 cm visual analogue scale (VAS)	• The leg of the patient, lying in supine position, was lifted 2–3 cm and then repositioned immediately, while thigh, knee and ankle was in extension for a total of 8 times, starting as soon as they responded to verbal stimuli in the recovery room (0) and at postoperative 1/2, 1, 4, 8, 12, 24 and 48 hours	• Mean VAS scores were significantly lower in group I both at rest and movement during the first postoperative 12h and also at movement 24h postoperatively
Lan, 2019	To compare the effects of continuous (adductor canal block (ACB) added to an intraoperative single-dose local infiltration analgesia (LIA) after medial unicondylar knee arthroplasty (UKA)	• Sample size: 46 • Participants: after undergoing UKA • Comparison: ropivacaine (Group RP) vs. saline (Group Control) • Age range, years: 55–75 • Age, mean years: 67 • Gender, n (%) F: 80.4 • Body region: knee • Timing: 24 hrs after surgery • Country: China	• Primary: pain scores with active knee flexion in the operated knee at 24 h after surgery • Secondary: Pain scores in patients with NRS>3 at 8, 12, 24, and 48h after surgery were measured at rest and with movement, breakthrough pain (where pain was initially reported as NRS>3) was measured	• 11-point NRS	• Active knee flexion	• The primary end point of pain scores with active knee flexion in the operated knee at 24 h after surgery was significantly reduced in Group RP compared with Group Control • Time until breakthrough pain (NRS > 3) was significantly longer in Group RP than that in Group Con

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
						• NRS pain scores at rest and with • movement at 8, 12, 24 and 48 h after surgery and rate of patients with NRS > 3 with movement within 24 and 48 h postoperatively were significantly lower in Group RP than in Group Con
Page, 2016	To (1) explore the acute postoperative pain trajectories after total hip athroplasty (THA); (2) identify baseline predictors of pain trajectory membership; and (3) examine how these pain trajectories are associated with pain-related outcomes up to 6 months after surgery	• Sample size: 150 • Participants: patients undergoing THA • Comparison: n.a. • Age range, years: 18–75 • Age, mean (SD) years: 60 (9.2) • Gender, n (%) F: 47.3 • Body region: hip • Timing: every 4h until operation and 6 weeks & 6 months after surgery • Country: Canada	• Pain-related outcomes at 6 weeks and 6 months post-surgery compared to postoperatively	• 11-point numeric rating scale (NRS)	• Movement-evoked pain upon moving from lying to the sitting position at the edge of the bed	• There was an overall significant difference in levels of pain intensity at 6 weeks after surgery, but no significant difference at 6 months

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
Rakel, 2012	To determine which preoperative characteristics predict moderate to severe movement and resting pain immediately following Total Knee Replacement (TKR) using a comprehensive set of physiological and psychological variables	• Sample size: 215 • Participants: patients undergoing unilateral TKR • Comparison: n.a. • Age, mean (SD) years: 61.68 (9.82) • Gender, n (%) F: 58.1 • Body region: knee • Timing: during tasks, pre- and postoperatively • Country: USA	• Movement and resting pain following TKR	• 21-point NRS	• Active flexion: participants flexed their surgical knee as far as possible while keeping their foot flat on the exam table • Extension of the knee: towel roll was placed under the ankle of the surgical leg and participants straightened their leg as far as possible	• Participants with severe movement pain preoperatively were 20 times more likely to have severe movement pain postoperatively • Participants who were screened as depressed prior to surgery were 2.7 times more likely to experience severe postoperative movement pain
Rudin, 2008	To evaluate the predictive potential of a combination of pre-operative psychological and physiological variables in estimating severity of postoperative pain following a laparoscopic tubal ligation procedure	• Sample size: 59 • Participants: patients undergoing laparoscopic tubal ligation • Comparison: n.a. • Age range, years: 35–41 • Age, mean years: 38 • Gender, n (%) F: 100 • Body region: pelvis • Timing: 2 & 4hr after surgery, in the evening on Day 0, twice on Day 1, and once each evening until	• Severity of postoperative pain	• 100 mm visual analogue scale (VAS)	• Change from supine to standing • Walking and staircase climbing	• Six patients reported VAS470 both at rest, during walking and during staircase climbing and all of these patients reported pre-operative pain • Ten patients reported VAS470 during change from supine to standing position, and seven of these patients also reported preoperative pain

