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Van Dieën, Jaap H.; Peter Reeves, N.; Kawchuk, Greg; Van Dillen, Linda R.; Hodges, Paul W.

published in
Journal of Orthopaedic and Sports Physical Therapy
2019

DOI (link to publisher)
10.2519/jospt.2019.7916

Analysis of motor control in low-back pain patients, a key to personalized care?

Jaap H. van Dieën, PhD
Department of Human Movement Sciences, Vrije Universiteit Amsterdam, Amsterdam Movement Sciences, Amsterdam, The Netherlands

N. Peter Reeves, PhD
Michigan State University Center for Orthopedic Research, Michigan State University, Lansing, Michigan, USA
Department of Osteopathic Surgical Specialties, Michigan State University, East Lansing, Michigan, USA

Greg Kawchuk, PhD
Faculty of Rehabilitation Medicine, Department of Physical Therapy, University of Alberta, Edmonton, Canada

Linda van Dillen, PT, PhD
Program in Physical Therapy and Department of Orthopaedic Surgery, Washington University in St. Louis School of Medicine, St. Louis, MO, USA

Paul W. Hodges, PT, PhD
The University of Queensland, Centre for Clinical Research Excellence in Spinal Pain, Injury and Health, School of Health & Rehabilitation Sciences, Brisbane Queensland, 4072, Australia

Correspondence
prof.dr. Jaap H. van Dieën
Department of Human Movement Sciences
VU University Amsterdam
van der Boechorststraat 9
NL-1081 BT Amsterdam
Netherlands
t: (31) 20 5988501, f: (31) 20 5988529, e: j.van.dieen@vu.nl

conflict of interest: The authors have no conflict of interest to report.

This paper reports a literature review, not supported by specific funding. Ethical approval does not apply.

Synopsis

Motor control exercise has been shown to be effective in the management of low-back pain (LBP), but effect sizes are modest, possibly due to the fact that studies have used a one-size-fits-all approach, whereas literature suggests that patients may differ in presence or type of motor control issues. In this commentary, we address the question whether consideration of such variation in motor control issues might contribute to more personalized motor control exercise for patients with LBP. Such an approach is plausible, since motor control changes may play a role in persistence of pain through effects on tissue loading that may cause nociceptive afference in particular in case of peripheral sensitization. Subgrouping systems used in clinical practice which comprise motor control aspects allow reliable classification that is in part aligned with findings in studies on motor control in patients with LBP. Motor control issues may have heuristic value for treatment allocation, as the different presentations observed suggest different targets for motor control exercise, but this remains to be proven. Finally, clinical assessment of patients with LBP should take into account more aspects than motor control alone, including pain mechanisms, musculoskeletal health and psychosocial factors, and may need to be embedded in a stratification approach based on prognosis to avoid undue diagnostic procedures.

Keywords: back pain, postural control, exercise, diagnostics, subgrouping

In the treatment of low back pain (LBP), exercise that targets motor control is commonly used and with some success.[10, 49, 75] Motor control can be defined as the way in which the nervous system controls posture and movement to perform a given motor task and includes consideration of all the associated motor, sensory and integrative processes. Here we use the term "motor control exercise" (MCE) to refer to exercise that aims to change the manner in which a person controls their body (including posture/alignment, movement, muscle activation) to modify loading of the spine and adjacent structures.

The effectiveness of MCE has been the subject of several systematic reviews that have undertaken different comparisons.[10,49,75] A consistent outcome is that MCE is better than minimal intervention in reducing pain in the short-, intermediate- and long-term, and in reducing disability at long-term follow-up.[49] The pooled effect size was ~14% for pain and ~11% for disability when compared to minimal intervention.[49] Effects were better than for many other interventions, although they were still modest and only better than other exercise interventions in the short-term.[49] Recent systematic reviews provide contrasting evidence for comparison of effects of MCE and general exercise on disability: one reported better outcomes for MCE; [10] the other concluded there is low to high quality evidence that MCE is not clinically more effective than other exercises.[75] Of note, most large clinical trials with modest effects investigated application of MCE in a standardised manner to a heterogeneous group of patients with non-specific LBP. This contrasts the prevailing clinical view that treatment effects may be larger if treatments are targeted to the right patients, at the right time, and in a tailored, individualized manner. This has been the topic of considerable research and clinical attention.

