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# REVIEW OF THE LITERATURE

## Postural Dynamics: Clinical and Empirical Implications

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### ABSTRACT

**Objective:** To provide a rationale for the examination of posture from a dynamic (behavioral) perspective and to relate the vertebral subluxation to postural instability and motion sickness via inefficiency.

**Data Collection:** A manual search of available reference texts and a computer search of literature from Index Medicus, PsycINFO, and ISI Science Citation Index Expanded were collected with an emphasis on postural dynamics, vertebral subluxation, and motion sickness.

**Results:** Evidence linking behavioral and health research has emerged from the study of posture and postural dynamics. Studies examining the relation between postural control and motion sickness have shown that motion sickness is preceded and predicted by postural instability. Motion sickness is characterized by maladaptive response to unusual motion events. The symptoms are nonspecific and variable. Although the Postural Instability theory of motion sickness predicted that instability should precede sickness, it did not make any claims regarding the symptoms associated with it. Chiropractic literature has emphasized the effects of vertebral subluxation on neurologic dysfunction. Vertebral subluxation is a condition that is postulated to interfere with neurologic processes and may influence organ system function and general health. As in the case of motion sickness, symptoms are nonspecific and variable (and in some instances the person may have no symptoms). So what do these disorders have in common? In each instance the disruptions lead to inefficiency in the system.

**Conclusion:** Given this potential commonality, we propose that some of the methods used by behavioral researchers to study postural dynamics may also be of great utility to health care practitioners and psychologists alike. Furthermore we propose that this link will provide a framework that will allow scientists to address seemingly intractable problems such as motion sickness or subluxation. (J Manipulative Physiol Ther 2001;24:340-9)

**Key Indexing Terms:** Posture; Motion Sickness; Biomechanics; Dysponesis

## INTRODUCTION

Chiropractors have long been concerned with the relationship between postural alignment and its association with symptom generation[1,2] and its effects on health. Posture has been assessed during lying,[3] sitting,[4] standing,[5-7] lifting,[8] working,[9] walking,[10] daily routine performance,[11] and running,[12] to name a few. Postural stress has been correlated to office work,[13] work lifting injuries,[14] driving,[15] sitting,[16] space flight,[17] sports injuries,[18] and back pain.[19] Current chiropractic education places emphasis on the structure and function of the neuromusculoskeletal system in health and disease. The importance of posture is recognized within this context; however, there is another perspective on posture that may also aid in the promotion of health. This perspective comes out of the psychological literature in which posture is treated as a fundamental behavior that serves to facilitate the completion of other behavioral goals.

Traditionally, posture has been characterized in the chiropractic field as a form of biomechanical linkage (attitude) in terms of musculoskeletal symmetric relationships between segments; this is indicated by the work of Harrison et al,[20-22] who have extensively modeled posture in engineering terms as rotations and translations of the head, thoracic cage, and pelvis in 3 dimensions. In this article we take a different approach, treating posture not as a particular alignment of segments per se but instead as a dynamic behavior whose goal is to facilitate other overt behaviors (actions) that we perform. Taking this perspective yields a number of new issues and factors to be addressed that would not be obvious from the traditional viewpoint. This alternative view also allows for the generation of new assessment and research techniques in addition to the ones currently used. Our purpose in this article is to illuminate some of these issues with

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the hope that it will stimulate research into the relationship between chiropractic and postural control from a behavioral perspective.

We would like to elaborate on basic research that has been done on postural dynamics in relation to one's behavior and link these findings with those of chiropractic subluxation to illustrate the potential impact of postural control on health and well-being. We use posture in this review as a target behavior (given its fundamental role in executing subsequent actions), but the principles discussed hereinafter can be applied to a wide variety of behaviors. Several articles discuss the importance of posture throughout the life of an individual.[23-25] Postural control is necessary in child development including motor, perceptual, cognitive, and social development.[23] Postural control is also seen as a means to study the aging process and its subsequent ill effects such as falls resulting from reduced stability.[25] Because of its role in development, dependence on multiple organ systems, and its continuous need for accurate regulation, human posture and the behaviors it facilitates may represent an ideal construct for use in the measurement of health and wellness.

## DISCUSSION

### Biomechanics of Posture

The upright human body behaves like an inverted pendulum in that it is passively unstable.[26] On being disturbed, passively stable entities such as a normal pendulum will eventually return to their original or resting state without expending energy. In contrast, passively unstable objects, such as a pencil stood on end, on being disturbed will deviate further and further from their resting state and will eventually topple over (again without energy expenditure).[26-28] Passively stable entities do not have to actively regulate themselves to achieve stability, but passively unstable entities such as bipedal humans do. In other words, without active control on the part of the person, the body would simply topple over. The control of posture is further complicated by the fact that humans are not composed of a single rigid structure; rather, we are a set of linked segments.[26,28-30]

At this level the immediate goal of nonlocomotive posture appears to be to keep the center of mass (of the body) over the base of support with respect to relevant forces acting on it (eg, gravity).[29] More precisely, the task undertaken by the postural system is the maintenance of equilibrium (balance: often characterized as the ability to maintain a stable position[26]) with respect to gravito-inertial force, the vector sum of the forces resulting from gravity and acceleration. Given the relatively small base of support afforded by the feet, it becomes evident that the task of keeping balance is paramount for posture. In fact, this is often stated as being the biomechanical purpose for static (nonlocomotive) posture.[28,31-33] This equilibrium is achieved by keeping the center of mass (or more properly force) in line with the base of support (feet).

However, posture must also account for the multisegment nature of most creatures (humans in this case). In upright stance it is necessary to balance with respect to gravito-inertial force, but it must also maintain the balance of the segments in the body as well. Maintenance of both is not necessary for all forms of posture; nonerect or stooped posture is balanced with respect to the body but not (necessarily) gravito-inertial force.[29] This description illustrates the fact that the multisegmental nature of the human body allows for the assuming of different states of equilibrium (stable or unstable[26]). In the case of motion, this is further complicated by the fact that the arrangement of the segments changes, in turn producing a change in the center of mass (at least to some degree) that must also be controlled.[34]

It appears that the task is the same in instances of locomotion or activity. However, the equilibrium in these situations is a dynamic one, specified by a goal state rather than a particular point or area.[28,35] This is due to two major differences that exist during locomotion, the first being the fact that the center of mass is never directly above the base of support. Second, the base of support itself is constantly changing (from step to step, for example). Throughout these situations it remains the case that the task is to maintain some goal state; biomechanically, this state consists of balancing out the forces impinging on the body to remain upright. Another feature of posture is that it is a control minimization process; that is, posture will always use the most efficient (mechanically or metabolically)[34] method of control, reducing the amount of energy required to maintain balance.[29,30]

It is possible from this discussion of the biomechanical purpose of posture to derive a more general biomechanical definition of posture. Posture is a mechanism that acts to keep the body (center of mass) in equilibrium with the relevant forces acting on it using the least amount of energy.[30] This statement, although biomechanically accurate, is problematic in that it leads to the inference that posture has the express and sole purpose of keeping the body upright.[36] We propose that posture serves a larger purpose than simply keeping the body upright. In the next section we will recast posture in this larger context by considering posture itself as a behavior.

