On Stability

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Static or dynamic descriptions of nature are two fundamental concepts used in science today. The ancient Greek philosophers Heraclitus and Parmenides did the earliest known recordings on the static and dynamic aspects of nature. Heraclitus described how the universe is in a state of flux and is famous for saying "no man steps in the same river once", whereas Parmenides on the other hand describes how change is impossible, existence is timeless, uniform, necessary and unchanging. Static is defined as having no motion, fixed or stationary, whereas dynamic refers to motion, change, activity or progress. A property often used when describing the dynamic and static aspects of nature is stability.

Stability is defined as "the strength to stand or endure, the quality of being stable, the property of a body that causes it when disturbed from a condition of equilibrium or steady motion to develop forces or moments that restore the original condition, resistance to chemical change of physical disintegration" (http://www.merriam-webster.com/dictionary/stability). Stability is a term used by different sciences to describe nature.

Stability is used differently by the different sciences depending on what is being described or measured. In social sciences economic stability is one example that refers to an economy with fairly constant output with a low and stable inflation. In the natural sciences, such as chemistry, thermodynamic stability is defined by the energy released when one chemical reacts with another. Stable chemicals have more energy that can be released in a reaction, whereas more stable chemicals have less energy that can be released upon reacting with another chemical. This energy principle is based upon a universal law that all things seek a lower energy state. A ball would roll down a hill and not up a hill, and the ball is more likely to stay at the bottom of a hill and not roll back up. In biology a differentiation between stability, the response of the system to perturbations, and structural stability (robustness), "the capability of for functional and structural preservation under external impacts", is made (Nikolov, Yankulova, Wolkenhauer, & Petrov, 2007). Furthermore in biology ecological systems are said to be stable if the system can have a similar assemblage after the perturbation (Rixon, 1998). Stability is also used to describe human movement.

Locomotion, functional tasks and athletic performances are dependent upon the concurrent movement of multiple joints. How the joints move, and how much they move, is dependent upon the structure and functional capabilities of the joints, and the specific movement requirements of the functional task. Without the coordinated effort of active and passive structures, governed by the neurological system, the body would collapse, let alone being able to handle other external forces than gravity and the ground reaction force. The property known as stability enables the body to deal with disturbances under static and dynamic conditions. The general definition of stability, described previously, includes disturbance or perturbation. Perturbation is included the different definitions of whole body, regional or joint stability. Furthermore these definitions include the static and dynamic aspects of human movement (Full, Kubow, Schmitt, Holmes, & Koditschek, 2002; Pope & Panjabi, 1985; Smith, Nyland, Caudill, Brosky, & Caborn, 2008; Zazulak, Cholewicki, & Reeves, 2008). In order to study and quantify the stability of human movement biomechanics is commonly used.

Biomechanics combines the natural and physical sciences and it has been defined as the study of structure and function of biological systems such as humans, animals, plants and cells by means of the methods of mechanics (Hatze, 1974). Different biomechanical methods and variables are used to define stability in both static and dynamic conditions. Static conditions can be different positions such as standing and sitting, whereas dynamic conditions includes various forms of locomotion (Full, et al., 2002), athletic performances or other functional tasks such as reaching with arms and legs (Delahunt et al., 2013; Steffen et al., 2013). Biomechanics is used to describe stability of the entire body, specific region or joint.

Static and dynamic balance, or postural stability, is used to describe stability of the whole body in standing positions. Center of pressure (COP) has been used extensively to quantify both static and dynamic balance (Palmieri, Ingersoll, Stone, & Krause, 2002). Different variables pertaining to COP are used to determine static balance such as maximum and minimum amplitude and average amplitude from an average point of the COP. A decrease in both is considered good static balance (Palmieri, et al., 2002). Furthermore total COP excursion and velocity are also used, where a decrease in velocity is thought to represent better balance. Good static balance is therefore little movement at a low rate. One might argue that this is somewhat artificial and removed from human movement. Rather than minimal movement at a low rate it would seem logical that the motor control system would seek the barriers of stability and do this at a higher rate with the confidence of being able to control this. In a study where subjects with ACL-deficient knees were tested against controls one found that the controls had a higher COP velocity, thus poorer balance (K. Davids, Kingsbury, George, O'Connell, & Stock, 1999). Therefore increased movement, within limits, might be a better measure of static balance, since this is a dynamic process of the postural-control system. Static, which implies lacking movement, is not an accurate description, since there always will be some movement. Less dynamic is a better description. What magnitude and rate of movement in standing upright best describes static balance, or postural stability, is up for debate (Palmieri, et al., 2002). One thing is certain that is the dynamic aspect of static balance or postural control.

