Integrating Contemporary Models of Motor Control and Health in Chronic Ankle Instability

A Review of the Literature

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ABSTRACT
Numerous structural and functional alterations have been identified as contributing factors associated with chronic ankle instability (CAI). However, little evidence has connected local instability with self-reported disability or functional loss. The dynamical-systems theory of motor control offers a constraints-led approach for interpreting movement dysfunction based on organismic, task-specific, and environmental factors. These factors interact to organize sensorimotor coordination, creating functional variability to complete movement goals. The International Classification of Functioning, Disability, and Health (ICF) is a model of health, examining function at the level of the body or body parts, the whole person, and the whole person in his or her environment. Combining the fundamental components of both theories offers a model that may recognize the link between instability and function. The purpose of this literature review is to discuss the dynamic systems theory, the ICF model, and how integrating both concepts can be used to address, track, and interpret deficits associated with CAI.

Ankles sprains are the most frequently reported injury among physically active individuals. Approximately 1 of 3 people who sustain a single ankle sprain experience reoccurring sprains and residual bouts of joint instability known as chronic ankle instability (CAI). In addition, ankle sprains are one of the major contributing factors in the development of posttraumatic ankle osteoarthritis. High re-occurrence rates and the prevalence of long-term functional loss related to ankle sprains begs the question if current rehabilitation strategies are effective. Examining CAI through the integration of the most contemporary theory of motor control and the most contemporary model of health may provide a comprehensive assessment of a person’s overall functional ability and elucidate the link between disability and health in this population.

Recent advancement in motor control theory may help interpret how sources of functional loss and disability are manifestations of impaired sensorimotor coordination. This theory, known as dynamic systems, views movement from a context-specific perspective. The dynamic systems theory aims to explain how we use the freedom of the sensorimotor system to develop strategies to cope with changes in health, task complexity, and the environment. Similarly, the International Classification of Functioning, Disability, and Health (ICF) examines the effects of injury and illness on the dynamic nature of function based on quality of life, overall health status, and impairment associated with societal and environmental factors.
The theoretical framework set forth by dynamic systems theory corresponds with many of the fundamental concepts proposed by the ICF model. Applying framework from both theories can aid athletic trainers in making health care decisions that focus on the unique needs of individual patients. Specifically, this integration can help to understand the relationship among many of the contributing factors identified in those who experience CAI with self-reported decreases in function. The purpose of this article is to discuss the dynamic systems theory of motor control, the ICF model of health, and how integrating both theories can address, track, and aid in the interpretation of deficits associated with CAI.

LITERATURE REVIEW

Chronic Ankle Instability
The factors currently thought to contribute to CAI include mechanical and functional deficits, which focus on impairment as a direct result of pathology. This view of CAI provides an explicit and thorough illustration of the arthrokinematic, structural, neuromuscular, and proprioceptive deficits thought to contribute to this condition, but not necessarily the functional loss or disability experienced by the individual. The study of impairment has been valuable for advancing knowledge directly associated with CAI; however, it places no emphasis on function as a dynamic and fluctuating continuum. This is evident because the impairments associated with CAI have been detected through objective measures of function in the form of proprioception, postural control, and neuromuscular control; however, little evidence has investigated the relationship between measures of local instability and self-reported disability.

Function is not solely the cumulative effect of structural and functional impairments directly associated with a health condition. Function must also take into account an individual’s perception of ability or disability. Because of a disconnect between measures of local instability and self-reported function, there is a need to view CAI through contemporary models of motor control and disability. Applying the framework described in these models may provide a more holistic perspective of the true alterations in functional capacity created by CAI in the presence of organismic, environmental, societal, and task-oriented factors. In addition, viewing CAI through these models may redirect rehabilitation goals to satisfy patient needs and diminish the reoccurrence of injury.

The Dynamic Nature of the Sensorimotor System
In the past, movement variability was viewed as error, noise, or deviation from optimal movement patterns. However, more recent theories of motor control recognize movement variability as a beneficial subconscious compensatory mechanism for coping with change, maintaining stability, preventing injury, and attaining higher skill levels. This theory, known as dynamic systems theory, views sensorimotor coordination as constantly changing and fluctuating based on the interaction of multiple environmental (external) and individual or personal (internal) stimuli. The foundation of dynamic systems theory is that movement coordination is shaped by constraints originating from the organism, environment, and task. Examples of constraints include injury and illness, complexity of the task, and uneven terrains.