### Posture from a Behavioral Perspective

"Behavior depends on posture and is inseparable from it."[37] It is important to note that the control of posture itself is a behavior. Posture is something that is done by the animal, not something that happens to it.[36] In other words, posture is not maintained for its own sake; rather, posture is maintained to facilitate other actions.[30,38] The implication of this finding is that posture is a means to an end, not an end in itself. In light of this, the traditional assumption that posture is a static nonbehavioral attribute of upright humans must be changed to reflect this factor. The idea that posture serves as a facilitator for other behaviors can readily be observed in the act of locomotion. Upright stance allows for the initiation of bipedal locomotion (walking); other postures will not. A stooped posture will facilitate picking something off the ground or sitting, whereas an upright posture will not. Another important point to be considered is that goal behav-

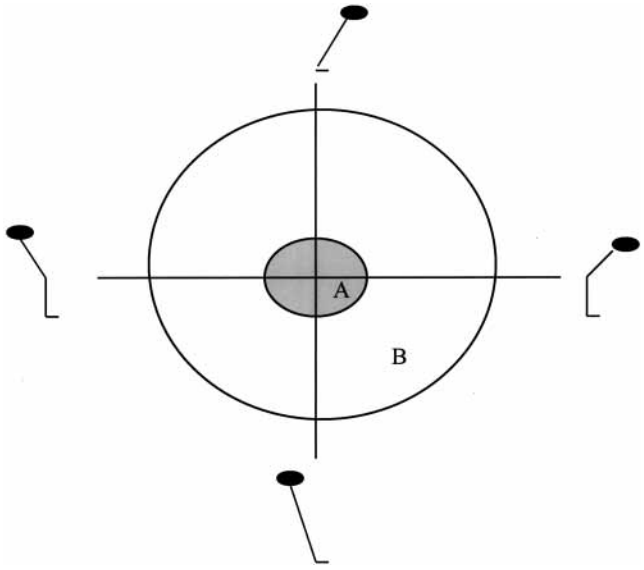

**Fig 1.** *Hip-ankle configuration plane for upright stance.* ***A,*** *Region of tolerance;* ***B,*** *region of reversibility (idealized). Adapted from Nashner and McCollum[29] and Riccio and Stoffregen.[30]*

iors often involve postures that violate biomechanical equilibrium. This is in direct conflict with a strictly biomechanical definition of posture. An example of this is leaning. When a person leans, either to look at something below him or her or to do some other task specifying the need to lean, biomechanical balance is compromised but not lost, even though the center of mass is no longer above the base of support.[30,39,40]

Behaviorally, posture has been presented previously as any given arrangement of the body, whether static or dynamic, that facilitates other suprapostural activities.[30,38] However, a truly functional model of posture and postural control must account for the joint constraints of behavior (goals) and biomechanics (as discussed in the previous section).

Given these parameters, we have adopted a new model of posture. In this context we define posture as a behavior whose purpose is to facilitate other behaviors through the maintenance of a given coordination of segments that are biomechanically viable (ie, goal is achieved without loss of balance) and efficient (energy expenditure is minimized).

Note that posture is now defined as a behavior rather than a static representation of the body in space. Although most researchers examining posture statically would agree that a symmetric-vertical anteroposterior posture would constitute "normal" posture, there is a debate about "average" versus "ideal" upright posture in the lateral view within the literature.[41] Our definition of posture as a dynamic process suggests that a single "ideal" or "normal" posture (read: alignment of body segments) may not exist; rather, these postures can be defined only with respect to the goal (task) and biomechanical and environmental constraints on the system. This definition also precludes the treatment of posture as purely a "reflex" (although the responses do not have to be the result of explicit mental commands). This assertion is suggested partly by the fact that postures are rarely isolatable responses, and the responses themselves tend to be anticipatory, ongoing, or corrective in nature.[28,36] In a similar vein, Horak and Kuo state, "[P]ostural adaptation allows changes in postural behavior so that it is optimized for changes in environmental contexts, particular tasks, and subjects' intentions."[42] In short, the postural control system should be thought of as having two goals: the maintenance of balance and orientation with respect to the environment and the facilitation of the achievement of other behavioral goals.[30,37,38,43]

Nashner and McCollum[29] discovered that two control strategies are predominately used in stance: ankle strategies involving rotations about the ankle joint and hip strategies that entail rotations about the hip. From this finding they were able to represent in biomechanical form standing postures in a 2-dimensional configuration space (Fig 1). The knee joint was hypothesized to be involved in vertical adjustments of posture (termed nonerect stance). Postural control is achieved through basic muscle coordination produced by neural firing patterns; perceptual information is assumed to have a regulatory role. Nashner and McCollum[29] were careful in noting that these patterns are not reflexes per se; rather, they represent control strategies that allow for the simplest and most efficient use of the appropriate muscles and joints. Riccio and Stoffregen[30] modified this configuration space to depict the behavioral goals beyond stance by adding control regions: the region of tolerance where explicit control is not needed and the region of reversibility where control is necessary and can be achieved without changing behavioral modes (eg, taking a step, Fig 1). Including these regions, it is now possible to depict both the biomechanical and behavioral constraints for a given posture. For a detailed account of how postural control is influenced by biomechanical and behavioral constraints (and data-based depictions of the tolerance and reversibility regions), see Bardy et al,[44] who studied how alterations of these factors affect postural coordination.

## Postural Control and Motion Sickness

Posture is useful only if it is stable.[45] Day-to-day functioning depends on the ability to maintain stable posture. When this stability is compromised, the ability to function appropriately is compromised in turn. In short, the ability to control one's posture is paramount for the achievement of many subsequent actions. If this fundamental process is disrupted, the impairment will also degrade the ability to perform suprapostural behaviors. Although there has been extensive research concerning how postural stability is achieved and maintained, few studies have addressed the consequences of the loss of stability. Riccio and Stoffregen[46] suggested that one of the consequences of prolonged postural instability is the occurrence of motion sickness. Instability is defined as a reduction or loss of the capacity to efficiently minimize uncontrolled movements of the perception and action systems.[30]

Most of the previous work in motion sickness has examined differences in the incidence of sickness, the presence/severity of symptoms, and the presence/severity of aftereffects. A problem with these types of studies is the focus on subjective measures that allow for the drawing of many different and possibly incompatible inferences (especially given that the symptoms associated with motion sickness are both varied and variable). It would be useful to have another index of sickness that is less susceptible to extraneous influences. In particular, although much of the motion sickness literature has acknowledged that postural instability is present during and after sickness, no causal properties are attributed to this loss of control. Given the importance of postural control for the execution of other behaviors and the variety of means to record and quantify postural motion, the study of postural control under provocative conditions could potentially yield a wealth of information regarding the cause of motion sickness.

