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Research article

Learning Effects Associated With the Least Stable Level of the Biodex® Stability System During Dual and Single Limb Stance

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Abstract
The Biodex® Stability System (BSS) has high test-retest reliability when stable (high) resistance levels are used. However, reliability data for lower stability levels, associated with more pronounced learning curves, are rare in the existing literature. Thus, it is likely that BSS scores obtained from lower stability levels require greater familiarization (i.e. practice) to achieve a stable score both within and between test sessions. Therefore, the purpose of this investigation was to determine if a commonly reported 6 trial sequence (3 practice trials, 3 test trials) used with the BSS can achieve a stable within session score on the lowest stability level (i.e. level 1). The secondary purpose was to evaluate the test-retest reliability of the lowest BSS resistance level over a 10-week period. Twenty sedentary university students (11 male, 9 female; age: 21.5 ± 1.9 years, height: 1.7 ± 0.1 m, weight: 66.3 ± 12.1 kg, BMI: 22.4 ± 2.3) voluntarily participated. Participants completed two test sessions separated by 10-weeks. Twelve, 20-second trials (six dual limb stance, six single limb stance on the dominant limb) on the lowest stability level were completed during both test sessions by all participants. A stable within session dual and single limb stance score was achieved with a maximum of 3 familiarization trials. Reliability ranged between poor and good across all outcomes but all outcomes had large minimal detectable change scores. At least 3 stance specific familiarization trials are needed to achieve a stable BSS score within a single test session on the lowest resistance level. However, the inconsistent reliability and high minimal detectable changes scores suggest that the lowest resistance level should not be used as an objective marker of rehabilitation progress over extended periods of time (e.g. 10-weeks).

Key words: Practice, postural control, test-retest reliability.

Introduction

Maintaining balance is a complex function involving visual, vestibular, and somatosensory input, as well as appropriate muscle activity to maintain the body's center-of-gravity over it's base of support during static and dynamic tasks (Emery, 2003). A variety of clinical (e.g. Star Excursion Balance Test) and laboratory devices (e.g. force platforms) have been developed to evaluate static and dynamic balance (Clifford and Holder-Powell, 2010). One of the most frequently used devices for dynamic balance is the Biodex Stability System (BSS) which provides quick and quantitative measures of postural control, center of pressure location, and (indirectly) the overall function of the sensorimotor system. The stability of the BBS platform can be varied by adjusting the level of spring resistance (i.e. support) from 1 (least stable) to 12 (most stable) (Hinman, 2000; Schmitz and Arnold, 1998). Numerous papers report high test-retest reliability for the BSS when using high resistance levels (Cachupe, et al., 2001; Parraca et al., 2011, Sherafat et al. 2013). However, reliability data for lower stability levels, which are more challenging and dynamic in nature, is almost non-existent within the literature (Cachupe et al, 2001). More challenging tasks, such as balancing on a highly unstable surface, have also been associated with more pronounced learning curves (Nordahl et al., 2000; Valovich et al, 2003). Thus, it is likely that BSS scores obtained from lower stability levels are inherently less stable and require greater familiarization (i.e. practice) to achieve a stable score both within and between test sessions. Unfortunately, no empirical data is available to determine an appropriate number of familiarization trials or the reliability of the low BSS resistance levels despite the continued use of lower stability levels in the evaluation of postural control during and after therapeutic interventions. Therefore, the primary purpose of this investigation was to determine if a commonly reported 6 trial sequence (3 practices, 3 test trials) used with the BSS is adequate to achieve a stable level 1 score within a single test session. The secondary purpose was to evaluate the test-retest reliability of the BSS at resistance level 1 over a 10-week period (ie. Does a 6 trial sequence achieve a stable score between test sessions?). Based on the existing literature we hypothesized that the standard 6 trial sequences would be adequate to achieve a stable BSS score within a single test session on resistance level 1 and that such a sequence would produce at least fair reliability scores.