Constraints placed on the sensorimotor system shape the functional variability, or available strategies, to complete a movement goal. This suggests that rather than having a single, rigid method of achieving a movement goal, the sensorimotor system spontaneously adapts its sensory and motor components to the demands from task and environmental factors. The notion of having multiple ways to achieve movement goals has been referred to as invariant results through variant means. Essentially, if a component of the movement system introduces error to the motor output, other parts of the system will reorganize their contribution to correct the fault. This demonstrates the essential role of functional variability when attempting to cope with change and adapt movement strategies to accomplish a movement goal. As constraints on the sensorimotor system increase, the ability to cope with change during movement goal execution decreases.

Injury and disease place additional constraints on the sensorimotor system, diminishing the ability to cope with or adjust to change. As rehabilitation professionals, athletic trainers aim to restore functional variability, or the ability to effectively cope with change, during movement goal execution. This can be accomplished through the purposeful manipulation of task and environmental constraints during rehabilita-
Chronic Ankle Instability through the Dynamical Systems Theory

Individuals with CAI have demonstrated a reduction in the ability to freely cope with changes in the task and environment. This is most evident through laboratory and clinical measures of postural control. A laboratory assessment known as time-to-boundary (TTB) is a static spatiotemporal measure of postural control that estimates the amount of time and strategies a person has to make postural corrections while maintaining single limb stance. Individuals with CAI have demonstrated less TTB magnitude and variability compared with healthy individuals. In addition, they failed a greater number of trials compared with the healthy control group. These alterations indicate that individuals with CAI have less time to make postural corrections and a diminished ability to successfully execute the movement goal. This suggests CAI is a source of organismic constraint on the sensorimotor system, which may contribute to the reoccurrence of ankle sprains and reductions in function. This conclusion has been supported through clinical measures of postural control, including the Balance Error Scoring System (BESS) and the Star Excursion Balance Test (SEBT).

Using the BESS and SEBT can give a basic sense of the constraint experienced in sensorimotor function. The BESS evaluates postural control through a series of single-leg balance tests on firm and unsupported surfaces with eyes closed. For each different stance and condition, participants are instructed to remain motionless for 20 seconds. The BESS score is generated from summing all the errors across all of the balance tasks, which indicates how the sensorimotor system can cope with changing task and environmental constraints. The SEBT is a battery of lower extremity maximal reach tests, whereas the contralateral limb attempts to maintain single-leg balance. In this test, a decreased reaching distance would indicate a level of constraint, suggesting the movement system needs to maintain a closer base of support. Those with CAI have demonstrated greater errors on the BESS and shorter reach distances on the SEBT, indicating the presence of diminished sensorimotor function.

By dynamically progressing task and environmental constraints, we can bolster the sensorimotor system’s ability to dynamically cope with change. This concept is supported by evidence indicating balance training programs effectively improves postural control and increases functional capacity in individuals with CAI. Using the dynamic systems model, McKeon et al developed a randomized control trial that used a static and dynamic balance training progression that consisted of static single-limb stance activities, single-limb hops to stabilization, single-limb hops to stabilization and reach, and unanticipated hops to stabilization. As participants performed the balance training program and progressed error free on the BESS, the task and environmental constraints were increased.

Errors were tracked on the BESS to indicate enhanced sensorimotor system function and the need to move forward to more challenging tasks in the balance training program. During a 4-week period, each exercise was progressed by changing the surface, task requirements, and visual input. Following cessation of the program, participants with CAI demonstrated significant improvement in TTB and increased reach on the SEBT from their baseline testing, compared with the control group. In addition to improved postural control, participants with CAI reported improved self-reported function. This investigation supports purposefully manipulating task and environmental constraints to improve self-reported function and functional variability. This investigation is unique in the sense it related motor control to measures of self-reported function. In doing so, connections were made between alterations in local instability and its effects on overall self-reported health status. Further examining this concept through contemporary models of health may expose how clinicians can evaluate patient functioning beyond the physical characteristics associated with injury and allow the dynamic systems theory to have a greater role in developing rehabilitation plans.