Riccio and Stoffregen[46] argued that a reliable index/predictor of motion sickness could be found by observing changes in postural control. Before the work of Riccio and Stoffregen,[46] postural instability was considered only as a side effect of motion sickness (eg, ataxia).[47] Riccio and Stoffregen[46] asserted that "motion sickness reflects perception of the consequences of instability for perceiving and acting." Furthermore they argued that the instabilities that are relevant to motion sickness are those that relate to postural control. In other words, motion sickness is produced by the perception of postural instability (via the changes in stimulation that it produces). The fact that postural motion is affected by motion sickness is not a new finding; it is well known that instability is exhibited after the onset of motion sickness. The important point is that postural instability has been treated primarily as a side effect. However, in recent studies attempting to determine predictors of motion sickness, it has been found that motion sickness was preceded and predicted by gross disruptions in postural control.[48-50] In other words, instability in postural control seems to have led to physiological and behavioral dysfunction.

## Postural Alignment and Chiropractic Subluxation

Commonly, posture is seen to the clinician as a form of biomechanical linkage (attitude) in terms of musculoskeletal symmetric relationships between segments. An extensive review of normal postural alignment and the effects of abnormal posture on the neuromusculoskeletal system with reference to chiropractic has already been presented elsewhere.[2] All possible human postures have been categorized by Harrison et al[20,21] from the perspective of abnormal postural permutations calculated as rotations and translations from an ideal normal upright static spine. This traditional analysis of posture (abnormal static alignment) being consistent with basic mathematics and physics principles is extremely useful in that these static alterations result in consequences for the involved tissues and how those tissues perform when in motion.

A brief discussion of certain aspects of posture in relation to chiropractic will clarify the role of subluxation affecting postural control. Any imbalances in symmetry or deviation away from the "normal" postural position may promote a host of biomechanical, degenerative, and neurologic disorders that degrade the health potential of the individual.[2] Because of the relationship between faulty posture and mechanical stresses on the neuromusculoskeletal system, there is potential for undesirable health consequences. Junghanns[51] and Troyanovich et al[2] cite several articles that report associations between postural deficiencies and pathologic changes in the spinal column. These include bone, disc, ligament, and myofascial degeneration.

There are an array of techniques to characterize static alignment and dynamic posture and their sequelae. Chiropractors have tended to concentrate on static measurements of human posture as reflected by the following assessment techniques: plain film x-rays, advanced diagnostic imaging, plumb line analysis with or without weight scales, moire topography, scoliometry, leg-length inequality, and range of motion instrumentation using discrete measurements.[52-54] On the other hand, examples of behavioral approaches to assess postural dynamics have included the following assessments: postural sway and gross movements via video photographic analysis, electromagnetic tracking devices to monitor 3-dimensional position and orientation (continuous measurements) of small sensors attached to anatomic structures with respect to a transmitter,[48] and optoelectronic recording.[44]

The medical profession has not typically managed posture well. However, physical therapy such as the McKenzie method,[55,56] osteopathy,[57] and chiropractors such as with the chiropractic biophysics (CBP) technique[22] have all addressed management issues of postural correction. In particular, chiropractors have focused on the concept of subluxation in the assessment and management of postural conditions.

The philosophical postulate and historical establishment of chiropractic is that the vertebral subluxation is the "cause of dis-ease," from which "disease" may arise.[58] More recently, the Association of Chiropractic Colleges[59] has established that the purpose of chiropractic is to optimize health. The Association notes that the body's innate recuperative power is affected by and integrated through the nervous system. Subluxation as described by the Association of Chiropractic Colleges is "a complex of functional and/or structural and/or pathological articular changes that compromise neural integrity and may influence organ system function and general health."[59] As Lantz[60] notes, neurologic involvement and kinesiologic dysfunction are common to all concepts of subluxation.

Given that subluxation "compromises" neural integrity and exhibits kinesiopathology, and the fact that posture is a complex behavior that demands precise perception-action coupling, subluxation (as corrected by chiropractic adjustment), like postural instability, can be predicted to result in physiological and behavioral dysfunction. With these principles in mind, abnormalities of posture (referred to as global subluxations by some)[2] can account for the histopathology, myopathology, neuropathophysiology, and kinesiopathology encountered in patients presenting to chiropractors.[2]

## The Common Link

The preceding sections outline problems that nominally have very little to do with each other. However, careful examination of these disorders reveals a potential common thread that may provide a mechanism for determining why these disorders occur and why they manifest themselves in such a peculiar manner. To maintain postural stability, the person must gather sensory information from a broad range of sources (eg, visual, vestibular, and somatosensory). This information is used to regulate complex motor responses (in terms of timing, direction, and magnitude) to accomplish the desired behavior. Thus alterations in sensory systems, neural activity, and subsequent transmission of information and the biomechanics of the musculoskeletal system could all inherently affect postural control.

From both behavioral (motion sickness) and clinical (chiropractic) perspectives, there seems to be a similar progression from inefficient energy expenditure for a given task that can manifest itself in observable behavior before the occurrence of symptoms. The subsequent symptoms, if and when they present, are both varied and variable. The point is that both disorders seem to follow from inefficiency in the system. The question now becomes why should this inefficiency lead to these disorders?

Dynamic systems (of which humans are one) seem to almost universally operate in a manner that tends to minimize the amount of energy necessary to achieve a given goal state. Coordination of body segments for control of dynamic equilibrium is characterized by energy-efficient movements controlling the many degrees of freedom involved in maintaining stability.[42] Stated briefly, these systems will "prefer" to function in a manner that allows for optimal performance with minimal effort. This mode of operation seems to apply equally well to both nonbiologic and biologic systems. In the case of human behavior, one of the most robust characteristics of everyday motor performance is the propensity to complete the task with the least energy expenditure.[30,42,61-63] Sparrow states:

> [C]asual observation of individuals performing a variety of everyday motor tasks invariably leads to the hypothesis that an attempt is being made to meet the task requirements with the least amount of energy expenditure. From a movement science perspective, the metabolic cost of performing mechanical work in order to interact with the environment describes the "efficiency" or "economy" of movement.[64]