It has been suggested that specific patient characteristics may predict who will or will not benefit from MCE,[48] or guide how it should be tailored to the individual patient. As reviewed by van Dieën et al.,[94] laboratory studies of motor control in individuals with LBP and healthy subjects demonstrate high variability between studies,[e.g. 52, 95] and between individuals with LBP within studies.[e.g. 16, 72] This concurs with the proposal that tailored rehabilitation programs are likely to be required to address the specific changes in motor control that are unique for the individual.

This commentary aims to address the overall question whether features of motor control could form an important element of a subgrouping scheme. Individualisation of MCE could involve identification of subgroups of patients with similar motor control issues or similar response to treatment, or individualising treatment to match each individual patientÚs presenting characteristics. A further aim is to highlight the research and development that is needed to address the major issues of subgrouping, particularly related to motor control, for application in clinical practice.

2 Subgrouping of patients with LBP

Based on diversity in presentation among individuals with LBP, it has been argued that no single treatment is likely to be effective for all patients and various authors have emphasized the need to administer more personalized treatment.[6, 7, 27, 97] Subgrouping of patients is generally considered to be a step towards personalization, and LBP is seen as a disorder for which subgrouping may be particularly useful in view of the large and heterogeneous patient population, the large variation in treatment outcomes, and the variety of available treatment options with varying costs and risks. Among clinicians it is generally believed that LBP includes many different conditions.[27] Consensus on the best way to subgroup patients or to personalize treatment is, however,

lacking[38, 97] and there is no strong evidence yet for effectiveness of subgroup-based treatment.[5, 24, 33 , 45, 54]

Towards resolution of the issues addressed above, Foster et al.[26] proposed a set of requirements for subgrouping in LBP. First, the subgrouping system should be plausible; in other words, it should be compatible with current knowledge about pathology of and risk factors for LBP. Second, subgrouping should be reliable; for instance, repeated testing or testing by different clinicians should assign the same patients to the same subgroups. Third, methods need to be simple enough to allow application in clinical practice. The simplicity of a method must be balanced with acceptability to patients and clinicians, and cost-effectiveness. Very sophisticated diagnostic instruments can be useful if the outcomes allow more effective treatment at a lower overall cost. Fourth, for clinical utility a subgrouping system should yield mutually exclusive subgroups, meaning all cases, at one point in time, should fit into only one subgroup and this subgroup membership should guide a unique treatment choice. In the following sections, we review motor control subgrouping based on the criteria proposed by Foster et al..[26]

3 Is subgrouping based on motor control plausible?

For subgrouping based on motor control to be plausible, issues with motor control would have to be relevant for the development or continuation of LBP and relevant variation in motor control presentation would have to exist in the population of individuals with LBP.

With respect to the first question, the nature of loads on the spine and adjacent structures depends on the quality of motor control, in combination with anatomical factors (e.g. muscle moment arms) and motor tasks that are performed. However,

whether loading of these structures is relevant with respect to development of LBP has been heavily debated.[3, 4, 42, 43, 53, 66, 83, 93] Recent systematic reviews and meta-analyses, however, provide consistent evidence for a prospective association between some activities and tasks that induce high mechanical loads on the back and LBP.[11, 14, 30] In addition, variables that quantify (cumulative) mechanical load on lumbar tissues, such as lumbar moments and compression forces, are associated with LBP incidence or prevalence.[12, 13, 40, 51, 61] Another line of evidence for the plausibility of a causal relation between mechanical loading and LBP stems from biomechanical studies in animal models and on human cadaveric material. Such studies indicate that loads on spinal tissues that occur in daily life can cause injury[8, 81] and, even without injury, ongoing mechanical stimulation of tissues can potentially activate nociceptors and initiate an inflammatory response.[47] Although, it is difficult to confirm the presence of micro-trauma let alone non-injurious noxious stimulation of tissues in the back in individuals with LBP, a range of literature supports the plausibility of a causal relation between mechanical loading and the development of LBP.[96] Finally, several mechanisms can play a role in transition to chronic LBP, specifically non-healing of injured tissues, ongoing nociceptive input, central sensitization and neuropathic pain development. Mechanical loading of tissues would be relevant in relation to the first two of these. It may both hamper and stimulate tissue healing, likely dependent on intensity and frequency of loading and time after injury,[23, 46, 82] and also in the absence of frank injury it can promote ongoing nociceptive input, especially in the presence of peripheral sensitization.[19, 59, 103]