The Dynamic Nature of Function

The ICF developed by the World Health Organization provides a scientific basis for assessing health and disability. Unlike previous models of disability that view health and disability as separate conditions, the ICF defines function as the dynamically fluctuating
continuum of disability and health. In essence, function refers to the level of freedom an individual experiences through personal and societal interactions. Health conditions and rehabilitation interventions can ramp up or down this freedom. This then translates into the changing experiences of health and disability on the continuum of function. The goal of the ICF is to capture the dynamic nature of function through the integration of the body or body part, the person as a whole, and the person as a whole in societal and environmental contexts. This is accomplished by examining the influences of health conditions, environmental factors, and personal factors on the domains of body structure and function, activity, and participation.

Accounting for structural and functional impairments, activity limitations, or participation restrictions in these respective domains can assess how health conditions and other contextual factors influence the changing nature along the continuum of function. Contextual factors encompass environmental elements that are physical, social, and attitudinal; as well as, personal elements such as age, gender, coping styles, social background, education, self-efficacy, and overall behavior patterns. As the domains and contextual factors interact, the results on the continuum of function can be different between individuals. For example, 2 patients suffer from acute ankle instability (health condition). Both patients may have decreased range of motion (structural and functional alteration) and both may lack the ability to run at full speed. However, when examining their participation restrictions, one may not be restricted at all (eg, playing soccer with his 3-year-old son), but the other may have significant restrictions (eg, playing competitive soccer). The ICF identifies these factors as potential influences on an individual’s continuum of function; therefore, as discussed in the example above, it is possible to have structural and functional impairment with no manifestation of activity limitation or participation restrictions.

The ICF stresses the importance of using patient self-report outcome measures to gauge the patient’s overall perception of health status. This information becomes essential when identifying patient needs and developing rehabilitation goals. Patient self-report forms can compliment objective evaluation techniques to provide a means of assessing a person’s functional capacity from the patient’s point of view. Functional capacity represents the level in which an individual is able to perform activities and participate in desired life experiences without the use of assistive devices. Applying self-report forms can identify specific sources of functional loss and disability that can be useful when determining the appropriate intervention strategies.

**Application to Chronic Ankle Instability**

Individuals with CAI may exhibit structural impairment of the ankle in the form of ligamentous laxity, decreased range of motion, arthrokinematic restrictions, and degenerative changes. These individuals also experience functional impairments in postural control, proprioception, and neuromuscular control. The culmination of these impairments results in an ankle that is prone to sensations of giving way and bouts of joint instability, creating a predisposing factor for future ankle injuries. A reduction in functional capacity manifests, resulting in limitations in a person’s ability to perform certain activities and participate in desired life situations.

Individuals with CAI often report heightened activity limitation when moving on uneven surfaces, stairs, and during lateral movements. In addition, personal factors such as poor coping mechanisms, social support, medical assistance, and education can add to reductions in functional capacity. Contributions from these factors can cause activity limitations because certain tasks are unable to be executed to their original or expected level of performance and participation restrictions because these individuals may refrain from activities that produce greater levels of risk for sustaining future injuries. To identify factors that influence functional capacity, athletic trainers need valid and reliable instruments for determining sources of functional loss through patient self-report evaluations.

Several patient self-report forms are available to identify sources of functional loss and disability in the foot and ankle. On the basis of evidence from the most recent systematic review of several self-report measures, the Foot and Ankle Disability Index (FADI) and Foot and Ankle Ability Measure (FAAM) provide the most appropriate global ratings of function for assessing ability in patients with CAI. This conclusion was reached because these instruments have high content and construct validity, readability, reliability, internal consistency, and interpretability. The validity and sensitivity of these instruments have deemed them reliable for detecting self-reported functional alterations.
related to CAI.\textsuperscript{24,25} The FADI and the FAAM contain 26 and 21 items, respectively, pertaining to activities of daily living. In addition, these instruments have a supplementary 8-item index related to sport activities and participation.\textsuperscript{24,25} The FADI and FAAM support the goals of the ICF because they attempt to recognize functional capacity based on the perspective of the patient, which provides clinicians with additional support for developing intervention strategies that address patient needs.