Data also suggest that other phenomena are associated with the principle of energy minimization. Instability may be associated with a greater expenditure of energy, and it has generally been concluded that the more stable the movement pattern is, the more efficient the motion is.[65-67] During certain behaviors humans and other animals shift, or make a transition, from one coordination pattern to another such as the transition from walking to running. In some situations these transitions have been suggested to be energy-saving mechanisms.[68,69] For example, it may be more economical to transition to jogging rather than to continue to walk fast. In observation of a wide range of motor actions (unconstrained by outside agents), individuals adopt a preferred mode or "comfort mode." The disposition to adopt preferred modes is referred to as "self-optimizing"[70] to suggest that preferred modes are self-selected (ie, no augmented feedback required) and optimal with respect to variables such as work, time, or energy. These preferred modes are associated with the lowest physiologic cost and therefore the highest efficiency. Much of the research on preferred modes associated with movement economy is reviewed in a chapter by Sparrow et al.[71] Mark et al[72] examined the issue of preferred modes with unconstrained reaching for a small block. The results obtained in this study were consistent with the idea that the preferred critical boundary (preferred mode), which dictates when a single or multiple degrees of freedom reach is warranted, reflects the relative biodynamic efficiency, comfort, and effort of available modes of reaching. Another aspect of these transitions is that they occur well before the critical maximum (the point at which the behavioral mode must be changed). This finding suggests that in performing a given task, the person "prefers" not to operate near the boundaries of a given behavior.

O'Dwyer and Neilson provide evidence that optimization of metabolic economy and movement accuracy are linked by minimization of muscle activity: "The increase in accuracy and stability of movement with increasing skill appears to be linked to the level of muscle activation and force employed, since accuracy and stability of control appear to be enhanced at lower levels of muscle activity."[73] Also, perception of central motor commands provides an individual with a sense of effort associated with muscle activation and on cardiorespiratory responses to muscle activation. Thus the sense of effort and cardiorespiratory activity are related by the level of activation of muscles.[73] The primary influence of muscle on autonomic activity is termed "central command"[74]; that is, all motor outflow is accompanied by a parallel, proportional, and obligatory input to cardiovascular control centers. Smith and Cox[75] discuss central command along with muscular and cardiovascular function in relation to chiropractic.

Given the observed propensity of a dynamic system to be attracted to stable, efficient modes of operation, any mechanism that leads to altered energy expenditure will potentially have a negative impact on the efficiency of the biologic system. Postural (behavioral) instability and vertebral subluxation can be linked in terms of the concept of dysponesis, which connects inefficiency with negative health effects that may or may not be accompanied by specific symptoms. Dysponesis is defined as a reversible physiopathologic state composed of errors in energy expenditure that interfere with nervous system function and thus with control of organ function. Dysponesis is capable of giving rise to a variety of widespread health conditions.[76] In regard to errors in energy expenditure themselves, Whatmore and Kohli state:

> …most of them lie in the bracing, representing, and attention categories and, being covert in nature, go unnoticed by both the person making them and others observing him. They occur concomitantly with our productive efforts and interfere with the efficiency, productivity, and health of the organism. The detrimental influence of these misdirected efforts results from the fact that action-potentials (or nerve impulses) con-

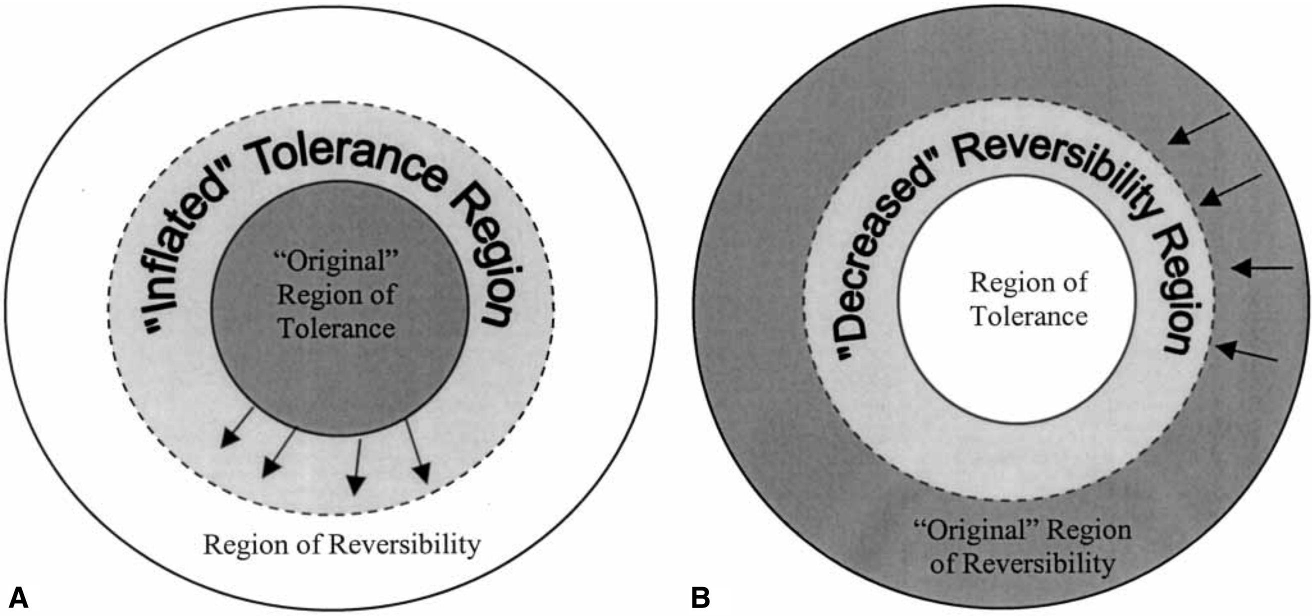

**Fig 2.** *Factors influencing control regions.* ***A,*** *Tolerance "inflation": artificial expansion of tolerance region conceived as resulting from loss of perceptual capabilities;* ***B,*** *reversibility "restriction": artificial reduction of reversibility region conceived as resulting for loss of action capability (see text for full explanation).*

> stituting effort follow not only the well-known pathways from motor and premotor cortex to anterior horn cells, and thus to muscle fibers, but they also feed signals (by way of side-branches and feed-back mechanisms) into the reticular activating system, the hypothalamus, the limbic system, and the neocortex, thus producing widespread additional effects.[76]

The signals described lead to excitatory or inhibitory messages that are inappropriate to the immediate objectives of the organism. For example, it has been shown that quiet standing will elicit little, if any, activity from the paraspinal musculature as measured by surface electromyography. Thus widespread activation of paraspinal and trunk musculature can be regarded as inappropriate and inefficient for the performance of quiet standing, assuming no overt pathologic condition is present. This results in interference of many aspects of neural function including the organism's emotional reactivity, ideation, and regulation of various bodily organs.[76]

Although inefficiency may provide a common mechanism for these disorders, it is difficult to study directly (noninvasively). However, we propose that it is possible to measure the effects of inefficiency through the study of overt behavior (in this case the control of posture). Recall the two control regions depicted in Fig 1, the region of tolerance and the region of reversibility. Riccio and Stoffregen[30] stated that these regions are defined by the biomechanical properties of the person (animal) relative to the physical properties of the environment and, perhaps most important for this analysis, the behavioral goals of the person. Given these influences, we suggest that it is possible to constrain these control regions "artificially" (see following paragraphs and Fig 2). Doing so would increase the likelihood that the person would be functioning in an inefficient manner, which in turn could manifest itself as postural (behavioral) instability.