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		postoperative day 10 • Country: Sweden				
Simon, 2016[a]	To determine whether older age was a prognostic factor of pain recovery three and six months after shoulder arthroscopy	• Sample size: 139 • Participants: patients undergoing shoulder arthroscopy • Comparison: young vs. middle-aged vs. older • Age range, years: 20–79 • Gender, n (%) F: 34.5 • Body region: shoulder • Timing: pre-operative and 6 months post-operative • Country: USA	• How post-operative movement-evoked pain and experimental pain responses differ among older adults compared to middle-aged and young adults	• 101-point numeric pain rating scale (NPRS) • NPRS known to assess musculoskeletal pain	• Shoulder abduction	• Preoperatively, movement-evoked pain and experimental pain response did not differ between older and middle-aged adults, or older and young adults • Pre-operative movement-evoked pain was higher among middle-aged adults compared to younger adults • Older age was the strongest predictor of 6 month movement-evoked pain after controlling for pre-operative, intra-operative, and post-operative
Van Boekel, 2017	To quantify relationships between numeric rating scale (NRS) and other methods of pain assessment and to examine the ability of an NRS cut-off point to predict either patients' willingness to accept pain or functional capacity	• Sample size: 9,082 • Participants: patients underwent surgery • Comparison: n.a. • Age, mean (SD) years: Day 1 – 53.5 (16); Day 2	• Relationships between movement-evoked NRS and acceptability of pain, functional impact of pain, and a measure combining the two	• 11-point numeric rating scale, specifically noted for MEP (NRS-MEP)	• Measured pain upon physical activities, such as coughing, deep breathing, early movement and walking	• Patients associated low NRS-MEP scores 0–4 with unacceptable pain in approximately 9% of the observations • On average, in 23% of the

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Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		– 56.5 (15); Day 3 – 57 (15) • Gender, n (%) F: Day 1 – 56; Day 2 – 48.5; Day 3 – 44.5 • Body region: full body • Timing: during physical activities on post-operative days 1, 2 and 3 • Country: Denmark				observations patients with an NRS-MEP of 8–10 considered their pain acceptable • On average, in 17% of the observations patients with an NRS-MEP of 8–10 showed appropriate movements • In 22% of the observations with an NRS-MEP = 7, and, on average, in 7% of the observations with an NRS-MEP of 8–10 an observed relationship between the NRS-MEP scores and the presence of a clinically desirable situation is seen where acceptable pain coexists with pain-free physical functioning
Van Boekel, 2019	To establish in a prospective cohort the relationship between postoperative pain and 30-day postoperative complications including deviations from the ideal postoperative course, in real-world practice	• Sample size: 1014 • Participants: patients undergoing surgery • Comparison: lowest/low expected pain vs. moderate	• Post-operative pain and 30-day postoperative complications	• 11-point numeric rating scale, specifically noted for MEP (NRS-MEP)	• In morning time after bathing and getting dressed	• Patients who score an average NRS-MEP of 9 have 2 times the odds of having 1 or more complications as those with an average

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		expected pain vs. high/highest expected pain • Age range, years: 18–90 • Age, mean (SD) years: 55 (15) • Gender, n (%) F: 51.7 • Body region: full body • Timing: on morning of postoperative day 1, 2, & 3 • Country: Denmark				NRS-MEP of 1
Axial						
Bauer, 2016	To investigate the effect of low back pain (LBP) intensity on movement control impairments using two direction specific movement control tests, and one repetitive movements test	• Sample size: 94 • Participants: episode LBP persisting 4 weeks or longer & if they reported moderate disability • Control: 31 pain free individuals • Comparison: LBP vs. control • Age range, years: 18–65 • Gender, n (%) F: 51 • Body region: back • Timing: before test • Country: Switzerland	• Lumbar range of motion (ROM) • Ratio of lumbar and hip ROM, which indicates direction specific movement control (DSCM) • Recurrence and determinism of repetitive lumbar movement patterns	• 11-point numeric rating scale (NRS)	• **Sitting Knee Extension**: participant sat upright & were asked to stabilize their lumbar spine whilst extending their right knee • **Waiters Bow**: instructed to stand upright & then flex their hips as far as possible whilst keeping their lumbar spine stable • **Pick Up A Box**: consisted of ten cycles, of four seconds duration, starting in upright	• No real MEP related results on the task characteristics

