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Development of a collaborative model of low back pain: report from the 2017 NASS consensus meeting.

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Abstract

BACKGROUND CONTEXT: Low back pain (LBP) is a multifactorial problem with complex interactions among many biological, psychological and social factors. It is difficult to fully appreciate this complexity because the knowledge necessary to do so is distributed over many areas of expertise that span the biopsychosocial domains.

PURPOSE: This study describes the collaborative modeling process, undertaken among a group of participants with diverse expertise in LBP, to build a model to enhance understanding and communicate the complexity of the LBP problem.

STUDY DESIGN: The study involved generating individual models that represented participants' understanding of the LBP problem using fuzzy cognitive mapping (FCM), and four subsequent phases of consultation and consensus with the participants to characterize and refine the interpretation of the FCMs.

METHODS: The phases consisted of: proposal of Categories for clustering of model Components; preliminary evaluation of structure, composition and focal areas of participant's FCMs; refinement of Categories and Components with consensus meeting; generation of final structure and composition of individual participant's FCMs. Descriptive statistics were applied to the structural and composition metrics of individual FCMs to aid interpretation.

RESULTS: From 38 invited contributors, 29 (76%) agreed to participate. They represented nine disciplines and eight countries. Participants' models included 729 Components, with an average of 25(SD=7) per model. After the final FCM refinement process (Components from separate FCMs that used similar terms were combined, and Components from an FCM that included multiple terms were separated), there were 147 Components allocated to ten Categories. Although individual models varied in their structure and composition, a common opinion emerged that psychological factors are particularly important in the presentation of LBP. Collectively, Components allocated to the "Psychology" Category were the most central in almost half (14/29) of the individual models.

CONCLUSIONS: The collaborative modeling process outlined in this paper provides a foundation upon which to build a greater understanding and to communicate the complexity of the LBP problem. The next step is to aggregate individual FCMs into a meta-model and begin disentangling the interactions among its Components. This will lead to an improved understanding of the complexity of LBP, and hopefully to improved outcomes for those suffering from this condition.

Keywords: low back pain, collaborative modeling, expert opinion, biopsychosocial model

Introduction

Low back pain (LBP) is a multifactorial problem with complex interactions among many biological, psychological and social factors [1-6]. While this concept is widely accepted, its translation into clinical practice is lacking [7]. Because of the biopsychosocial complexity of pain, the variable ways in which different individuals are affected and, in most cases, the lack of biomarkers identifying the underlying processes, it is difficult to select the appropriate treatment strategy [8]. Research indicates that amalgamating interventions from different specialties into a multidisciplinary biopsychosocial rehabilitation is more effective than single therapies or usual care, but these differences are modest and may not be cost-effective [9, 10]. Such results are consistent with the notion that there is no simple isomorphic relationship between pathology, nociception, psychosocial factors, and pain, and that the interactions among these factors are complex [11].

To study very complex problems and the effects of specific solutions under various conditions, a "system" approach is advocated whereby the entire system's behavior is being studied, including the interactions among its elements (in contrast to a reductionist approach whereby a system is broken down into smaller elements, which are then studied in isolation) [12]. For example, a system dynamics model was used to study the impact of three types of policy interventions to reduce adverse outcomes of prescribing pain medicine [13]. In the context of LBP, such an approach would consist of two steps. In the first step, factors contributing to the presentation of LBP and their causal relationships are identified (system's composition and structure is identified first). In the second step, the dynamics (time dependent behavior) among these factors are described to provide a full representation of the LBP problem.

The implementation of a systems approach to study the LBP problem is difficult because the knowledge necessary to do so is distributed over many areas of expertise that span the biopsychosocial domains. One method that has been developed within the field of systems science specifically for enhancing the understanding of complex, multi-factorial problems among diverse groups of stakeholders is "participatory" or "collaborative" modeling. Collaborative modeling has been validated extensively in the environmental management and conservation field and has been applied to a range of case studies in support of decision-making processes [14-16]. The National Socio-Environmental Synthesis Center defines collaborative modeling as a "purposeful learning process for action that engages the implicit and explicit knowledge of stakeholders to create formalized and shared representation(s) of reality. In this process, the participants co-formulate the problem and use modeling practices to aid in the description, solution, and decision-making actions of the group" (participatorymodeling.org). Often, this co-creation process uses computational modeling software [17].

Although attempts to integrate knowledge across several domains of LBP have been made, they have mostly been limited to qualitative and descriptive models [18-22]. The purpose of our current research is to initiate the development of a broad collaborative model of LBP representing the synthesized knowledge of a multidisciplinary group of LBP experts. In this paper, we describe the process of identifying and refining the composition and structure of such a model, which constitute the first step in the systems approach defined earlier. To this end, the study involved generating individual models ("mental models"[23]) of participants with diverse expertise in LBP using fuzzy cognitive mapping (FCM) [24, 25] and several phases of consultation and consensus with the participants to characterize and refine the interpretation of the FCMs. This is the first effort to apply the collaborative modeling process to study quantitatively the disease process of LBP.