The region of tolerance, where explicit control is not needed, can be affected (inflated) by the loss of perceptual capabilities, or an increase in "sensory noise." These changes in ability to pick up relevant information (ie, loss of sensitivity caused by aging or toxins, for example) may account for the postural instability exhibited in the elderly.[33] "Inflation" of the tolerance region could also be produced by dysafferentation. For example, the central nervous system is greatly influenced by somatosensory input, and consequently alteration of mechanoreceptive input caused by joint dysfunction has the potential to promote numerous symptoms (ie, vertigo, dizziness, imbalance, or ataxia) that could mimic lesions of the cerebellum, vestibular nuclei, cerebral cortex, and basal ganglia.[77-81]

Likewise, the region of reversibility can be affected (restricted) by loss of action capabilities produced by the changes in the biomechanical properties of the person (eg, loss of strength or flexibility).[82] The person's skill level, that is, the ability to perform a particular behavior, may also influence this region, particularly when the task is novel or difficult (eg, the biomechanical and esthetic constraints placed on gymnasts are often very difficult to meet and tend to limit the number of viable behavioral strategies).[83] Restriction of the reversibility region can also be produced by interference with efferent neural mechanisms.[75] For example, the elderly person who exhibits a degradation of the perceptual and motor capabilities (as a result of degeneration to the neurologic and biomechanical systems) necessary for stable activity may be more likely than the average person to make an unintentional transition (eg, fall from standing position).[84-86]

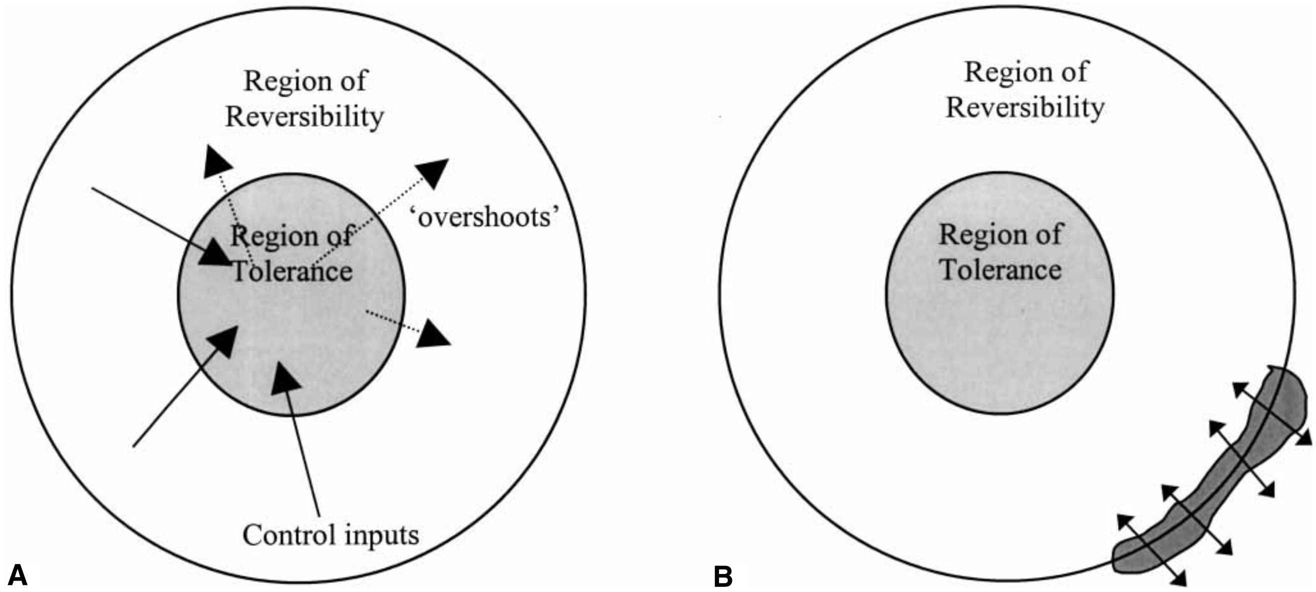

**Fig 3.** *Inefficient control strategies.* ***A,*** *Hypercontrol;* ***B,*** *hypo- ("border") control (see text for full explanation).*

In both instances (tolerance inflation or reversibility restriction) instability may occur as a result of having fewer options or less time to make the appropriate adjustments that would maintain efficient (stable) functioning. However, in the absence of structural or biomechanical anomalies, it is still possible to engage in behaviors that are inefficient. Inefficiency can be produced by adopting "faulty" or inappropriate control strategies for a given behavior.

Two inappropriate control strategies that may affect the efficiency of the system are illustrated in Fig 3. Hypercontrol represents the state when an individual exerts tighter constraints on the system (behavior) than needed (attempting to control actions within the tolerance region). This can create inefficiency caused by "overshooting" (in the same manner that positive feedback can produce chaotic behavior in mechanical systems)[87] the minimal actions required for a particular task. Examples of this type of strategy include bracing responses, where the person exhibits excessive muscular activity ("clenching")[76] and cases where the goal constraints are greater than the person's ability (ie, standing at attention for long periods of time[88]). It is interesting that muscle activity can be decreased in accomplishing the same task after chiropractic and osteopathic care.[89-91] Hypo- ("border") control, on the other hand, represents operating at the boundaries of a given system or behavior (ie, operating at the outer edge of the reversibility region). This strategy may be used in novel situations where the person does not know the appropriate actions to take. Control techniques that the person has do not aid stability in these situations (eg, attempting to move about in orbit in the same manner that you would on the ground). Another instance of this type of control is when a given behavior is maintained beyond the point that a transition to another behavior is mandated (eg, "speed-walking").