With respect to the question whether there is relevant variation in motor control presentation among individuals with LBP, a recent review of the literature concluded that the group with LBP may show overlap with or be at either extreme of the

distribution in motor control found in healthy participants.[94] The groups deviating from normal motor control can be divided based on the mechanical consequences of the changes in motor control. One pattern of change involves increased activation of trunk muscles and may provide tight control over lumbar movements, but at the cost of higher loads on muscles and on the spine.[91] The opposite pattern, involves lower muscle activation and might avoid high muscle forces and compressive loading, but with the cost of a loose control over movement and a potential result of higher tensile strains of tissues. In the following we will refer to these two ends of a spectrum as "tight" and "loose" control. Clearly tight and loose control would have different mechanical consequences that could both be relevant for development and continuation of LBP, but they also suggest different targets for MCE.

4 Is subgrouping based on motor control practically applicable and reliable?

Studies on motor control in LBP, summarized in van Dieën et al.,[94] have used a broad range of laboratory-based measurement techniques to characterize motor control. In principle, these techniques could provide a basis for the development of clinical tests to assess motor control to inform clinicians regarding subgrouping. However, generally speaking application of these techniques involves substantial costs and requires specific expertise that is not readily available. Therefore, the following considers the extent to which subgrouping systems already applied in clinical practice take motor control aspects into account and to what extent this results in reliable classification.

Several systems for subgrouping or profiling that are in common use clinically incorporate motor control aspects in the assessment of patients with LBP. Those that have been studied most extensively are, the "Treatment Based Classification" (TBC), the "Multi-Dimensional Clinical" framework (MDC) (formerly named the "O'Sullivan

Classification"), and the "Movement System Impairment" classification (MSI). If these assessments capture the differences in motor control that have been identified in laboratory-based motor control measures, this would indicate that assessment of motor control issues based on clinically applicable tools can yield reliable outcomes.

4.1 Treatment Based Classification

The TBC system, originally proposed by Delitto et al.,[18] and updated by Fritz et al.[28] and Alrwaily et al.[1] proposes four LBP subgroups, each named for the treatment to which the patient is most likely to respond; (1) manipulation, (2) stabilization, (3) specific exercise, and (4) traction. The inter-rater reliability of examiners (physical therapists who are familiar with the classification system) to classify patients is clinically acceptable.[97]

With respect to the current understanding of motor control changes in LBP,[94] the criterion of hypomobility of the lumbar spine, as one of the criteria for allocation to the TBC *manipulation* subgroup, could be considered to align with a group of patients with LBP who present with tight motor control. Importantly, other criteria for subgroup allocation (e.g. time since symptom onset, age) cannot be considered specific to this motor control phenotype. Furthermore, it would seem plausible that the TBC *stabilization* subgroup could involve individuals who use loose motor control,[94] as this group are described to require restriction of excessive segmental motion. Consistent with this proposal, studies report that individuals classified into this group more often have excessive segmental rotations or translation on flexion/extension radiography than others,[29] more aberrant segmental lumbar movement on flexion/extension radiography,[84] poorer ability to contract the transversus abdominis muscle in isolation from other abdominal muscles,[85] and lower multifidus activation,[32] which could all be considered to align the loose motor control phenotype.

4.2 Multi-Dimensional Clinical framework

The MDC framework has evolved from a subgrouping approach[62] to a multidimensional clinical profiling approach.[65] Within the MDC, motor responses are described in three broad contexts: adaptive/protective motor responses to an acute tissue injury and or underlying pathological process (i.e. "movement impairment"), motor responses secondary to dominant central pain mechanisms, or maladaptive/provocative motor responses that may contribute to the pain (i.e. "motor control impairment"). These presentations may be associated with directional patterns of pain provocation (flexion, extension, rotation, side bending) or multiple directions (multidirectional).[69] Reliability testing among trained physical therapists has shown good to excellent inter-rater reliability in classification of patients.[17, 99]

