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Biomechanical assessment of dynamic balance: Specificity of different balance tests

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ABSTRACT

Dynamic balance is vitally important for most sports and activities of daily living, so the assessment of dynamic stability has become an important issue. In consequence, a large number of balance tests have been developed. However, it is not yet known whether these tests (i) measure the same construct and (ii) can differentiate between athletes with different balance expertise. We therefore studied three common dynamic balance tests: one-leg jump landings, Posturomed perturbations and simulated forward falls. Participants were 24 healthy young females in regular training in either gymnastics ($n = 12$) or swimming ($n = 12$). In each of the tests, the participants were instructed to recover balance as quickly as possible. Dynamic stability was computed by time to stabilization and margin of stability, deduced from force plates and motion capture respectively. Pearson's correlations between the dynamic balance tests found no significant associations between the respective dynamic stability measures. Furthermore, independent t-tests indicated that only jump landings could properly distinguish between both groups of athletes. In essence, the different dynamic balance tests applied did not measure the same construct but rather task-specific skills, each of which depends on multifactorial internal and external constraints. Our study therefore contradicts the traditional view of considering balance as a general ability, and reinforces that dynamic balance measures are not interchangeable. This highlights the importance of selecting appropriate balance tests.

1. Introduction

The term "balance" describes the dynamics of body posture to prevent falling (Winter, 1995). In consequence, proper balance is crucial for most activities of daily living and for many sports, not only for athletic performance but also injury prevention (Hrysomallis, 2007).

The literature commonly distinguishes between static and dynamic conditions of balance. Whereas static stability relates to balance under unperturbed conditions such as during quiet standing (Macpherson & Horak, 2013), dynamic stability is considered the maintenance or recovery of balance in response to internal or external disturbances (Horak, Henry, & Shumway-Cook, 1997). These may include voluntary segmental or whole-body movements during quiet stance or locomotion, as well as instabilities resulting from the support surface or upper body perturbations (Macpherson & Horak, 2013; Winter, Patla, & Frank, 1990). Hence, from a neuromechanical perspective, the postural control system is permanently required to maintain or relocate the center of mass over the base of support (Woollacott & Shumway-Cook, 2002).

Research has shown that the risk of falling is more closely related to dynamic stability than static stability (Rubenstein, 2006) and

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that most fall-related events occur under dynamic conditions (Blake et al., 1988). Given the dynamic nature of most sports, the assessment of balance under dynamic conditions has become an important issue. In consequence, a large number of dynamic balance tests have been established. However, some of the clinical and functional tests suffer ceiling effects (Era et al., 2006) and can also be affected by muscular strength and flexibility (Hrysomallis, 2011). Other tests use fine-grained biomechanical methods to assess dynamic stability under laboratory conditions. Some of the most frequently-used tests are one-leg jump landings (e.g., Fransz, Huurnink, Kingma, & van Dieën, 2014; Liu, Dierkes, & Blair, 2016; Pau et al., 2015), perturbations of an unstable platform (e.g., Giboin, Gruber, & Kramer, 2015; Wälchli, Tokuno, Ruffieux, Keller, & Taube, 2017) and simulations of forward loss of balance (e.g., Arampatzis, Karamanidis, & Mademli, 2008; Barrett, Cronin, Lichtwark, Mills, & Carty, 2012; Do, Breniere, & Brenguier, 1982).

Previous studies have shown that the correlations are very low between different static stability measures and even lower between static and dynamic stability measures (e.g., Granacher, Bridenbaugh, Muehlbauer, Wehrle, & Kressig, 2011). Therefore, different mechanisms of the postural control system have been suggested to control balance under static and dynamic conditions (Shimada et al., 2003). This scientific evidence contradicts the traditional view on the construct of postural balance. In sports and human movement science, especially in the older basic literature, postural balance has often been treated as a general ability. However, recent studies have suggested that the principle of task-specificity also applies to balance (e.g., Giboin et al., 2015; Muehlbauer, Besemer, Wehrle, Gollhofer, & Granacher, 2012).

Horak, Wrisley, and Frank (2009) developed a clinical balance test battery consisting of 36 tests in six categories. The authors reported that participants with deficiencies in one category did not score poorly in other categories, indicating that these tests measured specific sensorimotor skills rather than a general ability. This assumption is further supported by several balance training studies showing task-specific training effects (e.g., Donath, Roth, Zahner, & Faude, 2016a; Ogaya, Ikezoe, Soda, & Ichihashi, 2011; Yaggie & Campbell, 2006). In particular, these studies showed strong improvements in the trained balance task but that there was minimal or no transfer to non-trained balance tasks (for review, see Donath, Roth, Zahner, & Faude, 2016b; Kummel, Kramer, Giboin, & Gruber, 2016). Consequently, balance training did not affect postural stability in a general way.

Despite this evidence, to date no studies have investigated the relationships between various biomechanical dynamic balance tests in healthy young athletes. Previous studies focused on clinical or functional tests (e.g., Y Balance Test, Star Excursion Balance Test, Timed Up and Go Test) or studied children (Broglio, Sosnoff, Rosengren, & McShane, 2009; Faigenbaum et al., 2015). Therefore, the purpose of our study was to investigate whether different dynamic balance tests measure the same construct; that is dynamic postural stability. We also investigated if these tests could differentiate between athletes with different balance expertise. It is known from the literature that transfer between motor skills is minimal (Schmidt & Lee, 2011) but that generalizability increases with expertise (Magill & Anderson, 2014). Therefore, long-term balance training may lead to a greater degree of skill transfer between different but related tasks.

We employed a study design that included three dynamic balance tests, which were performed by athletes practicing gymnastics (high balance demand) and swimming (low balance demand). We hypothesized that associations between the tests are low, but that the gymnasts would outperform the swimmers in each of the tests.

2. Material and methods

2.1. Participants

The study population consisted of 24 healthy young females (Table 1). They trained regularly either in artistic gymnastics ($n = 12$) or swimming ($n = 12$) and competed at regional level. These two sports were chosen as the majority of balance studies comparing high level athletes showed that gymnasts outperform non-gymnasts, including swimmers (for review, see Hrysomallis, 2011). All participants were naïve to the experimental procedure and had no known muscular or neurological diseases that could have affected their ability to perform the experiments.

The study was approved by the Institutional Review Board. All participants were informed about the protocol and gave their written informed consent before participating in the study.

Table 1
Sample characteristics.

	Overall	Gymnasts	Swimmers	*p*
Participants [*n*]	24	12	12	
Age [yrs]	23.7 ± 1.0	24.2 ± 1.3	23.2 ± 1.3	0.320
Body height [m]	1.67 ± 0.02	1.67 ± 0.03	1.68 ± 0.03	0.472
Body mass [kg]	59.6 ± 1.8	59.4 ± 2.1	59.7 ± 3.2	0.859
BMI [kg/m^2]	21.3 ± 0.5	21.4 ± 0.5	21.2 ± 1.0	0.680
Physical activity [h/w]	5.6 ± 0.8	4.8 ± 1.1	6.4 ± 1.2	0.040*

BMI = Body Mass Index.
P values as revealed by independent *t*-tests ($p < 0.05$): *statistically significant.