Now that we have elaborated on the common link, one might ask the question: what is the difference between the description of abnormal posture being rotations and translations from an ideal upright static posture such as that formulated by Harrison and Troyanovich[22] and the behavioral model we have presented? The difference is that static descriptions of posture cannot assess the consequences on behavioral (dynamic) variables associated with inefficiency such as instability, movement transitions, and accuracy or movement variability. Accordingly, posture thought of statically in terms of abnormal rotations and translations found in "neutral resting" posture (traditional approach), although extremely helpful in delineating the effects of asymmetric deformations of tissues, fails to account for the fact that maintaining stability even during quiet stance is dynamic, because the body is never completely motionless.[92] The advantage of using a static "snapshot" description of posture (eg, radiograph) is that any abnormal rotations and translations found in resting posture can be compared with a neutral resting symmetric posture. The maintenance of these static abnormalities of posture (global subluxations) might be predicted to cost extra energy compared with a symmetric posture. However, any inference regarding the resulting dynamics (ie, potential inefficiency) cannot be assessed through static measures. The model that we propose can potentially expand on the traditional alignment method of postural assessment by allowing for a quantitative approximation of biodynamic efficiency. The assertion that posture is a behavior means that posture may be modeled and characterized in the dynamic terms we have proposed in addition to the standard biomechanical analyses in use.

## CONCLUSION

From this discussion, we hope that is it is clear that chiropractors and basic science researchers who are interested in posture (behavior) have much to benefit from collaboration. The focus of the discussion has concentrated on factors that lead to system inefficiency. Paramount among these factors is the idea that everyday movements appear constrained by the directive to optimize metabolic economy. The concept of dysponesis bridges the two fields of study together by (1) neurologic dysfunction, (2) errors in energy expenditure, and (3) the capability of producing widespread health effects and symptoms. The evidence presented in this article allows for the vertebral subluxation and postural instability to be associated via inefficiency. The speculation as to a causative relationship between these variables is beyond the scope of this article; our mission was simply to point out their conceptual similarities. It is our hope that illustrating this association will lead to future investigation by a variety of researchers from different specialties to further elucidate the nature of the relations among efficiency, subluxation, postural stability, health, and behavior. Our primary emphasis in this article has been on postural control because of its fundamental role in behavior and its potential broad impact on health. In fact, Lennon et al[93] hypothesized that posture affects and moderates every physiologic function from breathing to hormonal production and that it appears that homeostasis and autonomic regulation are intimately connected with posture. It should be recognized, however, that the principles illustrated through the use of postural analysis could also be applied to a wide variety of behaviors.

The concepts we propose are original in the sense of looking at human health by linking the concepts of subluxation and behavioral dysfunction via inefficiency. It is not original in demonstrating the need for simplifying assumptions in the neurologic regulation of motion and behavior. The appeal of using such a combined approach, however, is that it provides a framework that is compatible with mechanical, behavioral, and physiological information and is amenable to experimental tests that would either confirm or refute its assumptions. Specifically, what we proposed were behavioral variables by which to study the overall state of a dynamical system. We have suggested that system inefficiency may be addressed through exploration of its consequences for behavior that include but are not limited to instability, preferred modes, and movement transitions. We believe that approaching many of the issues concerning psychologists and chiropractors from this perspective will yield ideas for future research and exploration.

We echo the suggestions by Mark et al[72] that future studies must develop more direct measures of biodynamic efficiency. As for chiropractic, attempts have been made to define and characterize subluxation and its impact on neural regulation[59,94]; however, further research must be done to be able to explicitly locate and correct vertebral subluxation. It is interesting that regarding vertebral subluxation as an alteration of posture necessarily means that subluxation influences behavior, given our model. In lieu of being able to study the nervous system directly in relation to energy expenditure and regulation, the behavioral approach, which emphasizes the study and quantification of global system dynamics, is an attractive measure to investigate the system indirectly. Besides the theoretical advances in our understanding of system dynamics through combined behavioral and clinical research, we suggest that there will be significant practical consequences as well.

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## REFERENCES

1. Panzer DM, Fechtel SG, Gatterman MI. Postural complex. In: Gatterman MI, editor. Chiropractic management of spine related disorders. Baltimore: Williams & Wilkins; 1990. p. 256-84.
2. Troyanovich SJ, Harrison DC, Harrison DD. Structural rehabilitation of the spine and posture: rationale for treatment beyond the resolution of symptoms. J Manipulative Physiol Ther 1998;21:37-50.
3. Carr EK, Kenney FD, Wilson-Barnett J, Newham DJ. Interrater reliability of postural observation after stroke. Clin Rehabil 1999;13:229-42.
4. Jones CJ, Rikli RE, Max J, Noffal G. The reliability and validity of a chair sit-and-reach test as a measure of hamstring flexibility in older adults. Res Q Exerc Sport 1998;69:338-43.
5. Benvenuti F, Mecacci R, Gineprari I, Bandinelli S, Benvenuti E, Ferrucci L, et al. Kinematic characteristics of standing disequilibrium: reliability and validity of a posturographic protocol. Arch Phys Med Rehabil 1999;80:278-87.
6. Smidt GL, Day JW, Gerlman DG. Iowa anatomical position system. A method of assessing posture. Eur J Appl Physiol 1984;52:407-13.
7. Lafferty-Braun B, Amundson LR. Quantitative assessment of head and shoulder posture. Arch Phys Med Rehabil 1989; 70:322-9.
8. Burdorf A. Reducing random measurement error in assessing postural load on the back in epidemiologic surveys. Scand J Work Environ Health 1995;21:15-23.
9. Burt S, Punnett L. Evaluation of interrater reliability for posture observations in a field study. Appl Ergon 1999;30:121-35.
10. Lu TE, O'Connor JJ. Bone position estimation from skin marker co-ordinates using a global optimisation with joint constraints. J Biomech 1999;32:129-34.
11. Jette AM, Jette DU, Ng J, Plotkin DJ, Bach MA. Are performance-based measures sufficiently reliable for use in multicenter trials? Musculoskeletal impairment (MSI) study group. J Gerontol A Biol Sci Med 1999;54:M3-6.
12. Downs FS, Fitzpatrick JJ. Preliminary investigation of the reliability and validity of a tool for the assessment of body position and motor activity. Nurs Res 1976;25:404-8.
13. Leskinen T, Hall C, Rauas S, Ulin S, Tonnes M, Vükari-Juntura E, et al. Validation of Portable Ergonomic Observation (PEO) method using optoelectronic and video recordings. Appl Ergon 1997;28:75-83.
14. Pan CS, Gardner LI, Landsittel DP, Hendricks SA, Chiou SS, Punnett L. Ergonomic exposure assessment: an application of the PATH systematic observation method to retail workers. Postures, activities, tools, and handling. Int J Occup Environ Health 1999;5:79-87.
15. Harrison DD, Harrison SO, Croft AC, Harrison DE, Troyanovich SJ. Sitting biomechanics part II: optimal car driver's seat and optimal driver's spinal model. J Manipulative Physiol Ther 2000;23:37-47.
16. Mucha RF, Weiss RV, Mutz R. Detection of the erect position

in the freely-moving human: sensor characteristics, reliability, and validity. Physiol Behav 1997;61:293-300.