Methods and results

Study design

To achieve the aims of the study, five sequential Phases were undertaken to generate individual FCMs by participants with diverse expertise in LBP and to establish an agreeable process for interpretation of models. An FCM is a graphical representation of the elements that are considered important for a problem (Components), and the relationship between them (Connections). Each Connection is weighted to indicate the strength of the relationship (i.e., how much a change in one Component would change another Component) [25]. The study was granted exemption from Institutional Review Board at Michigan State University. As each Phase built on the findings of the previous Phase, the following sections present methods and results for each Phase of the study, in sequence:

1. Generation of individual FCMs of LBP by expert participants.
2. Proposal of Categories for clustering of model Components.
3. Preliminary evaluation of structure, composition and focal areas of individual participant's FCMs.
4. Refinement of Categories and Components with consensus meeting.
5. Generation of final structure and composition individual participant's FCMs.

Phase 1: Generate individual Fuzzy Cognitive Maps of LBP by expert participants

Aim

This phase aimed to generate individual FCMs from a group of participants who were selected to ensure a breadth of representations from different backgrounds/disciplines with expertise in LBP and a proven track record in clinical and/or basic research.

Participants

Potential contributors were identified by members of the investigator team (JC, JP, PH) by extensive search of the literature, speaker lists of relevant conferences and through discussion with other experts in LBP. Potential contributors were considered eligible for inclusion if he/she represented major discipline in management/research of LBP, and there was evidence that he/she had made a substantial and ongoing contribution to the literature related to LBP, as evidenced by at least two of the following:

i. Contribution to at least 3 published works in the preceding 3 years

ii. Keynote/invited presentations at major meetings related to LBP

iii. Contribution to major working groups/committees of LBP organizations

iv. Contribution to organization of major LBP meetings/conferences

v. Contribution to LBP texts

vi. Contribution to clinical practice guidelines/systematic reviews

Methods

Invited participants who agreed to contribute an FCM were contacted by a member of the investigator team (PA) via video conferencing and guided through generation of their FCMs using a free-access program *Mental Modeler* (MentalModeler.org) [26]. Using this program, Components can be added along with their Connections to other Components. For each Connection, the direction of effect (one Component leads to an increase or decrease in another Component) and strength of each Connection (bounded by -1 to 1) are specified. Each participant was initially presented with three Components – “Pain”, “Disability” and “Quality of Life”, representing main outcomes of living with LBP. These Components, to be retained in the individual models of all participants, could affect each other and have different causes (inputs) and consequences (outputs) for a person with LBP. All participants were then asked to name additional Components (major factors contributing to LBP) that they considered would “directly affect” these three outcome Components, and to consider all possible interactions between Components (including feedback loops) in their model. As a new Component was added, the participant was required to confirm the direction of the relationship, whether it caused an increase or decrease in the Components it was connected to, and the strength of each Connection. After completion of the inclusion of Components, participants were asked to identify all of the treatments that they considered would impact directly or indirectly the three main outcomes of LBP, identify pathways for this impact (Connections), and to nominate the strength of these Connections. Sessions were recorded with the consent of the participant for later clarification of meaning of elements of the model.

Results

From a total of 38 potential contributors, 29 (76%) agreed to participate. These participants were invited to generate preliminary FCMs of LBP. The disciplines represented by these participants and their country of residence are presented in Table 1. All models included a total of 729 Components, with an average of 25(SD=7) per model. Example FCMs from representative participants are presented in Figure 1.

Phase 2: Proposal of Categories for clustering of model Components

Aim

This phase aimed to propose and then seek expert participants consensus about Categories to which the Components in each individual FCMs could be allocated for more detailed analysis of the FCMs (e.g., identification of predominant concepts within a participant's FCM). The purpose of the Categories was to:

i. Highlight major conceptual groupings of Components within each FCM
ii. Reduce the complexity of the FCMs to simplify conceptualization of their Components, but without losing detail of the FCM
iii. Aid analyses of models – e.g., link between conceptual models and treatments, etc.
iv. Provide a foundation for aggregation of individual FCMs into a meta-model (i.e., an aggregated model inclusive of all individual FCMs)

Methods

The study team (JC, JP, PH) reviewed the 260 Components (Components from separate FCMs that used the same or similar terms were combined, and Components from an FCM that included multiple terms were separated) included in the initial 22 FCMs generated by the invited participants. The objective was to propose 6-10 preliminary thematic Categories into which each Component could be allocated to highlight major conceptual groupings of Components and to provide a foundation for integrating data from individual FCM into a single overall meta-model. The study team also proposed initial definitions to explain each proposed Category.