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
					standing. During each cycle the participants were asked to pick up the box from the ground and put it back down again	
Christensen, 2017	To investigate activity and coordination between axioscapular muscles during repeated arm movements in groups of Insidious Onset Neck Pain (IONP), Whiplash-Associated Disorder (WAD) and healthy controls as well as the effects on pain sensitivity and pain perception	• Sample size: 50 • Participants: 3 months of IONP or WAD neck pain. Pain during active cervical range of motion and palpation • Comparison: pain vs. healthy individual control group • Age range, years: 18–50 • Gender, n (%) F: 68 • Body region: axial • Timing: during tasks • Country: Denmark	• Intensity, area, quality of pain during movement • Muscle activity • Pressure pain threshold	• 10 cm visual analogue scale (VAS)	• Participants were asked to perform an abduction in the scapular plane • Total of six series of arm movements performed where first three series (Bout-I) of arm movements were separated by approx. 8 min & the last three series (Bout-II) of arm movements were separated by approx. 42 sec. • Bout I & II separated by a 10-min break • Categories of three movements were: slow-up, slow-down, and fast-up movements	• 67% of the WAD group scored ≥1 on the Likert scale reflecting the perceived difficultness of performing the movement while this was only the case for 25% of the IONP group and none from the control group • Neck pain patients [WAD & IONP] perceived bilateral neck pain expanding in the course of movements • A significant difference was found for the serratus anterior muscle for the slow-up movement, with an increased activity for the WAD group during Bout-II compared with Bout-I, as well as when compared with

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
						both IONP and control groups
Hadjistavropoulos, 2000	To examine the utility of both self-report and nonverbal measures of pain in frail elders experiencing exacerbations of chronic musculoskeletal pain; these were assumed to be more representative of the day-to-day pain experience of elderly patients	• Sample size: 58 • Participants: inpatients of rehab undergoing physical therapy for various conditions • Comparison: n.a. • Age, mean (SD) years: 77 (8.1) • Gender, n (%) F: 52 • Body region: axial • Timing: after tasks • Country: Canada	• Self-reported MEP • Nonverbal indicators of pain (body movement/ facial actions)	• Colored Visual Analogue Scale (CAS) • Successfully used with elders who had mild to moderate cognitive impairments • Moving a plastic glide along a 14.5 cm long triangular shape varying in width and color from one cm wide and light pink color at the bottom to three cm wide and deep red color at top. Scale extremes were No Pain and Most Pain	• Preformed sit, stand, recline, walking and transferring during periods of testing	• No explanation of MEP-related results regarding self-reported MEP
Lauche, 2014	To determine reliability, validity, and responsiveness of the pain on movement (POM) questionnaire, an instrument developed to determine pain intensity induced by head movement	• Sample size: 482 • Participants: Chronic nonspecific neck pain for at least 5 days a week for a least three consecutive months with an average pain intensity at rest of 40–45 mm on a 100-mm VAS • Comparison: n.a. • Age range, years: 19–81	• Primary: Pain on movement • Secondary: Pain (VAS), HRQoL, neck disability index, cervical ROM	• 100-mm visual analogue scale (VAS) • Mean POM score was calculated	• To measure POM, patients were asked to subsequently flex, extend, laterally flex, and laterally rotate their necks to the left and right as far as possible • Each movement illustrated with a picture • Evoked pain during each movement for	• Pain intensity was 47.7 mm VAS (±20.3 SD) on average; POM was comparable with average rating of 43.9 ± 20.8 mm VAS • Study focuses on reliability and validity of POM as an instrument more than MEP tasks described in study