17. Ferrigno G, Baroni G, Pedotti A. Methodological and technological implications of quantitative human movement analysis in long term space flights. J Biomech 1999;32:431-46.
18. Gaebler C, Kukla C, Breitenseher MJ, Nellas ZJ, Mittlboeck M, Trattnig S, et al. Diagnosis of lateral ankle ligament injuries. Comparison between talar tilt, MRI and operative findings in 112 athletes. Acta Orthop Scand 1997;68:286-90.
19. Luoto S, Aalto H, Taimela S, Hurri H, Pyykko I, Alaranta H. One-footed and externally disturbed two-footed postural control in patients with chronic low back pain and healthy control subjects. A controlled study follow-up. Spine 1998;23:2081-9.
20. Harrison DE, Harrison DD, Troyanovich SJ. Three-dimensional spinal coupling mechanics: Part I. A review of the literature. J Manipulative Physiol Ther 1998;21:101-13.
21. Harrison DD. Abnormal postural permutations calculated as rotations and translations from an ideal normal upright static spine. In: Sweere JJ, editor. Chiropractic family practice. Gaithersburg (MD): Aspen Publishers; 1992. p. 6-1, 1-22.
22. Harrison DD, Troyanovich S. Chiropractic biophysics technique. In: Lawrence D, editor. Advances in chiropractic. Vol 4. St. Louis: Mosby–Year Book; 1997. p. 321-48.
23. Gramsbergen A, Hadders-Algra M. Development of postural control, a basic aspect of neuro-ontogeny. Neurosci Biobehav Rev 1998;22:463-4.
24. Kroker P. The problem of remaining upright. BMJ 1999;319:1-2.
25. Maki BE, McIlroy WE. Postural control in the older adult. Clin Geriatr Med 1996;12:635-58.
26. Hamill J, Knutzen KM. Biomechanical basis of human movement. Baltimore: Williams and Wilkins; 1995.
27. van Asten WNJC, Gielen CCAM, Denier van der Gon JJ. Postural adjustments induced by simulated motion of differently structured environments. Exp Brain Res 1988;73:371-83.
28. Roberts TDM. Understanding balance. New York: Chapman and Hall; 1995.
29. Nashner LM, McCollum G. The organization of postural movements: a formal basis and experimental synthesis. Behav Brain Sci 1985;8:135-72.
30. Riccio GE, Stoffregen TA. Affordances as constraints on the control of stance. Human Movement Science 1988;7:265-300.
31. Blaszczyk J, Hansen PD, Lowe DL. Postural sway and perception of the upright stability borders. Perception 1993;22:1333-41.
32. Collins JJ, De Luca CJ. Open-loop and closed-loop control of posture: a random-walk analysis of center-of-pressure trajectories. Exp Brain Res 1993;113:243-8.
33. Blaszczyk J, Lowe DL, Hansen PD. Ranges of postural stability and their changes in the elderly. Gait Posture 1994;2:11-7.
34. Winter DA. Biomechanics and motor control of human movement. 2nd ed. New York: John Wiley and Sons; 1990.
35. Warren WH, Kay BA, Yilmaz E. Visual control of posture during walking: functional specificity. J Exp Psychol Hum Percept Perform 1996;22:818-38.
36. Reed ES. Changing theories of postural development. In: Woollacott MH, Shumway-Cook A, editors. Development of posture and gait across the lifespan. Columbia: University of South Carolina Press; 1989. p. 3-24.
37. Gibson JJ. Notes on Action. In: Reed E, Jones R, editors. Reasons for realism: selected essays of James J. Gibson. Hillsdale (NJ): Lawrence Erlbaum Associates; 1974/1982. p. 385-92.
38. Stoffregen TA, Smart LJ, Bardy BG, Pagulayan RJ. Postural stabilization of looking. J Exp Psychol Hum Percept Perform 1999;25:1641-58.
39. Martin EJ. An information based approach to postural control: the role of time-to-contact with stability boundaries [master's thesis]. Urbana-Champaign (IL): University of Illinois; 1990.
40. Fouque F, Bardy BG. Effects of postural stability on perception-movement coupling. In: Schmuckler MA, Kennedy JM, editors. Studies in perception and action IV. Hillsdale (NJ): Lawrence Erlbaum Associates; 1997. p. 343-6.
41. Kuchera M. Gravitational stress, musculoligamentous strain, and postural alignment. Spine: State of the Art Reviews 1995;9:463-89.
42. Horak F, Kuo A. Postural adaptation for altered environments, tasks and intentions. In: Winters JM, Crago PE, editors. Biomechanics and neural control of posture and movement. New York: Springer-Verlag; 2000. p. 267-81.
43. Stoffregen TA, Riccio GE. An ecological theory of orientation and the vestibular system. Psychol Rev 1988;95:1, 3-14.
44. Bardy BG, Marin L, Stoffregen TA, Bootsma RJ. Postural coordination modes considered as emergent phenomena. J Exp Psychol Hum Percept Perform 1999;25:1284-301.
45. Gibson JJ. The senses considered as perceptual systems. Boston: Houghton-Mifflin; 1966.
46. Riccio GE, Stoffregen TA. An ecological theory of motion sickness and postural instability. Ecological Psychol 1991; 3:195-240.
47. Kennedy RS, Stanney KM. Postural instability induced by virtual reality exposure: development of a certification protocol. Int J Hum Comput Int 1996;8:25-47.
48. Stoffregen TA, Smart LJ. Postural instability precedes motion sickness. Brain Res Bull 1998;47:437-48.
49. Stoffregen TA, Hettinger LJ, Haas MW, Roe M, Smart LJ. Postural instability and motion sickness in a fixed-base flight simulator. Hum Factors 2000;42:458-69.
50. Smart LJ. A comparative analysis of visually induced motion sickness [dissertation]. Cincinnati (OH): University of Cincinnati; 2000.
51. Junghanns H. Clinical implications of normal biomechanical stresses on spinal function. Rockville (MD): Aspen Publishers; 1990. p. 144-54.
52. Triano JJ, Skogsbergh DR, Kowalski MH. The use of instrumentation and laboratory examination procedures by the chiropractor. In: Haldeman S, editor. Principles and practice of chiropractic. 2nd ed. East Norwalk (CT): Appleton & Lange; 1992. p. 319-60.
53. Council on chiropractic practice clinical practice guideline (number 1) vertebral subluxation in chiropractic practice. Council on Chiropractic Practice; 1998.
54. Schafer RC. Clinical biomechanics: musculoskeletal actions and reactions. Baltimore: Williams & Wilkins; 1987. p. 93-142.
55. McKenzie RA. The cervical and thoracic spine: mechanical diagnosis and therapy. Waikane, New Zealand: Spinal Publications, Ltd; 1990.
56. McKenzie RA. The lumbar spine: mechanical diagnosis and therapy. Waikane, New Zealand: Spinal Publications, Ltd; 1981.
57. Peterson B. Postural balance and imbalance. Newark (OH): American Academy of Osteopathy; 1983.
58. Palmer DD. The science, art, and philosophy of chiropractic. Portland: Portland Printing House; 1910.
59. The Association of Chiropractic Colleges. Position paper 1, 1996.
60. Lantz CA. The vertebral subluxation complex. In: Gatterman MI, editor. Foundations of chiropractic subluxation. St. Louis: Mosby; 1995. p. 150-74.
61. Sparrow WA, Newell KM. Metabolic energy expenditure and the regulation of movement economy. Psychonomic Bull Rev 1998;5:173-96.
62. Farfan H. Biomechanics of the lumbar spine. In: Haldeman S, editor. Principles and practice of chiropractic. 2nd ed. East Norwalk (CT): Appleton & Lange; 1992. p. 149-64.
63. Kugler PN, Lintern G. Risk management and the evolution of instability in large-scale, industrial systems. In: Hancock P, Flach J, Caird J, Vicente K, editors. Local applications of the