Next, using a Delphi-type process, the preliminary Categories and the associated definitions were presented to the participants who had contributed FCMs for feedback using an on-line survey. This survey asked participants to; consider the list of proposed Categories; comment whether he/she agreed/disagrees with each Category; and comment whether they would recommend: wording changes, Categories that could be combined, or additional Categories that should be considered for inclusion.

Results

The core team proposed nine preliminary Categories: “(Neuro)biology of pain”; “Behavioral/ Lifestyle”; “Biology of tissue”; “Environment/Policy”; Psychological”; “Social/Work”; “Biomechanical”; “Treatment/Intervention”; and “Outcomes”. Participants were also asked whether “Genetics” should have a separate Category and whether “Psychological” and “Social/Work” should be grouped together.

Feedback was received from 86% (19/22) of the initial model participants. Feedback from participants resulted in the addition of one more Category, “Individual factors” (including features such as age, history of LBP, etc.), and a change in name for the following Categories;

"(Neuro)biology of pain" to "Nociceptive detection and processing", "Biology of tissue" to "Tissue Injury or pathology", and "Environment/policy" to "Contextual factors".

Phase 3: Preliminary evaluation of structure, composition and focal areas of individual participant's FCMs

Aim

This phase aimed to allocate all Components to the Categories specified in Phase 2, and then undertake preliminary examination of the structure and composition of individual FCMs.

Methods

The core team (JC, JP, PH) allocated all model Components for the original 22 models and an additional 7 models contributed after the process for development of Categories. Each team member individually allocated the terms to the Categories. Any disagreement in Category allocation was discussed until consensus was reached. Any Components with synonymous meaning (different terms used for similar concepts by different participants) were collapsed into a single Component under a common term. FCMs were analyzed in two ways: 1) Network Structure and 2) Composition [27].

Analysis of network structure involves calculation of the following measures:

i. *Total Components (N)* - number of Components included in an FCM
ii. *Total Connections (C)* - total number of Connections in either direction included in an FCM

iii. *Density (D)* - number of Connections as a proportion of the number of all possible Connections in both directions, thus

$$D = \frac{C}{N * (N-1)}$$

iv. *Connections per Component* - average number of Connections in either direction per Component

v. *Number of Driver Components* - total number of Components that only have outputs

vi. *Number of Receiver Components* - total number of Components that only have inputs

vii. *Number of Ordinary Components* - number of Components with both inputs and outputs

viii. *Complexity Score* - calculated as the ratio of Receiver/Driver Components and provides a measure of the degree to which effects of Drivers are considered

Composition analysis of each FCM involved generation of three measures:

i. *Sum of Centrality (Sc)* - centrality (c_i) measures the weighted contribution of each Component i within the FCM:

$$c_i = \Sigma_{k=1}^{n} |a_k|,$$

where n is the number of Connections going to and from a Component and a is the weight of each Connection. Sc is then calculated as the sum of centralities of all Components in a Category:

$$Sc = \Sigma_{i=1}^{N^*} c_i,$$

where N* is a total number of Components in a given Category. Finally, a standardized Sc (NSc) score was calculated by normalizing the Sc for each Category to the total Sc for all Categories, excluding “Outcomes” and “Treatment/Intervention”, for each FCM.

ii. *Cognitive Color Spectrum* - color bar chart that demonstrates the sequence of dominance of Categories in a participant’s FCM. It is generated by sorting the NSc of each Category by their color starting from the most central Category.

iii. *Cognitive Diversity Index (CDI)* - quantitative measure that reflects how many different Categories are represented in an FCM, and simultaneously considers how evenly the Components are distributed among those Categories. A higher value indicates that an FCM has Components representing more Categories and contributing more evenly to these Categories, whereas a lower value indicates fewer Categories and bias towards specific Categories. It is calculated using the following equation:

$$CDI = e^{-[\sum_{j=1}^{M} NSc_j \times Ln(NSc_j)]},$$

where M is a total number of Categories.

The above metrics were calculated for each participant’s FCM and prepared for further evaluation in Phase 4.

Results

After preliminary classification and the core team discussion, all Components were classified to Categories. Preliminary analysis of all Network Structure and Composition metrics was completed for all FCMs for consideration in Phase 4.

Phase 4: Refinement of Categories and Components with consensus meeting

Aims

This Phase involved a face-to-face consensus meeting of participants with the aim to:

i. Confirm the preliminary allocation of Components to Categories for individual FCMs with each participant to ascertain agreement with interpretation

ii. Refine Categories to ensure that they are accurate and provided enough breadth to interpret FCMs

iii. Reduce number of Components to streamline data for interpretation of FCMs (and future generation of a meta-model)

iv. Clarify the subsequent steps for refining and expanding the model

v. Define the priority research agenda of questions to test with the model

Methods

All participants who had contributed an FCM in Phase 1 were invited to attend a face-to-face meeting that was held in Orlando, Florida, USA on the 26th of November 2017 in conjunction with the North American Spine Society (NASS) Annual Meeting. NASS provided financial support to enable attendance. Twenty participants were able to attend, but one withdrew due to personal issues. Four additional participants were invited to prepare FCMs and specifically to consider “lumbopelvic pain related to sacroiliac joint (SIJ) pain and/or dysfunction” to undertake preliminary consideration whether a model for this condition would differ from that of LBP. Two were able to attend the meeting.