RESULTS

The purpose of this article was to discuss the dynamic systems theory of motor control, the ICF model of health, and how incorporating both concepts can address, track, and aid in the interpretation of deficits associated with CAI. Addressing deficits associated with CAI can be accomplished by identifying patient-centered self-reported function assessments to identify areas of activity limitation and participation restriction. These identified alterations can then be addressed through purposeful manipulation of environmental and task constraints during rehabilitation. Throughout the rehabilitation process, progress can then be tracked by identifying error in movement goal execution during rehabilitation tasks and reassessing self-reported function. Finally, functional capacity and functional variability provide useful concepts to aid in the interpretation of identified deficits as they relate to an individual’s perception of their functional ability using a whole-person approach to healthcare. Although the ICF model and dynamic systems theory have different structure and terminology, both are multifactorial models that emphasize the need to understand functioning as a complex system with many interacting components. This shared view allows the ICF model and dynamic systems theory to compliment each other in many circumstances. This is evident by the similarity in impairment, activity limitation, and participation restriction in the ICF model and the sources of constraint in the dynamic systems theory (Figure).

Participation restriction in the ICF model and environmental constraints of the dynamic systems theory both examine the interaction and freedom a person has in his or her physical and social environments. A similar relationship is exhibited between activity limitations in the ICF model and task constraints in the dynamic systems theory. Finally, structural and functional impairment associated with ICF model and organismic constraints in the dynamic systems theory both examine how health influences function. Although the ICF aims at restoring functional capacity and the dynamical system theory aims at restoring functional variability in movement goal execution, the fundamental principles of both concepts allow them to achieve a homogenous goal of promoting overall function. The ICF model and dynamic systems theory are able to achieve similar goals because their basic framework is centered around a holistic examination of functioning rather than placing the emphasis directly on pathology.

When working with physically active populations, it is obvious that health conditions are going to have a significant role in functional loss; however, restoring function may be more effective if we examine, interpret, and address environmental, social, and personal factors as constraints on sensorimotor system organization based on a continuum of function. Integrating principles from both concepts may advance our understanding of function as it relates to health and disability. Based on this view, it may be beneficial to describe CAI as a reduction in functional capacity associated

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<td>2 Task</td>
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<td>3 Environmental</td>
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Figure. The relationship between the constraints of the Dynamic Systems Theory and the domains of the International Classification of Function.
with a decrease in functional variability resulting in recurrent ankle sprains and the residual sensation ankle instability.

CONCLUSION

Chronic ankle instability has provided a medium for the study of sensorimotor function integrating the fundamental principles of the dynamic systems theory and the ICF model of health. The dynamic systems theory provides a constraint-led approach to sensorimotor function that identifies ways to purposefully manipulate the environment and task to meet the needs of the individual patient. Incorporating the ICF model into clinical practice has several benefits, including a valuable tool for organization and communication, focusing rehabilitation on the unique needs of individual patients, and facilitating research into efficacy and effectiveness of rehabilitation interventions. Integrating sources of reduced function and increased constraints may create a working model that permits patient-centered care based on the goals of the individual, sources of functional loss, and the interaction of the person and his or her environment. Both concepts provide a multifactorial framework that will aid clinicians in making decisions in evaluation, treatment, and measurement of outcomes associated with injury. Although this article focused on CAI, this strategy is applicable to the rehabilitation of many musculoskeletal injuries and a wide variety of levels of health and disability.

FURTHER RESEARCH

Balance training offers a promising foundation for rehabilitating those with CAI, but further research is needed to identify additional rehabilitation interventions that improve functional variability in movement coordination, as well as functional capacity. Although balance training has demonstrated to be an effective intervention for improving self-reported function, it has yet to be determined whether this translates into a long-term reduction in reinjury in those with CAI. Finally, the purposeful manipulation of task and environmental constraints appears to enhance the functional capacity and functional variability of those with CAI; however, the relationship between these 2 processes needs further investigation.

REFERENCES

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