Methods

Twenty sedentary university students (11 male; age 22 ± 2.24 years height: 1.78 ± 0.08 meters, weight: 73.91 ± 9.49 kilograms, Body Mass Index: 23.04 ± 2.06 kg·m^{-2}; 9 female; age: 20.88 ± 1.16 years, height: 1.63 ± .5 meters, weight: 57.07 ± 7.76 kilograms, Body Mass Index: 21.34 ± 2.3 kg·m^{-2}; voluntarily participated. Participants were required to have a sedentary life style (i.e. <60 minutes exercise per week) and no regular participation in any sporting activity. All participants were free of musculoskeletal injury and had no known neurological, cardiovascular, metabolic, rheumatic or vestibular diseases. A health status questionnaire and the Exercise Stages of Change Levels Questionnaire were given to determine eligibility (Cengiz and Ince, 2009). All participants read

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and gave written informed consent on a University approved consent form, from the Ethics Committee of the University (FON 78/1597).

A BSS SD (Biodex®, Inc., Shirley, NY, USA) was used for assessments of dynamic balance. The BSS is comprised of a movable balance platform that provides up to 20° of surface tilt in a 360° arc of motion. The version of the BSS used in the study had 12 dynamic stability levels with level 12 being the most rigid (easiest) and level 1 the most unstable (difficult). Main outcome measures included the overall stability index (OSI), the anterior/posterior stability index (APSI), and the medial/lateral stability index (MLSI). The OSI represents the total variance of platform displacement (all directions), measured in degrees, with higher scores indicating worse postural control while the APSI and MLSI represent platform displacement in the sagittal and frontal planes respectively (Arnold and Schmitz, 1998, Riemer and Wikstrom, 2010, Sulewski et al., 2012). The following formulas (OSI=$[(\sum(0\text{-}Y)^2 + \sum(0\text{-}X)^2$ / number of samples$)]^{\wedge 0.5}$, APSI = $[(\sum(0\text{-}Y)^2/$ number of samples$)]^{\wedge 0.5}$, MLSI = $[(\sum(0\text{-}X)^2/$ number of samples$)]^{\wedge 0.5}$), where Y and X represent the degree of platform tilt in the sagittal and frontal plane respectively, were used to calculated the outcomes of interest.

For all trials, participants were tested barefoot with their eyes open and were allowed to visualize the real time feedback provided by the BSS computer interface. First, 6, 20-second trials of dual limb stance were completed. This stance required participants to stand with slight knee flexion (~15°), while looking straight ahead with their arms across their chest. Next, 6, 20-seconds trials of single leg stance were completed. These trials required an identical test position but were completed while standing on the dominant limb only. Limb dominance was defined as the limb a participant would use to kick a soccer ball. A 60-second rest was given between all trials. Participants returned to the laboratory 10 weeks later to repeat the above described testing protocol. This timeframe was chosen to establish reliability of level 1 BSS scores over an extended period of time because longer periods between assessments have been shown to neutralize initial motor learning in young adults (Wrisley et al., 2007).

To determine if a 6 trial sequence was adequate to achieve a stable within session score, the OSI, APSI, and MLSI for each stance (dual limb, single limb) were submitted to a 1-way repeated measures ANOVA [6 levels] (Robinson and Gribble, 2008). This analysis was also performed on data from the second test session. Because we were more concerned with making a Type II error, no adjustment was made on the a priori alpha level which was set at 0.05 despite multiple ANOVAs being run. If a statistically significant difference was noted among the trials of each test session, pairwise comparisons using the least significant difference method without a Bonferonni correction (to limit chances of a Type II error) were used to determine the location of those differences (Robinson and Gribble, 2008). Test-retest (10-week) reliability was quantified using dependent sample t-tests and intraclass correlation coefficients ($ICC_{2,1}$) (Wikstrom, 2012). These statistics were conducted for the following: 1) the best score within the final 3 trials of each test session for all outcomes and stance types and 2) the average score of the final 3 trials of each test session for all outcomes and stance types as both mean and best scores are commonly reported in the literature.

The precision of each level 1 BSS score (best and mean) was then calculated using the standard error of measure (SEM). Minimal detectable change (MDC) scores quantified how much a level 1 BSS score (best and mean) would need to change, following a rehabilitation intervention, for that change to be confidently considered a true change (improvement or degradation) due to the intervention and not measurement error (Beaton and Bombardier, 2001). For the purposes of this investigation, reliability coefficients were interpreted as follows; below 0.69 is poor, 0.70 to 0.79 is fair, 0.80 to 0.89 is good, and 0.90 to 1.00 is considered excellent (Cohen, 1988).