The meeting was divided into four parts. In Part 1, participants were presented with: their own model; the model structure and composition metrics; a list of all included Components and the Categories that they had been allocated to; and the definition of the Categories. Participants were asked to consider whether: the Sc for each Category in their individual FCMs were consistent with his/her belief; the allocations of Components to Categories was accurate; and if he/she identified inconsistencies, to consider possible reasons for this (e.g., ambiguity of terminology used in FCM; lack of a specific Category). Any errors were documented for correction after the meeting.

In Part 2, participants were asked to re-consider the Categories that had been proposed in Phase 2 to determine whether: other Categories should be included; and if there were instances where several Categories could be collapsed into a single Category. Any proposed changes were discussed until consensus by the group was achieved.

In Part 3, participants considered the list of all Components that had been included in the FCM generated by the participants. The purpose was to again consider whether Components had been accurately allocated to Categories and to identify Components with similar meaning that could be clustered together under a single term. The aim was to reduce the total number of terms by approximately 30% from 272. No Components were removed, all were retained or amalgamated with others. Some Components were split if they included topics that related to separate Categories with the weighting of Connections to and from that Component divided amongst them equally (e.g., if a Component called “biopsychosocial factors” was used in an

FCM, it was divided into separate Components in each of “Tissue injury or pathology”, “Psychology” and “Social/Work/Contextual” Categories). An important consideration of this phase was not to minimize the Components to a small number of very general terms but to retain the details and the intricacy of each participant’s consideration of the LBP problem without unnecessary complexity from inclusion of multiple synonymous words. To complete this task, participants were allocated to groups of 5-6 to consider Components within 1-2 Categories.

The 4th Part involved discussion of: the next steps for the collaborative model; possible uses for the model; and a framework for potential additional studies.

Results

Part 1: All participants were satisfied that the FCM generally represented their opinions.

Part 2: Discussion of Categories resulted in several key changes. First, the Categories were considered in terms of alignment with the structure and terminology of the International Classification of Functioning, Disability and Health (ICF) model developed by the WHO [28]. Categories were broadly considered with fit to this model as presented in Figure 2. “Social/Work” and “Contextual” Categories were combined as they involved considerable overlap. An additional Category, “Comorbidities” was added to reflect the growing awareness of comorbidity as a major issue in health and the frequent inclusion of Components related to comorbidity in individual models. Final names and definitions for each Category that were endorsed by the group are presented in Table 2. The participants who generated FCMs for “lumbopelvic pain associated with SIJ pain and/or dysfunction” confirmed that the same Categories could be used to allocated Components for that condition.

Part 3: As a result of discussion within the groups, the participants were able to reduce the number of Components in the 27 FCMs from 272 to 135. Thirty-five Components were moved from the original Category to a different Category. Seventeen Components were moved to the new Category of "Comorbidities", and ultimately collapsed into four Components in the final model.

Part 4: The process towards completion of the collaborative model included the following steps; (i) Refinement of allocation of Components to Categories by the investigator core team, (ii) Generation of summary data. These were to be completed by the core team as Phase 5 (see below). Priority areas for further investigation using the generated FCMs and the collaborative modelling approach were identified as outlined in Table 3.

Phase 5: Generation of final structure and composition of individual FCMs of participants

Aim

Refine and finalize the allocation of Components to Categories for individual FCMs for re-creation of refined FCMs and to generate summary data of the broad conceptualization of the LBP produced by the group.

Methods

The core group (JC, JP and PH) plus an additional member (AL) applied the recommendations for minor changes to individual FCMs derived from Phase 4. Two additional FCMs were included. The team reviewed all Components individually and made further recommendations for terms that could be combined as synonymous. The team met to clarify differences and reached consensus. The meaning of any Component that was unclear or ambiguous (e.g., whether “exercise” was intended as a “treatment/intervention” for LBP, or a “behavioral/lifestyle” issues) were clarified by: observation of the Connections in the FCM; review of the audio recording of the video conference session in which the FCM was generated; or by contacting the participant if necessary.

A final face-to-face meeting of the core group was undertaken to review all of the collapsed Components and their allocation to Categories before generating the summary data. Descriptive statistics were applied to the structural and composition metrics of individual FCMs as outlined in Phase 3.