Dynamic balance, or dynamic postural control, can be quantified as the performance of given tasks (Delahunt, et al., 2013; Steffen, et al., 2013), anticipatory and behavior during the task (Huang & Brown, 2013), or the response upon completion of the task (Huang & Brown, 2013; Ross & Guskiewicz, 2004). Path and jerk scores of the COP during a task such as an upper extremity reach (Huang & Brown, 2013), time to balance or stability after a jump (Ross & Guskiewicz, 2004) or upper extremity reach (Huang & Brown, 2013) is used to quantify dynamic balance. Performance on tests, such as the Star Excursion Balance Test (SEBT), is also used to quantify dynamic balance or dynamic postural stability. A decreased performance, reach distance in a given direction, has been defined as decreased dynamic postural stability (Delahunt, et al., 2013; Steffen, et al., 2013). All these measures have one thing in common; they all describe the different dynamic phases of movement.

The interchangeable use of the terms balance and postural stability is confusing. Therefore it is of importance to clarify these two terms. Balance is the ability to maintain the center of gravity within the limits of stability as determined by the base of support (Palmieri, et al., 2002). Stability is the robustness in response to perturbations as described previously. A perturbation is defined as a disturbance of motion, course, arrangement, or state of equilibrium. Based on this definition of stability, bilateral or unilateral balance does not fit the criteria to be called postural stability since there is no perturbation in a physical sense imposed on the system. However other stimuli such as visual or auditory and mental status, such as a lack of concentration, could serve as a perturbation. As described previously - dynamic balance is measured while performing clearly defined activities such as arm and leg reaches and jumping. These tasks are known, therefore one might argue that this is not a perturbation and cannot be defined as dynamic postural stability. However, such tasks are perturbations to the state of equilibrium in upright standing. Overall it seems that there is some confusion on how to use the terms stability and balance in upright standing under both static and dynamic conditions.

One region that has received a lot of attention in regards to stability is the trunk, or core. This might be due to the fact that this is a big part of the body, but also because it is the dynamic crossroads of the kinetic chain in many athletic activities (Anderson, Strickland, & Warren, 2001; Young, 1996). The trunk is an integral part of the coordinated and sequenced movement of different body segments that constitutes different athletic movements (Hirashima, Kudo, Watarai, & Ohtsuki, 2007; Putnam, 1993). Therefore, trunk stability has to encompass both static and dynamic conditions (Reeves, Narendra, & Cholewicki, 2007). Trunk stability has been described as "the capacity of the body to maintain or resume a relative position (static) or trajectory (dynamic) of the trunk following a perturbation" (Zazulak, et al., 2008). However there are numerous other definitions of trunk and core stability (Cosio-Lima, Reynolds, Winter, Paolone, & Jones, 2003; Crisco & Panjabi, 1991; Full, et al., 2002; Keele, 1983; Kibler, Press, & Sciascia, 2006; Lehman, 2006; Panjabi, 1992; Pope & Panjabi, 1985; Smith, et al., 2008; Tanaka, Nussbaum, & Ross, 2009; Tse, McManus, & Masters, 2005).

In order to understand and discuss the different definitions of trunk stability it is important to describe Panjabi´s well established model (Panjabi, 1992). He suggested that trunk stability is provided by; the passive, active and neural control system. The passive structures that provide intrinsic stability is the spinal column with its ligamentous structures, while the active system is the muscles surrounding the spinal column providing the dynamic stability (Panjabi, 1992). The neural control system coordinates this system under expected and unexpected conditions (Panjabi, 1992). The active system, the muscles, has been differentiated into a global and local system by Bergmark (Bergmark, 1989). The global system consists of the muscles, and the intra-abdominal pressure, that transfer the load directly between the thorax and the pelvis. The local system is made up of all the muscles that have their origin and insertion on the vertebrae, with the exception of the psoas major and minor (Bergmark, 1989). Both the global and local system of the trunk function to accomplish the following: 1) stabilize the spine to maintain upright posture (Bergmark, 1989; Crisco & Panjabi, 1991; Davey, Lisle, Loxton-Edwards, Nowicky, & McGregor, 2002; McGill, Grenier, Kavcic, & Cholewicki, 2003). 2) Create counterforces in the chain of force transmission to the base of support as a response to the forces accelerating the limbs in dynamic movements (Aruin & Latash, 1995; Friedli, Cohen, Hallett, Stanhope, & Simon, 1988; P. Hodges, Cresswell, & Thorstensson, 1999; P. W. Hodges & Richardson, 1997; McGill, et al., 2003). 3) They contribute to the regulation of the abdominal pressure (Cholewicki, Juluru, & McGill, 1999; Cresswell, Oddsson, & Thorstensson, 1994; P. W. Hodges, Eriksson, Shirley, & Gandevia, 2005) and protect and support the inner trunk organs. 4) They stiffen the spine for stability and controlling motion of the pelvis relative to the thorax (Granata, Orishimo, & Sanford, 2001; Hirashima, et al., 2007; McGill, et al., 2003). 5) They generate force and mechanical energy to the extremities by rotating the thorax relative to the pelvis (Bulbulian, Ball, & Seaman, 2001; Hirashima, et al., 2007; Shaffer, Jobe, Pink, & Perry, 1993; Toyoshima, 1974). In order to accomplish these functions the core muscles must function through their full range of motion.