Results

Significant differences were noted for all of the chosen outcome measures across dual and single limb stance among the six trials completed during the first test session: dual limb OSI [$F(5,95) = 17.26$, $p < 0.01$)], dual limb APSI [$F(5,95) = 15.19$, $p < 0.01$)], dual limb MLSI [$F(5,95) = 13.83$, $p < 0.01$)], single limb OSI [$F(5,95) = 4.70$, $p = 0.01$)], single limb APSI [$F(5,95) = 4.54$, $p = 0.01$)], and single limb MLSI [$F(5,95) = 4.17$, $p = 0.02$)]. The results of the pairwise comparisons conducted on the data from the first test session (Table 1) indicate that a stable dual and single limb stance score can be achieved on level 1 of a BSS with a maximum of 3 familiarization trials. Significant differences were also noted among the six trials completed during the second test session for the single limb OSI [$F(5,95) = 3.36$, $p = 0.04$)], single limb APSI [$F(5,95) = 2.96$, $p = 0.05$)], and single limb MLSI [$F(5,95) = 3.35$, $p = 0.05$)]. The results of the pairwise comparisons conducted on the data from the second test session (Table 1) confirm that no more than 3 familiarization trials are needed but that just 1-2 familiarization trials may achieve a stable score in subjects with previous experience on a BSS. Figure 1 illustrates the improvements observed with the OSI in both dual and single limb stance but similar patterns were observed for the APSI and MLSI in both stances.

Reliability of best scores (from trials 4-6 per test session) revealed that test-retest reliability of dual limb stance outcomes ranged from fair to good (Table 2). However, the best score all three dual limb stance outcomes (OSI, APSI, and MLSI) were significantly improved at the second test session 10-weeks later based on the dependent t-tests (Table 2). The single limb stance best score results demonstrated poor ICC values but not statistically significant different between the test sessions. However, the calculated SEM and MDC values for best score data showed high variability associated with level 1 BSS scores in both dual and single limb stance (Table 2). Mean score data demonstrated poor reliability for all dual limb stance outcomes but good reliability for all three outcomes (OSI, ALSI, MLSI) assessed during single limb

Table 1. **Raw Biodex Stability System trial means and standard deviations for the first and second test session.**

Outcomes	1st Test Session						2nd Test Session					
	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5	Trial 6
Dual limb	6.34	3.95	3.52	3.12	2.57	2.29	2.12	2.14	1.98	1.76	1.59	1.61
OSI (°)	(4.52)	(2.71)*	(3.27)*	(3.2)*	(2.3)*‡	(1.85)*†‡	(1.86)	(2.04)	(2.0)	(1.42)	(1.22)*	(1.24)*
Dual limb	4.34	2.78	2.50	2.15	1.91	1.64	1.47	1.62	1.44	1.27	1.12	1.14
APSI (°)	(3.15)	(1.93)*	(2.41)*	(2.06)*†	(1.64)*†	(1.23)*†‡	(1.22)	(1.55)	(1.39)	(1.03)	(.68)*†	(.82)
Dual limb	3.66	2.23	1.95	1.83	1.34	1.26	1.21	1.07	1.07	.94	.87	.89
MLSI (°)	(2.67)	(1.59)*	(1.89)*	(2.07)*	(1.35)*†	(1.21)*†	(1.16)	(1.16)	(1.19)	(.81)	(.92)*	(.78)
Single limb	4.17	3.03	2.40	2.41	1.97	2.22	2.81	2.06	2.02	1.87	1.90	1.77
OSI (°)	(3.56)	(3.36)	(2.15)*	(1.93)*	(1.41)*	(2.12)*	(2.14)	(2.25)	(1.91)*	(1.65)*	(1.88)*	(1.59)*
Single limb	3.39	2.44	1.84	1.84	1.53	1.71	2.22	1.56	1.55	1.46	1.48	1.36
APSI (°)	(3.12)	(2.71)	(1.65)*	(1.50)*	(1.03)*	(1.72)*	(1.73)	(1.89)	(1.64)*	(1.23)*	(1.50)*	(1.29)*
Single limb	1.92	1.42	1.26	1.22	1.04	1.12	1.35	1.10	1.06	.93	.99	.84
MLSI (°)	(1.46)	(1.46)	(1.14)*	(.92)*	(.81)*	(1.01)*	(.99)	(1.04)	(.84)*	(.84)*	(.87)*	(.74)*†