Results

After the final FCM refinement process there were 147 Components allocated to ten Categories. The number of Components per Category are presented in Table 4. The individual data, group average and range of structural and composition metrics are presented in Table 5. The FCMs differed greatly; they included as few as 13 Components and as many as 40 and the Components were linked by 28 to 212 unique Connections. Density was inversely related to the number of Components (R=0.54, p=0.003), i.e., when more Components were included, fewer of the total possible Connections were made. Relatively few Components only received inputs. On average, 2% (SD=3%) of Components within individual FCMs were Receiver Components; that is, most Components had impact on other Components. In contrast, 41% (SD=15%) of Components only had outputs (Driver Components) to other Components.

Cognitive Color Spectra for each individual and the group, along with the magnitude of the group mean of the NSc for each Category, are shown in Figure 3. The NSc for each individual FCM, along with CDI, is shown in Figure 4. The Category with the highest mean NSc was "Psychology" and the values summed for the group were more than double that of any other Category. "Psychology" was the highest ranked Category by NSc for almost 50% (14/29) of the individual FCMs. The thematically related Categories of "Tissue injury or pathology" and "Biomechanics" were ranked highest in 31% (9/29) of FCMs, but when considered separately were ranked second and third, respectively. "Biomechanics" and "Social/Work/Contextual" Categories had the second and third highest Sc for the group of participants, respectively.

The CDI shows variation in FCMs with some using mostly Components from few Categories, whereas others were more generalists and used Components from all or nearly all Categories. Comparison of the CDI with the NSc show that the FCMs with the lowest diversity varied with respect to the Category toward which the model was biased. Of the 10 least diverse FCMs, six had a bias of NSc related to Components in the "Psychological" Category; and single FCMs with bias toward each of the "Nociceptive detection and processing", "Individual factors", "Tissue injury or pathology", and "Biomechanics" Categories. The analysis does not imply that one model is better than another, just that there are different conceptualizations of LBP by experts. The CDI was not correlated with the Density of the FCM (R=-0.23, P=0.222) or Number of Connections (R=0.18, P=0.344) but was positively correlated with the Number of Components (R=0.44, P=0.016).

Discussion

This paper described the process undertaken by a diverse group of experts to initiate the development of a broad collaborative model of LBP. Such a model represents collective knowledge of participants representing many clinical and scientific fields concerned with the different aspects of the problem of LBP. This first step focused on identifying the model structure and composition. Future studies will describe the dynamic processes occurring among the Components of this model.

Collaborative modeling provides a platform for integrating scientific knowledge with individual and group learning being among the most important outcomes from this process [29]. Indeed, the individual models (presented here) and the future aggregated models, constitute a physical record of this activity. As an overall outcome, the collaborative modeling process enabled the participants to see how their way of thinking about a problem of LBP relates to that of others with similar or different expertise. It demonstrated to the group how complex the problem of LBP is when attempting to integrate knowledge from many different science fields into a general model. This collaborative process also provided a foundation for planning studies to fill gaps in knowledge and to test the elements of these models.

Several conclusions can be drawn from examining the individual models. The main finding is that the conceptualization of LBP among experts is diverse. Individual models varied considerably in their structure (number of Components and complexity) and composition (Components selected by participants emphasized different Categories). The collaborative modeling approach, however, does not place value on the metrics, but instead provides quantitative description of the individual models. In other words, a more complex or diverse FCM does not necessarily imply a better model. Rather, collaborative modeling allows quantification of the differences and similarities in the understanding of LBP among the participants.

The total number of Components initially identified by the participants (729), which were then condensed to a unique set of terms through group consensus (147), indicates the extent of LBP complexity. These numbers are on par with the number of ICF core sets for LBP [30]. After initially identifying 505 ICF terms, 18 experts from 15 different countries, through a consensus meeting, included 78 terms in the core set. The order of magnitude of these numbers suggests how many different factors might have to be considered when studying LBP using a systems science approach.

Despite diversity among individual models, a common opinion emerged that psychological factors are particularly important in the presentation of LBP. “Psychology” had the highest NSc among all the Categories and it was the most central Category in almost half (14/29) of the individual models. Although, this might have been the result of a bias stemming from the area of expertise of the participants, only two participants identified psychology as their professional field. The consensus around the psychology is consistent with the most recent clinical practice guidelines for the management of non-specific LBP in primary care. These guidelines endorse a more thorough assessment of psychosocial factors and tend to de-emphasize the importance of a patho-anatomical diagnoses (except for the red flags) [31]. Similarly, a panel of 66 experts representing 24 countries and 13 specialties/professions formulated a model for spine care and implementation using a modified Delphi method [22]. They too advocate a transformation of care from a biomedical to biopsychosocial model noting that spinal pathology has been overemphasized as a cause of pain.

One limitation of this study is related to the sample of participants. Participants' biases may vary depending on the discipline or country. Although we sought to assemble a diverse group of experts (from 9 disciplines and 8 countries), the representation of disciplines was not uniform. Future studies involving more participants from fields such as psychology, that could be considered underrepresented here, would strengthen the findings.