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Age, mean (SD) years: 50 (12.4) • Gender, n (%) F: 73 • Body region: axial • Timing: during tasks • Country: Germany			each of the six directions	
Lehner, 2017	To investigate if the activity of an axial muscle involved in postural control evoked changes in corticomotor excitability and whether this mirror activity would be modulated depending on whether or not painful movements were observed	• Sample size: 35 • Participants: right-handed, healthy individuals • Comparison: LEG vs. BACK vs. BACKPAIN vs. control • Age, mean (SD) years: 24 (3) • Gender, n (%) F: 51 • Body region: axial • Timing: after tasks • Country: Switzerland	• Corticomotor excitability • Vicarious pain perception based on video clips	• 11-point numeric pain rating scale (NPRS)	• Four groups: (1) a leg-lifting technique (LEG) while keeping the back straight, (2) a back-lifting technique (BACK) while keeping the legs straight, (3) a back-lifting technique with a short sharp pain (BACKPAIN), and (4) a control condition showing no movement • After each video clip showing a lifting action, participants rated the observed vicarious pain on numeric pain rating scale (NPRS)	• BACKPAIN condition resulted in a moderate level of vicarious pain intensity, whilst the BACK condition showed a low level of vicarious pain intensity • BACKPAIN was more painful than BACK & LEG and BACK was more painful than LEG • The lowest vicarious pain intensity was reported in the LEG condition • The NPRS differed significantly between the three conditions

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
Mankovsky-Arnold, 2017	To conduct a preliminary examination of the relation between sensitivity to movement-evoked pain and work-disability in individuals with whiplash injuries to examine whether adopting a multidimensional approach to pain assessment increased the amount of variance in occupational disability that was accounted for by pain	• Sample size: 105 • Participants: individuals sustained whiplash injury within 24 months, had salary indemnity from a motor vehicle insure for whiplash-related injuries • Comparison: gender, employment status • Age range, years: 17–57 • Gender, n (%) F: 47 • Body region: axial • Timing: during tasks • Country: Canada	• Spontaneous pain • Multi-site pain • Single-point movement-evoked pain • Sensitivity to movement-evoked pain • Pain disability Index	• 11-point numeric rating scale (NRS)	• Participants stood in front of a height-adjustable table and lifted and replaced a series of 18 weighted canisters • The canisters weighed 2.9, 3.4 or 3.9 kg and were arranged on the table in 3 rows of 6 columns	• Women obtained higher scores on the measure of single-point movement-evoked pain • No differences due to sex emerged for the measure of sensitivity to movement-evoked pain • Participants who were work-disabled, compared to participants who were employed, obtained higher scores on sensitivity to movement-evoked pain • The two groups did not differ significantly on the measure of single point movement-evoked pain
Mankovsky-Arnold, 2014	To examine the degree to which measures of spontaneous and movement-evoked pain accounted for shared or unique variance in functional disability associated with whiplash injury	• Sample size: 142 • Participants: individuals sustained whiplash injury within 24 months, had salary indemnity from a motor vehicle insure for whiplash-related injuries • Comparison: n.a.	• Spontaneous pain • Single point movement-evoked pain • Repetition-induced summation of activity-related pain • Fear of movement	• 11-point numeric rating scale (NRS)	• Participants stood in front of a height-adjustable table, and lifted and replaced a series of 18 weighted canisters • The canisters weighed 2.9, 3.4 or 3.9 kg and were arranged on the table in 3	• Single-point movement-evoked pain was found to be significantly correlated with lift tolerance and self-reported disability

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Age range, years: 20–60 • Gender, n (%) F: 48 • Body region: axial • Timing: during tasks • Country: Canada	• Self-reported disability		rows of 6 columns	
Palit, 2019	To examine the moderating role of pain resilience on the impact of fear-avoidance beliefs and pain catastrophizing on an established measure of functional performance (i.e., Back Performance Scale) and movement-evoked pain in older adults with chronic low back pain (cLBP)	• Sample size: 69 • Participants: older adults with cLBP • Comparison: n.a. • Age range, years: 60+ • Age, means (SD) years: 68.1 (7.0) • Gender, n (%) F: 56.7 • Body region: back • Timing: immediately after tasks • Country: USA	• Pain catastrophizing • Fear-avoidance beliefs • Pain resilience • Functional capacity and movement-evoked pain	• 101-Point NRS	• Completion of the Back Performance Scale (BPS): • Sock Test (grab toes with the fingertips of both hands), Pick-up Test (pick up a piece of paper from the floor), Roll-up Test (roll up slowly in to a sitting position without using arms and hands), Fingertip-to-Floor Test (reach as far as possible to the floor), and Lift Test (lift a 5 kg weighted box from the floor to a table)	• Overall moderation models with fear-avoidance and pain catastrophizing as predictors significantly accounted for 36% and 43% of the variance in movement-evoked pain, respectively • Higher fear-avoidance was associated with greater movement-evoked pain in individuals with low pain resilience, but not among those with average or high resilience • Greater pain catastrophizing was related to increased movement-evoked pain among those with low and average pain resilience, but not in individuals