There is strong potential alignment between the MDC characterisation of motor responses and the tight and loose motor control phenotypes of LBP. The movement impairment presentation aligns well with motor control changes interpreted as tight motor control. The MDC movement impairment is characterized by abnormally high levels of muscle guarding and co-contraction of trunk muscles.[62] Whether the subdivision on the basis of the movement direction avoided by the individual aligns with detailed assessment of motor control has not been tested.[69] The motor control impairment presentation, which is described as demonstrating "an impairment or deficit in the control of the symptomatic spinal segment in the primary direction of pain", can be hypothesized to overlap with the loose control end of the spectrum of motor control changes. This applies in particular to the flexion presentation, who tend to adopt flexed trunk postures, which provoke pain. These individuals gradually increase trunk flexion over time when cycling,[9] or when seated,[16, 64] less accurately resume a "neutral" trunk posture (perhaps caused by proprioceptive impairment[60, 63]), may have lumbar

hypermobility in forward bending,[41] and lower lumbar muscle activity in sitting.[15] The "passive extension" sub-group, who tend to hinge into extension with low trunk muscle activity,[62] may also align with a loose control group, while the "active extension" subgroup, who tend to adopt extended trunk postures characterized by high muscle activity,[15, 16] appear more aligned to a tight control phenotype.

4.3 Movement System Impairment classification

The MSI classification system, developed and described by Sahrmann,[73] has the underlying assumption that people with LBP tend to move one or more lumbar joints more readily than adjacent joints/segments (e.g. thoracic or hip joints). This is thought to result from habitual movement patterns during daily activity, eventually leading to excessive loading of tissues associated with the specific joint. Five LBP subgroups are proposed, named for the specific direction(s) of lumbar movement considered to contribute to the patient's symptoms: flexion, extension, rotation, rotation with flexion, and rotation with extension. Trained physical therapists can attain fair to excellent reliability in MSI classification.[97]

The MSI system describes motor impairments in LBP as a failure to constrain movement of some lumbar joints in a specific direction. This concurs with the notion of loose control, and the MSI system differentiates separate subgroups based on movement direction in which the impairment is most apparent and linked to pain provocation. Whether the direction inferred from MSI classification parallels direction-specific differences in trunk mechanics or muscle activity requires clarification. Also, it is unclear how a tight control subgroup might relate to the MSI classification.

4.4 Do clinical tools allow reliable classification of motor control?

Current subgrouping methods were not specifically developed to classify patients based on motor control issues. Nevertheless, the fact that these methods

reliably arrive at subgroups that likely show partial overlap with those that might be found using the laboratory-based biomechanical and electromyography measurements used in motor control studies is promising. Objective measurements may add to consistency, validity and reliability of subgrouping and might have as additional benefit that they would permit consideration as a measure of treatment effects, if found responsive. In several of the classification systems, motor control is assessed in a direction specific manner. The relation between directional specificity of the clinical presentation and underlying changes in motor control and their effects require further study.

5. Is subgrouping based on motor control clinically useful?

Subgrouping based on motor control can be considered of clinical value if it has heuristic value, meaning, if assignment of a patient to a specific subgroup implies a specific treatment and if such targeted care is more effective than a one-size-fits all approach. Review of biomechanical, electromyography and modelling studies reveals a spectrum of changes in motor control in LBP with extremes of tight control and loose control.[94] Motor control changes at both ends of this spectrum have the potential to lead to suboptimal mechanical loading of the spine, but in different ways. This implies that modification of motor control has potential benefit with opposite treatment targets for the subgroups at either end. Loose control implies that enhancement of muscle activity is required, whereas tight control implies an emphasis on reduction of muscle activity.[36] It should be kept in mind that these interpretations are based on the assumption that these motor control patterns are maladaptive and clinical benefit will be derived from "correction" of the strategy. For each of the motor control measures that have been used in research, there is a subgroup of individuals with LBP who show 'normal' motor

control,[94] which suggests that this subgroup would *not* benefit from MCE. There is some evidence to support this hypothesis. Two clinical trials have shown less clinical improvement for individuals without evidence of a motor control deficit (poor control of transversus abdominis) at baseline.[25, 87] On the other hand, baseline findings on trunk muscle control were not correlated to clinical improvements in two other studies.[50, 102]