Another limitation is that the individual models were not data-driven but formulated based on the expert opinions. However, the expectation is that, to a large extent, these opinions are based on the participant's knowledge derived from research and data. Rather than a weakness, we consider this a strength of the approach as it enables participants to formulate predications and hypotheses based on yet untested interactions. Potentially extreme biases in the models are controlled by the weighting added by multiple participants, with the aim to reflect the community-view. Furthermore, it is relatively straightforward to modify the model's Components and/or Connections based on the available data or to do so later when data become available. This feature illustrates a great potential for this collaborative process to provide an open access in the future to the scientific and clinical communities and other stakeholders for updating the model LBP as new evidence emerges.

Conclusion

The collaborative model generated using the process outlined in this paper provides a strong foundation upon which to build a greater understanding and to communicate the complexity of the LBP problem. The next step is to aggregate individual FCMs into a meta-model and begin the task of disentangling the dynamics (interactions) among its Components. This will lead to an improved understanding of the complexity of LBP, and hopefully to improved outcomes for those suffering from this condition.

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Figure legends

Figure 1: *Fuzzy Cognitive Maps (FCM) for three representative participants with different structure and composition.* The FCMs that were generated by the participants are shown (left) in their original form, prior to refinement of the Component terminology. The Sum of Centrality (Sc) (middle) and structural features are shown for the final FCM after refinement. Note the different Sc of the different models and range of structural features that characterize the models of different participants considering the problem of low back pain. Comp. – Component; Connect. – Connection. See Table 2 for full titles of Categories.

Figure 2: *Final Categories for clustering Fuzzy Cognitive Map Components developed and endorsed by multi-phase expert participants consultation.* The Categories are grouped into terms from the International Classification of Functioning, Disability and Health (ICF) model – Personal Factors, Environmental Factors, Body Structure and Function [28]. The ICF elements of Participation and Activity are considered amongst outcomes and an additional Category is included – “Comorbidities”. QoL – quality of life.

Figure 3: *Cognitive Color Spectra for the individual participants and a group average.* Each Category is ranked by magnitude of the Normalized Sum of Centrality (NSc) for each participant (#1 to #29). The mean NSc is shown (bottom left). The pie graph shows the relative magnitude of the group mean NSc for each Category. Note that “Psychological” Category has the highest mean NSc for the group and is the highest ranked Category for 14 of 29 participants.

Figure 4: *Normalized Sum of Centrality (NSc) and Cognitive Diversity Index (CDI) for individual participants Fuzzy Cognitive Maps (FCM).* The order of FCMs is identical to that in Figure 3. Colors in the NSc refer to the Categories (see Figure 3 for definitions of color). A high CDI indicates that a participant considers Components across a broad range of Categories with relatively similar NSc between Categories. A low CDI indicates that a participant considers Components across a few Categories with a bias of NSc to only some Categories. This analysis does not imply that one model of considering low back pain is better or worse, but characterizes the different ways that participants consider the problem.

Table 1 Disciplines and countries of participants to Phase 1

Discipline	**Subdiscipline**	**Country**	**Number**
Physical Therapy			10
	Clinical (2)	Canada; USA	
	Basic science/ neuroscience (2)	Australia	
	Musculoskeletal research (6)	Australia; Belgium; USA	

Chiropractic	Canada; Denmark; UK; USA	4
Biomechanics	Netherlands; USA	3
Orthopedic Surgery	Germany; USA	2
Psychology	Netherlands; USA	2
Physical Medicine & Rehabilitation	Netherlands; USA	2
Exercise Science	USA	1
Epidemiology	Australia; Netherlands	2
Basic Science	Canada; USA	3

Table 2 Final Categories for allocation of FCM Components

Category	Definition
Behavioral/Lifestyle	Lifestyle "choices" including: smoking; sleep; physical activity; diet; insufficient time.
Biomechanical	Factors that determine/cause/relate to tissue loading including lifting; posture; motor control; muscle imbalance; etc.
Comorbidities	Conditions that are comorbid with low back pain.
Individual	Factors that are part of the “make-up” of the person including:

	age; body weight; physical capacity; strength; genetics; and individual features thought to predispose to LBP such as prior history.
Nociceptive detection and processing	Biological factors related to pain/nociception including: sensitization; neuro-immune interaction; "neuromatrix", etc.
Psychological	All aspects related to psychology including: fear of pain/(re)injury; catastrophizing; self-efficacy; etc.
Social/Work/Contextual	Factors related to work and relationships including: work support; family environment; social status; spirituality/religion. Includes factors that are external to the person such as environmental/policy, access to treatment; political, physical environmental, social, cultural context.
Tissue injury or pathology	Biological factors of tissue/systems including: tissue injury; rheumatoid arthritis; disease; pathology; cytokines; cancer; diabetes; and consequences/outcome of loading rather than the mechanisms that cause loading, which are categorized as "Biomechanical".
Outcomes	Core outcome measures included in every model were "Pain", "Disability", and "Quality of Life". "Disability" was broadly considered as "Activity limitation" according to the ICF model, and "Quality of Life" as "Participation restriction".
Treatment/Intervention	Any intervention for treatment and prevention of LBP.