OSI: Overall Stability Index, APSI: Anterior/Posterior Stability Index, MLSI: Medial/Lateral Stability Index.
* Indicates significant changes when compared to trial 1 ($p < 0.05$). † indicates significant changes when compared to trial 2 ($p < 0.05$). ‡ indicates significant changes when compared to trial 3 ($p < 0.05$).

stance (Table 2). T-test results illustrate that all mean scores for dual limb stance were significantly improved at the second test session. Similarly, the mean MLSI score was significantly improved at the second test session while the OSI and APSI demonstrated a trend towards an improvement at the second test session (Table 2). For all mean score data, the calculated SEM and MDC scores illustrated high variability in both dual and single limb stance.

Discussion

The results of this investigation partially support our a priori hypotheses. More specifically, the results appear to indicate that the commonly used 3 familiarization trials, produce stable BSS scores over 3 subsequent test trials within the same test session in both dual and single limb stance on resistance level 1. However, the test-retest reliability of level 1 BSS scores over a 10-week period was inconsistent between stances and across outcomes (OSI, APSI, MLSI) based on the best or mean score. Further, all significant differences observed between the first and second test session, indicate a continued improvement at the second test session regardless of best or mean scores. This trend was more prominent in dual limb stance but improvements, although not always statistically significant, were also observed by the single limb stance data.

Measurement reliability is the level of steadiness displayed by a device and/or outcome when repeated under identical conditions (Emery, 2003). High test-retest reliability is needed to determine if changes (preferably improvement) in outcome scores were caused by a therapeutic intervention or the result of high variability within the outcome score (Gribble and Hertel, 2003). However, it should be noted that an acceptable test-retest reliability score does not guarantee that learning effects are not occurring within the testing protocol. Indeed, learning effects have been found within a test session for the Star Excursion Balance Test (Gribble and Hertel, 2003) and among test sessions for the Sensory Organization Test (Wrisley et al., 2007). Specific to the Star Excursion Balance Test, Hertel et al. (2000) found a consistent improvement with practice until a plateau appeared during trials 7 through 9. Therefore, Hertel et al. (2000) recommended having participants perform 6 familiarization trials in each direction before recording test scores that would be used for further analysis.

There are several plausible explanations of the

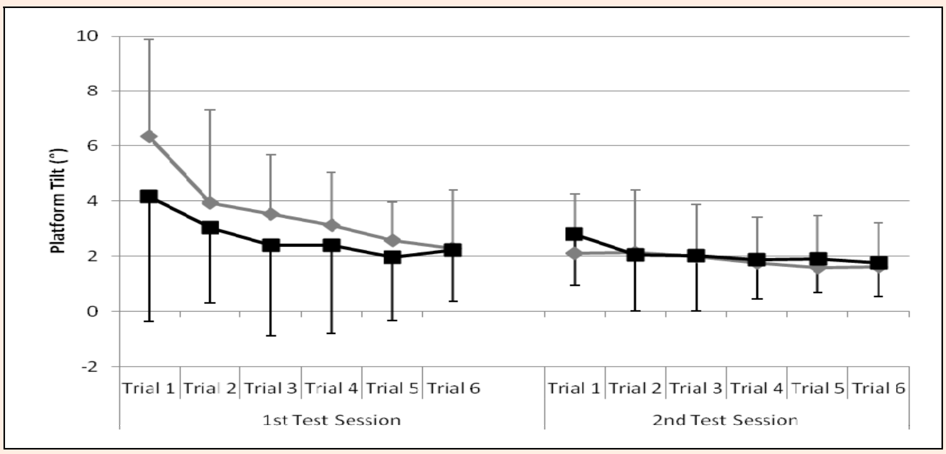

Figure 1. **Visual representation of the mean trial data. The dual limb Overall Stability Index (black line) and single limb stance overall stability index (grey line) are depicted but these trends are similar across all outcomes.**

Table 2. Session means, standard deviations (SD), intraclass correlation coefficient (ICC), standard error of mean (SEM), minimal detectable changes (MDC) for Biodex® Stability System scores.