ecological approach to human-machine systems. Hillsdale (NJ): Lawrence Earlbaum Associates; 1995. p. 416-50.
64. Sparrow WA. Energetics of human activity. Champaign (IL): Human Kinetics; 2000. p. 6.
65. Brisswalter J, Mottet D. Energy cost and stride duration variability at preferred transition gait speed between walking and running. Can J Appl Physiol 1996;21:471-80.
66. Holt KG, Hamill J, Andres RO. Predicting the minimal energy costs of human walking. Med Sci Sports Exerc 1991;23: 491-8.
67. Holt KG, Jeng SF, Ratcliffe R, Hamill J. Energetic cost and stability during human walking at the preferred stride frequency. J Motor Behav 1995;27:164-78.
68. Hoyt DF, Taylor CR. Gait and the energetics of locomotion in horses. Nature 1981;292:239-40.
69. Caldwell GE, van Emmerik REA, Hamill J. Movement proficiency: incorporating task demands and constraints in assessing human movement. In: Sparrow WA, editor. Energetics of human activity. Champaign (IL): Human Kinetics; 2000. p. 66-95.
70. Cavanagh PR, Kram R. Mechanical and muscular factors affecting the efficiency of human movement. Med Sci Sports Exerc 1985;17:326-31.
71. Sparrow WA, Hughes KM, Russell AP, Le Rossignol PF. Movement economy, preferred modes, and pacing. In: Sparrow WA, editor. Energetics of human activity. Champaign (IL): Human Kinetics; 2000. p. 96-123.
72. Mark LS, Nemeth K, Gardner D, Dainoff MJ, Paasche J, Duffy M, et al. Postural dynamics and the preferred critical boundary for visually guided reaching. J Exp Psychol Hum Percept Perform 1997;23:1365-79.
73. O'Dwyer NJ, Neilson P. Metabolic energy expenditure and accuracy in movement: relation to levels of muscle and cardiorespiratory activation and the sense of effort. In: Sparrow WA, editor. Energetics of human activity. Champaign (IL): Human Kinetics; 2000. p. 1-42.
74. Rowell L. Human cardiovascular control. New York: Oxford University Press; 1993.
75. Smith DL, Cox RH. Muscular strength and chiropractic: theoretical mechanisms and health implications. J Vertebral Subluxation Res 1999-2000;3:1-13.
76. Whatmore GB, Kohli DR. Dysponesis: a neurophysiologic factor in functional disorders. Behav Sci 1968;13:102-24.
77. Seaman DR, Winterstein JF. Dysafferentation: a novel term to describe the neuropathophysiological effects of joint complex dysfunction. A look at likely mechanisms of symptom generation. J Manipulative Physiol Ther 1998;21:267-80.
78. Kessinger RC, Boneva DV. Vertigo, tinnitus, and hearing loss in the geriatric patient. J Manipulative Physiol Ther 2000; 23:352-62.
79. Galm R, Rittmeister M, Schmitt E. Vertigo in patients with cervical spine dysfunction. Eur Spine J 1998;7:55-8.
80. Bolton PS. The somatosensory system of the neck and its effect on the central nervous system. J Manipulative Physiol Ther 1998;21:553-63.
81. Simoneau GG, Ulbrecht JS, Derr JA, Cavanagh PR. Role of somatosensory input in the control of human posture. Gait Posture 1995;3:115-22.
82. Konczak J, Meeuwsen HJ, Cress ME. Changing affordances in stair climbing: the perception of maximum climbability in young and older adults. J Exp Psychol Hum Percept Perform 1992;18:691-7.
83. Marin L, Bardy BG, Bootsma RJ. Level of gymnastic skill as an intrinsic constraint on postural coordination. J Sports Sci 1999;17:615-26.
84. Shupert CL, Horak FB. Adaptation of postural control in normal and pathologic aging: implications for fall prevention programs. J Applied Biomech 1999;15:64-74.
85. Robinovitch SN, Cronin T. Perception of postural limits in elderly nursing home and day care participants. J Gerontol Bio Sci 1999;54A:B124-B130.
86. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: a review. Neurobiol Aging 1989;10:727-38.
87. Briggs J, Peat FD. Turbulent mirror: an illustrated guide to chaos theory and the science of wholeness. New York: Harper & Row; 1971.
88. Smart LJ, Pagulayan RJ, Stoffregen TA. Self-induced motion sickness in unperturbed stance. Brain Res Bull 1998;47:449-57.
89. Shambaugh P. Changes in electrical activity in muscles resulting from chiropractic adjustment: a pilot study. J Manipulative Physiol Ther 1987;10:300-4.
90. Grice AS. Muscle tonus change following manipulation. JCCA 1974;12:29-31.
91. Ellestad S, Nagle R, Boesler D, Kilmore M. Electromyographic and skin responses to osteopathic manipulative treatment for low-back pain. JAOA 1988;88:991.
92. Horak FB, Macpherson JM. Postural orientation and equilibrium. In: Rowell LG, Shepherd JT, editors. Exercise, regulation and integration of mulitple organ systems. New York: Oxford University Press; 1996. p. 255-92.
93. Lennon J, Shealy CN, Cady RK, Matta W, Cox R, Simpson WF. Postural and respiratory modulation of autonomic function, pain, and health. Am J Pain Man 1994;4:36-9.
94. Integrating chiropractic theory, evidence, and practice. Research Agenda Conference. Chicago, IL: July 21-23, 2000.