ICF – International Classification of Functioning, Disability and Health [27].

Table 3: Proposed research agenda using the collaborative model of low back pain (LBP)

i. Create structure into which models from other contributors can be added – consensus from community of the basic structure of the model.
ii. Generate meta-model from individual FCMs.
iii. Repeat process for generation of FCMs for *patients* with LBP.
iv. Build a simplified model with a limited number of pre-specified Components for ease of communication and comparison between groups of participants.
v. Use the model to compare the conceptualization of LBP held by different professional groups that work with LBP.

Table 4: Number of Components per Category in final endorsed scheme for FCM analysis.

Category	**No. of Components**
Behavioral/Lifestyle	14
Biomechanical	14
Comorbidities	4

Individual factors	17
Nociceptive detection & processing	6
Psychological	9
Social/Work/Contextual	21
Tissue injury or pathology	13
Outcomes	7
Treatment/Intervention	42

Table 5: Metrics describing structure of FCMs for each participant.

FCM No.	Total Comp.	Total Connections	Density	Connections per Comp.	No. of Driver Comp.	No. of Receiver Comp.	No. of Ordinary Comp.	Complexity Score
#1	36	122	0.10	3.39	9	1	26	0.11
#2	40	92	0.06	2.30	6	2	32	0.33
#3	26	66	0.10	2.54	12	1	13	0.08
#4	34	42	0.04	1.24	18	2	14	0.11
#5	27	63	0.09	2.33	22	0	5	0.00

#6	24	57	0.10	2.38	15	0	9	0.00
#7	18	36	0.12	2.00	10	1	7	0.10
#8	20	66	0.17	3.30	9	0	11	0.00
#9	25	54	0.09	2.16	10	0	15	0.00
#10	21	63	0.15	3.00	8	1	12	0.13
#11	34	173	0.15	5.09	9	0	25	0.00
#12	20	40	0.11	2.00	5	1	14	0.20
#13	24	100	0.18	4.17	10	0	14	0.00
#14	17	112	0.41	6.59	3	0	14	0.00
#15	34	212	0.19	6.24	7	0	27	0.00
#16	33	90	0.09	2.73	17	0	16	0.00
#17	27	57	0.08	2.11	11	0	16	0.00
#18	21	40	0.10	1.90	12	0	9	0.00
#19	22	108	0.23	4.91	8	1	13	0.13
#20	25	93	0.16	3.72	7	0	18	0.00
#21	13	36	0.23	2.77	7	1	5	0.14
#22	20	46	0.12	2.30	10	0	10	0.00

#23	31	61	0.07	1.97	11	0	20	0.00
#24	34	132	0.12	3.88	15	0	19	0.00
#25	26	58	0.09	2.23	11	0	15	0.00
#26	16	59	0.25	3.69	5	1	10	0.20
#27	18	54	0.18	3.00	10	0	8	0.00
#28	20	74	0.19	3.70	6	1	13	0.17
#29	23	28	0.06	1.22	7	1	15	0.14
Mean	25	77	0.14	3.06	9.9	0.5	14.7	0.06
SD	7	42	0.08	1.33	4.2	0.6	6.5	0.09
Min.	13	28	0.04	1.22	3	0	5	0
Max.	40	212	0.41	6.59	22	2	32	0.33

Comp. – Component; No. – number. Order of FCM numbers is identical to that used in Figures 3 and 4.

Figure 1 in MS Office (color should be used in print)