Testing and training of trunk stability then has to be discussed based upon the existing definitions of trunk stability, and Panjabi´s model of trunk stability. Isometric (Liemohn, Baumgartner, Fordham, & Srivatsan, 2010; McGill, 2001; McGill, Childs, & Liebenson, 1999; Sharrock, Cropper, Mostad, Johnson, & Malone, 2011) and isokinetic (Willson, Dougherty, Ireland, & Davis, 2005, Cosio-Lima, 2003 #1258) measures trunk of muscle function in different planes of motion are commonly used measures. These measures are often presented as reflecting trunk stability, but they merely reflect isometric and concentric strength and endurance of trunk muscles in non-functional positions such as seated, prone, supine or quadruped. An analogue to this stability argument of the trunk based upon these tests would be that a static and dynamic squat would represent knee stability, which is not done by anyone. These tests have also given rise to similar trunk or core stabilization exercises (Arokoski, Valta, Airaksinen, & Kankaanpaa, 2001; Beach, Howarth, & Callaghan, 2008; Escamilla et al., 2006; Escamilla et al., 2010; Jorgensen et al., 2010; Monfort-Panego, Vera-Garcia, Sanchez-Zuriaga, & Sarti-Martinez, 2009; Schoffstall, Titcomb, & Kilbourne, 2010). It is also interesting to note that researchers are more interested in muscle activation patterns of different tests and exercises (Escamilla, et al., 2010), rather than focusing on how trunk muscles function during functional tasks. The tests used are in agreement with the definitions of stability on static and dynamic strength of the trunk muscles (Cosio-Lima, et al., 2003), but in obvious violation when it comes to perturbations (Smith, et al., 2008; Zazulak, et al., 2008) and integrating the entire kinematic chain (Kibler, et al., 2006; Zazulak, et al., 2008). The latter being of utmost importance, since the coordination of different joint motions is extremely useful in the analysis of human movement (Wilson, Simpson, van Emmerik, & Hamill, 2008).

Other tests and measures are also used in an attempt to quantify trunk stability such as the activation of specific muscles, Stability Index (SI) and Lyapunov exponent. The transversus abdominis (Mannion, Caporaso, Pulkovski, & Sprott, 2012) has been studied in an attempt to show the impact of this particular muscle on spinal stabilization exercise performance. However no real measure of trunk stability is provided, and an argument of its impact on trunk stability is made based upon how the muscle is activated by the Central Nervous System (CNS) during different tasks (P. W. Hodges, 1999). Activation patterns and the importance of individual muscles over other muscles have later been refuted (Cholewicki & VanVliet, 2002; Morris, Lay, & Allison, 2011), and opposing arguments to the unique and important activation patterns of transversus abdominis on spinal stability (Allison & Morris, 2008) with opposing results has been found (Morris, et al., 2011). Another measure is the SI, which is based upon the minimum potential energy principle and is a static measure of trunk stability. Average curvature of the surface of the system's potential energy in a vicinity of the static equilibrium served as the relative SI (Cholewicki & VanVliet, 2002). Rather than using the SI of static positions, it would be more beneficial to look if there was a generation or loss of energy through the trunk in different dynamic functional task. A loss of energy could indicate an "energy leakage" indicative of a loss of trunk stability. Negative or contracting Lyapunov exponents from kinematic data (Granata & England, 2006) is one measure used to define dynamic stability. This measure looks at how the motion is resuming its´ original trajectory after a perturbation. Only a small part of the range of motion is measured, but the response to perturbation while moving can be described.