The question whether subgrouping based on motor control is useful can only be answered after appropriate clinical trials have been performed. To date there is mixed evidence whether interventions that target treatment based on motor control subgrouping achieve better outcomes than non-targeted treatments for LBP. Two RCTs with a focus on matching exercise to movement subgroups showed no benefit over general exercise in the long-term primary outcomes of pain and disability in chronic LBP.[2, 45, 74] In contrast, several recent RCTs demonstrated superior long term outcomes with individualized MCE in people with chronic LBP, based on an integrated subgrouping approach, one included assistance of a wearable biofeedback device[39] and another used an individualized approach to targeting relevant cognitive, motor control and lifestyle factors in people with chronic LBP.[98] A missing link is whether the clinical effects in these trials were related to a change in motor control. The possibility that other factors mediated the positive outcomes remains to be excluded. Given the preceding discussions it can be concluded that an affirmative answer is plausible and hence subgrouping based on motor control would merit further research.

6. Are subgroups based on motor control mutually exclusive?

Mutual exclusivity of subgroups implies that an individual can only be allocated to a single subgroup and would only be expected to respond to the ascribed course of management. With the exception of the MDC, existing clinical approaches, described

above, force assessors to allocate patients to a single subgroup, making it difficult to evaluate whether subgroups are mutually exclusive. Some differences in subgroup allocation between testers (inter-tester variability) implies that overlap may exist.

The tight and loose control subgroups that are apparent in biomechanical and electromyography studies would appear to be mutually exclusive, but with some considerations. First, how the groups are separated is not yet clear. Literature indicates that a group with "normal" control sits between those with tight and loose control. The measures that would be considered to differentiate the groups and the cut-off scores have not been established. Second, some patients may even present with elements of both subgroups: an overall tight presentation may be combined with elements of low stiffness in specific directions or of specific joints. For instance, increased activity of some muscles with pain, causing an overall increase in trunk stiffness, may coincide with reduced activity in other muscles.[35] While the overall change in muscle activity would allow tight control over thorax movements, it might coincide with a reduced control over segmental movements in a specific direction in view of the inhibition of some muscles. Third, motor control patterns are somewhat context dependent. It cannot be excluded that an individual may show 'loose' control in one situation, and show tight control in another situation; for example, a more threatening task may elicit a compensatory strategy with high levels of muscle activity regardless of strategy adopted in a less threatening situation.[92]

Subgrouping of patients with LBP purely on the basis of motor control assumes that motor control and tissue loading is relevant for the underlying persistence of pain in all patients, yet not all pain is the same. As highlighted earlier, pain can be broadly considered to primarily involve nociceptive, neuropathic or central sensitization mechanisms. In the presence of a primary nociceptive mechanism, loading of tissue is

likely to be relevant. The motor control adaptation may be adaptive and potentially helpful or maladaptive and relevant for persistence. When the mechanism is neuropathic, loading may be relevant with respect to loading of neural tissue.

In the presence of primarily central sensitisation pain, pain may persist despite absence of ongoing nociceptive input from the tissue and treatment targeted to optimisation of tissue loading through motor control training is unlikely to address the underlying mechanism, but could aid recovery through exposure to healthy movement. Consideration of pain mechanisms in a motor control subgrouping approach could take two main paths. First, the approach may involve a hierarchical process where the first step is to identify the primary pain mechanism. If a nociceptive (and perhaps neuropathic) mechanism is identified, then the patient would be characterized according to motor control presentation. If central pain mechanisms are identified then an alternative course of management is planned to address the pain mechanism (pain coping training, pain education, fear-deconditioning, etc), without primary consideration of motor control. Second, the approach could also involve a parallel process whereby all patients are assessed on the basis of pain mechanism and motor control and a treatment package is developed that includes components of intervention targeted to both domains, based on the presenting features. This latter model assumes that pain mechanism and motor control phenotypes are not mutually exclusive and some central sensitisation may be present in those with nociceptive/neuropathic pain (which is highly probable) and some nociceptive input may contribute to maintenance of pain state. In each case assessment of the dominant pain mechanism requires attention. Several instruments have been proposed.[67, 68, 76-80] These assessments require further validation and development towards a clinical tool.