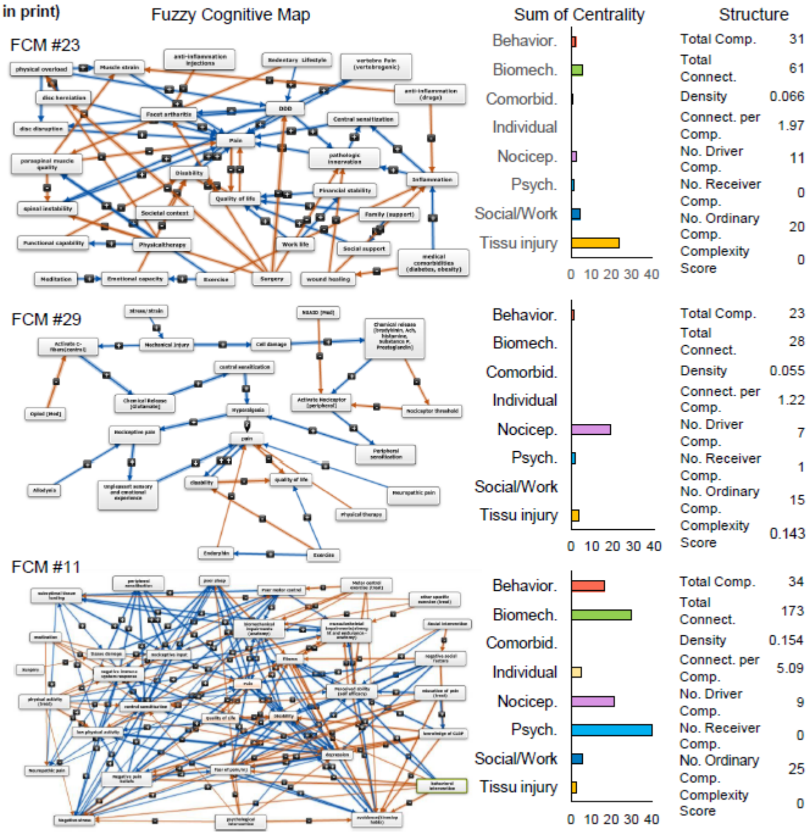
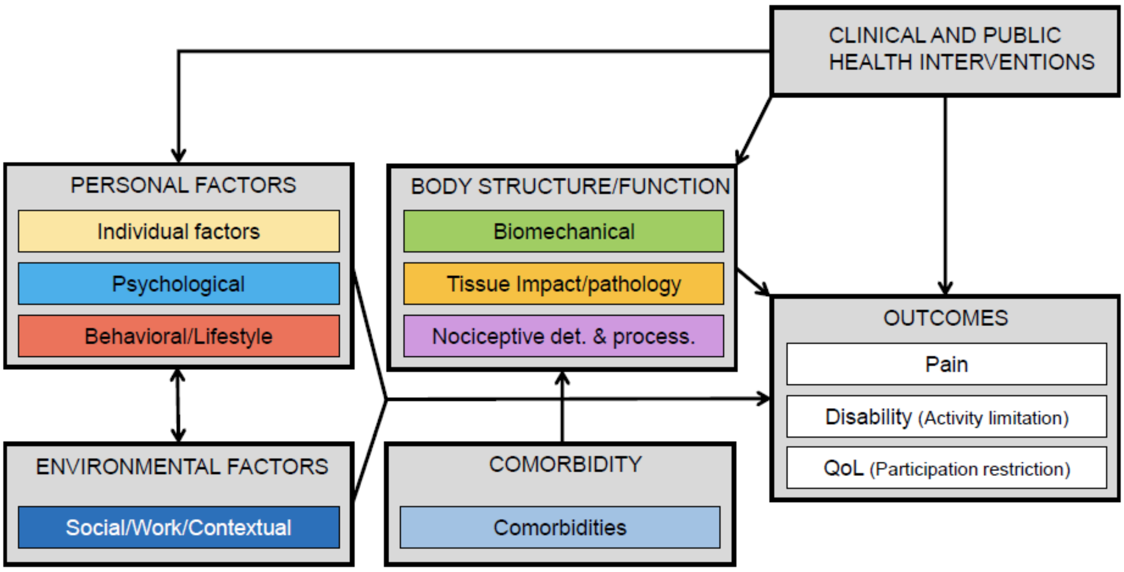


Figure 2 in MS Office (color should be used in print)



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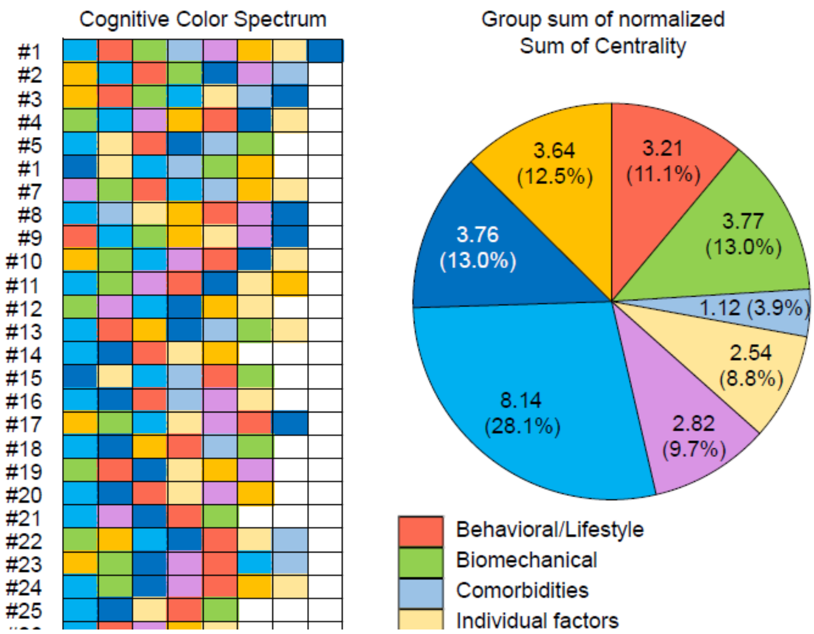

Figure 4 in MS Office (color should be used in print)