One measure that is currently not included in any of the definitions of trunk stability is movement variability. It is commonly believed that increased kinematic variability indicates greater instability (Dingwell & Marin, 2006), and that a more robust system will exhibit reduced system variability (Tanaka, et al., 2009). Kinematic variability has been assessed based upon three-dimensional linear displacement (Graham, Sadler, & Stevenson, 2011), angular displacement (Dingwell & Marin, 2006), position (K. B. Davids, S.; Newell, K., 2006), timing (K. B. Davids, S.; Newell, K., 2006) and COP (R. E. van Emmerik & van Wegen, 2002; R. E. v. W. van Emmerik, E.E., 2000). Increased variability of the COP in upright standing has been interpreted as a measure of loss of stability (R. E. v. W. van Emmerik, E.E., 2000). Furthermore, the Lyapunov exponent has been used to describe dynamic stability (England & Granata, 2007; Graham, et al., 2011; Granata & England, 2006; Granata & Gottipati, 2008). This is a measure of the time dependent kinematic variance about a state space trajectory. Diverging trajectories are considered unstable, whereas converging trajectories are considered stable. This is in agreement with the traditional motor learning perspective that suggests that a reduction in coordination, or kinematic variability, is important for the development of skilled performance (Fleisig, Chu, Weber, & Andrews, 2009; Wilson, et al., 2008).

The notion of decreased movement variability as being stable (England & Granata, 2007; Graham, et al., 2011; Granata & England, 2006; Granata & Gottipati, 2008), robust (Tanaka, et al., 2009) and yielding skilled performance (Fleisig, et al., 2009; Wilson, et al., 2008) is also being challenged. Movement variability is considered an inherent element of the movement patterns that are directly controlled by the CNS (R. E. van Emmerik & van Wegen, 2002). Increased movement variability may be a sign that the biological system can produce a variety of solutions to deal with unexpected or changing constraints of a particular movement (R. E. van Emmerik & van Wegen, 2002), and thus is able to adapt to perturbations (Hamill, van Emmerik, Heiderscheit, & Li, 1999; R. E. v. W. van Emmerik, E.E., 2000). Movement variability may therefore also be viewed as a resource of the biological system to respond to perturbations, which in turn then should be incorporated into the definitions on stability as described previously.

Furthermore it is interesting that the dynamic stability definition of the entire body, or the trunk, does not include a better description of the different parts that contribute to the overall movement. Any form of effective locomotion, functional task or athletic performance is dependent upon the coordinated mobility contribution and interaction of multiple joints. This has been neglected in the measures of trunk stability thus far, even though it is a part of different trunk stability definitions (Kibler, et al., 2006; Zazulak, et al., 2008). Many have argued that the inclusion of different joint motions, besides the trunk, would be useful in the analysis of human movement (Wilson, et al., 2008). Furthermore, only certain parts of the path of the joint mobility are analyzed with the current measures of dynamic trunk stability (Granata & England, 2006). This provides only limited information about how the entire system behaves. How the trunk would respond to a given functional task, such as arm and leg reaches, under different conditions through manipulations of leg positioning, rate and amplitude of movement as well as surface conditions, would be much more interesting to know. Maybe trunk stability is to have the resources in maintaining trunk motion under these different conditions since the system would have the variability of movement solutions to being able to solve the task effectively.

One aspect, or property, that has been alluded to previously is robustness, which has to be seen in context with stability. Reeves and coworkers describes how robustness is the ability to cope with uncertainties and disturbances (Reeves, et al., 2007). Uncertainty represents how the CNS would approximate the position of the spinal column, whereas a disturbance or perturbation has been described previously. Based upon this description it seems that robustness is a part of what others define as stability

There are many ways of defining and measuring different forms of stability. Reeves and co-workers describes this well with an analogy of stability being the elephant in the old Indian fable of the six blind men and the elephant (Reeves, et al., 2007). It seems that stability is an elusive term that changes with context. It almost seems like the definition of stability is unstable. However, based upon what we know about human movement and performance, stability must represent the continuum of movement, since all measures of stability represent some form of movement, not the absence of movement as Parmenides describes. How we as humans utilize our ability to move to solve a task in the most effective way under different conditions is a better measure of the stability of our body, region or joint. Providing a solution on how to do this would be a great contribution to science.

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