To be comprehensive, in addition to pain mechanism, the diagnostic system requires evaluation of patients across multiple biological, psychological and social dimensions. These would include features relevant to motor control such as patterns of pain provocation and relief,[20-22, 62, 73] muscle atrophy and weakness,[55, 56] proprioceptive impairment,[63, 86] as well as differentiation of psychological features including pain beliefs and fear of pain or re-injury,[57, 100] depression, catastrophising, self-efficacy, and social issues.[70] An important consideration is that domains are not independent. For instance, measures of motor control may reflect psychological factors such as fear of pain.[31, 44, 58, 71, 88-90] Overlap of domains, particularly some of the sensory and motor domains may reflect redundancy and may allow simplification of diagnostic schemes. Furthermore, in many cases characterization of patients occurs along a continuous scale, not necessarily yielding exclusive subgroups.[c.f. 67] In the parallel model, rather than fitting explicit subgroups, it may be more ideal to profile patients across these dimensions rather than fitting into explicit subgroups, allowing outcomes to be monitored with respect to each of the dimensions, in line with the MDC approach.[67]

Comprehensive profiling of patients or subgrouping may also benefit from being embedded in a system with stratification based on prognosis.[c.f. 1] Prognostic stratification tools such as StartBack[34] are based on the belief that many LBP cases recover within several weeks irrespective of treatment,[37, 101] and that more comprehensive management should be reserved for those with greater likelihood of poor outcome. These tools attempt to predict which patients belong to this group, to avoid unnecessary diagnostic procedures and over-treatment in the "low-risk" group. The StartBack tool specifically identifies greater psychological prognostic barriers for recovery in the "high-risk" group and recommends psychologically informed treatment. In the "moderate-risk" group, comprehensive treatment is recommended and our model

of patient characterisation across multiple domains including motor control (with or without allocation to subgroups) is likely to be most relevant in this group.

7. Potential role for objective tests of motor control in patient assessment

Although clinical assessments can be used to reliably allocate patients to subgroups, there may be additional benefit for interpretation of underlying mechanisms and objectively and sensitively tracking recovery by objective measurements. Further research is needed to verify that individuals can consistently be classified into motor control-based categories based on a minimal battery of objective tests.

Motor control of the trunk comprises modulation of intrinsic stiffness through tonic muscle activity, anticipatory control, and feedback control.[94] To characterize trunk control in LBP it may be necessary to evaluate these different aspects with dedicated tests. Given the emphasis on directional preferences or directional impairments in current classification systems, objective testing should probably be multi-directional. The potential existence of positive (adaptive) and negative (maladaptive) subcategories of both tight and loose control requires further consideration. An additional consideration is that adapted motor control may be context dependent; for example, individuals with LBP may show more pronounced changes when they perceive the task that they perform as threatening in terms of pain provocation or re-injury. These considerations would suggest that a comprehensive set of tests and test conditions is necessary to characterize motor control in LBP. This might cast some doubt on the practical applicability of subgrouping based on objective measures of motor control. As an alternative approach, assessment of trunk control in daily life could be considered as an efficient way to obtain a large amount of ecologically valid information with limited effort, although substantial work would be required to develop and test such an

409 analysis. Comprehensive testing may be shown to yield redundant information. If motor
410 control impairments in LBP can be sufficiently characterized based on a limited number
411 of tests, this would greatly simplify clinical implementation.
412
413
414 **8. Conclusions**
415 Targeting of treatment for the management of LBP based on motor control
416 presentation may be helpful. Although clinical trials provide evidence for some aspects
417 of the approach and motor control literature provides support for the plausibility, there
418 are major gaps remaining in the literature. Large RCTs are required to compare the
419 benefit of interventions that are matched to motor control presentation against
420 treatments that are not matched. Further insight might be gained from the establishment
421 of a minimal battery of objective tests that aid in the identification of the specific motor
422 control phenotypes. Approaches to allocate patients to subgroups to guide treatment or
423 alternatively to evaluate patients across a range of domains and measures should be
424 compared for their effectiveness. Both imply personalisation of care to the individual
425 patient, and both methods have positive and negative features.
426
427 **Acknowledgements**
428 The authors would like to thank dr. Peter O' Sullivan and dr. Julie Fritz for reviewing
429 a previous version of this paper.
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