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
						high in resilience
Penn, 2020	To examine the associations among chronic pain stigma, perceived injustice, and movement-evoked pain in adults with nonspecific chronic low back pain (cLBP)	• Sample size: 105 • Participants: patients reported cLBP that had persisted for at least three consecutive months and was present on at least half the days in the past six months • Comparison: n.a. • Age range, years: 18–82 • Gender, n (%) F: 59 • Body region: back • Timing: during completion of tasks • Country: USA	• Chronic pain-related stigma • Depression • Perceived injustice • Movement-evoked pain and physical function	• 101-point numeric rating scale (NRS)	• Assessed lower extremity function with balance tests (stand with their feet together in the side-by-side, semitandem, and tandem positions for up to 10 seconds each), chair tests (rise from a seated position in a chair and return to a seated position five times), and walking tests (walk a four-meter course twice)	• The mean level of movement-evoked pain in response to completion of the short physical performance battery (SD) was 25.9 (29.7) for balance, 35.6 (31.8) for transition from seated in a chair to standing, and 21.7 (28.2) for walking, with a range of 0 to 100 for all three tests
Rabey, 2017	To 1) determine whether data-driven subgroups with different, clinically-important pain responses following repeated movement exist in a large chronic low back pain (cLBP) cohort, specifically using a standardized protocol of repeated sagittal plane spinal bending and 2) determine if the resultant pain responses following repeated movement were associated with	• Sample size: 294 • Participants: recruited from private physiotherapy, psychology and pain management clinics • Comparison: n.a. • Age, mean years: 50 • Gender, n (%) F: 57.1	• Underlying pain responses to repeated movement in cLBP	• 11-point NRS	• Participants were asked to complete 20 forward bends followed by 20 backward bends using standardized instructions. • Participants were allowed to complete each movement in whatever speed and fashion they chose	• Only nineteen participants (6.5%) displayed decreases in pain intensity with backward bending of ≥two-points; while thirteen participants (4.4%) displayed decreases in pain intensity of ≥ two-points with forward bending

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
	pain and disability, pain sensitivity and psychological factors	• Body region: back • Timing: before task commencement, then every five repetitions • Country: Australia			• There was a brief pause every five repetitions for participants to rate their pain intensity	• For the 31 participants in total reporting a decrease in pain during forward and/or backward bending, eight were classified as no increase of pain (NIP) and 23 as unidirectional (UD) pain provocation pattern
Rabey, 2019	To investigate whether STarT Back Tool (SBT) risk subgroups in people with chronic low back pain (cLBP) differed across movement and sensory variables	• Sample size: 290 • Participants: recruited from private physiotherapy, psychology and pain management clinics • Comparison: high risk (greater pain summation following repeated forward bending than medium & low), medium risk (greater pain summation following repeated backward bending than low & high), low risk (faster forward bending times than high & medium) • Age range, years: 18–70 • Gender, n (%) F: 57.2	• Movement and sensory variables	• 11-point numeric rating scale (NRS)	• Participants were asked to complete 20 forward bends followed by 20 backward bends using standardized instructions • Participants were allowed to complete each movement in whatever speed and fashion they chose • There was a brief pause every five repetitions for participants to rate their pain intensity	• The results classified three groups: • High risk subgroup: greater pain summation following repeated forward bending than medium & low • Medium risk subgroup: greater pain summation following repeated backward bending than low & high • Low risk subgroup: faster forward bending times than high & medium

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Body region: back • Timing: before task commencement, then every five repetitions • Country: Australia				
Simon, 2016[b]	To determine how working memory and pain catastrophizing are associated with chronic low back pain (cLBP) measures of daily pain intensity and movement-evoked pain intensity	• Sample size: 90 • Participants: Primary complaint of cLBP for at least 3 months prior to study enrollment, with an average daily pain intensity of 40/100 • Control: 30 pain free individuals • Comparison: cLBP vs. control • Age, mean years: 48 • Gender, n (%) F: 67 • Body region: back • Timing: during tasks • Country: USA	• Daily pain intensity • Movement-evoked pain intensity • Working memory • Pain catastrophizing	• 101-point NRS	• Movement-evoked pain intensity was assessed through functional tasks of the Back Performance Scale (BPS) • All require sagittal plane mobility: Sock Test, Pick-up Test, Roll-up Test, Fingertip-to-Floor Test, and Lift Test	• Participants who were pain-free were validated based on very low daily pain and movement-evoked pain ratings that also were lower than the ratings for participants with cLBP
Williams, 2013	To investigate the immediate effects of pain relief on lumbar sagittal curvature during flexion, extension and lifting in participants with acute low back pain (aLBP) and chronic	• Sample size: 40 • Participants: referred from physical therapy clinics, experiencing either acute or chronic LBP	• Movement-evoked pain • Lumbar curvature	• 100-mm visual analogue scale (VAS)	• Participants were requested to bend forwards as far as possible, pause for a second before returning upright	• A significant reduction in kyphotic curvature was demonstrated following pain relief for flexion and lifting in the whole lumbar

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
	low back pain (cLBP)	• Comparison: acute LBP vs. chronic LBP • Age range years: 18–55 • Gender, n (%) F: 45 • Body region: back • Timing: after tasks • Country: United Kingdom			• Identical instructions were given for backward bending and lifting • A crate was positioned using floor markers to ensure identical start positions and all movements were completed three times	spine, and for lifting in the lower lumbar spine, in the aLBP group • No significant differences were observed for extension in the aLBP group or cLBP group • Pain relief did not attenuate the lumbar curvatures for acute or chronic LBP sufferers except for flexion and lifting in the acute LBP group
TMJ						
La Touche, 2015	To 1) investigate the influence that pain and disability of the neck may have on masticatory sensory-motor variables in patients with headache attributed to temporomandibular disorders (TMD) and 2) to identify whether the psychological or disability variables have any association with the studied sensory-motor variables	• Sample size: 83 • Participants: chronic headache attributed to TMD • Control: 39 healthy individuals • Comparison: mild neck disability vs. moderate neck disability vs. control • Age range, years: 19–65 • Age mean, years: 42 • Gender, n (%) F: 62.6	• Habitual and spontaneously perceived pain intensity • Pain intensity perceived at different times during the course of the chewing provocation test and at 24h after completion	• 100 mm VAS	• Chewing gum in upright, seated position with feet flat on the floor, knees and hips at 90 degrees, and arms resting freely alongside	• Higher values on the VAS during the provocation chewing test for the moderate neck disability group compared to the mild neck disability group and the control group • The results obtained 24 hours after the test showed no differences between the groups of patients, but there were differences

Author	Research aim	Sample characteristics	Outcome measures	Measurement scale	MEP task characteristics	MEP-related results
		• Body region: jaw • Timing: immediately after test and 24 hours after • Country: Spain				with the control group
Zhang, 2017	To examine the hypothesis that repetitive jaw movements would lead to increases in self-reported pain and perturbation of motor performance in patients with temporomandibular joint (TMJ) pain with disc displacement in comparison with a matched control group	• Sample size: 20 • Participants: TMJ pain • Control: 20 healthy individuals • Comparison: TMJ pain vs. control • Age range, years: 25–38 • Gender, n (%) F: 50 • Body region: jaw • Timing: immediately after each session • Country: China	• Pain during normal opening and closing • Pain during fast movements • Pain during horizontal movements	• 11-point numeric rating scale (NRS)	• Each session contained 4 continuous jaw movements with the starting and ending point at the intercuspal position (ICP), with 3 seconds of interval between each session, so a total of 20 repeated and standardized jaw movements were recorded for each scan • There were 10 minutes of rest between each of the 3 scans	• Self-reported pain increased and jaw movements deteriorated during repetition of standardized movements in patients with painful TMJ, and anterior disc displacement without reduction • (DDWOR) but not in a matched control group