Outcome Type	Stance & Outcome	1st Session Mean (±SD)	2nd Session Mean (±SD)	p	ICC	95% CI	SEM	MDC
Best Score	Dual Limb OSI (°)	1.7 (1.18)	1.32 (.85)	<.01	.80	.44-.92	.89	2.47
	Dual Limb APSI(°)	1.2 (.78)	.95 (.56)	<.01	.80	.45-.92	.59	1.64
	Dual Limb MLSI (°)	.91 (.75)	.69 (.53)	<.03	.75	.45-90	.61	1.69
	Single Limb OSI (°)	1.63 (1.27)	1.40 (1.24)	.34	.63	.28-.83	1.37	3.80
	Single Limb APSI (°)	1.21 (.93)	1.05 (.98)	.43	.58	.44-.91	1.09	3.02
	Single Limb MLSI (°)	.89 (.75)	.68 (.57)	.08	.68	.20-.81	.69	1.91
Average Score	Dual Limb OSI (°)	2.53 (2.07)	1.61 (1.18)	<.01	.67	.17-.87	1.82	5.04
	Dual Limb APSI (°)	1.81 (1.4)	1.15 (.76)	<.01	.65	.13-.87	1.24	3.44
	Dual Limb MLSI (°)	1.41 (1.26)	.88 (.75)	<.01	.67	.21-.87	1.11	3.08
	Single Limb OSI (°)	2.09 (1.64)	1.77 (1.50)	.06	.88	.71-.95	1.06	2.94
	Single Limb APSI (°)	1.61 (1.24)	1.38 (1.15)	.09	.88	.71-.95	.80	2.22
	Single Limb MLSI (°)	1.08 (.85)	.87 (.75)	<.03	.86	.64-.94	.58	1.61

OSI: Overall Stability Index, APSI: Anterior/Posterior Stability Index, MLSI: Medial/Lateral Stability Index

generally poor test-retest reliability and the high MDC scores observed in the current investigation. One possible explanation is the extreme instability of a level 1 resistance on the BSS. Given the difficulty of the task and high MDC scores observed, three practice trials per stance may be insufficient to allow the participants to generate adequate motor programs that will persist over long periods of time (e.g. 10-weeks). The significant improvements observed between the first and second test session in multiple outcomes provide evidence which supports this hypothesis. The literature clearly indicates that balance is not only an innate ability but also a learned and gained skill (Tjenstrom et al., 2002; Ruiza and Richardson, 2005). The more novel and challenging the task, the greater the time needed to overcome the associated learning effect (Valovich et al., 2003). In addition, Hansen (2000) has shown that it takes greater practice time when learning a dynamic, relative to static, balance task due to the inconsistent proprioceptive input and subsequent increase in difficulty with coordinating correctly timed movements. Indeed, practice has a profound effect on the development of efficient postural control strategies (e.g. increasing the stiffness in the ankles and knees) (Tjenstrom et al., 2002; Wrisley et al, 2007).

Similar to the results of the current investigation, a recent investigation (Pickerill and Harter, 2011) demonstrated low to moderate reliability of BSS limits of stability scores. Based on the findings, researchers did not recommend using the LOS measures from BSS as the gold standard. Regardless of the reliability estimates, the very high MDC scores strongly suggest that clinicians should not use level 1 BSS scores as an objective tool to monitor rehabilitation progress or intervention effectiveness. Indeed, the high MDC scores indicate that a substantial, and impractical, change in level 1 BSS scores are needed to exceed the error of the measurement. For example, all of the outcomes (best and mean score for OSI, APSI, and MLSI) had MDC scores larger than the mean score for the 1st test session. Further, some outcomes suggest that a change of up to 150% of the recorded mean is needed to be confident that inter-session change (Table 2) is due to the intervention delivered and not the measurement error.

We are confident that our sample is representative of the larger population based on the favorable comparison between our current data and those published previously. For example, the scores of Sherafat et al, using a dual limb stance on stability level 3 observed slightly higher (worse) OSI (3.33°), APSI (2.56°), and MLSI (2.24°) than those observed in the current study (Table 2) (Sherafat et al., 2013). However, current participants were given real time visual feedback during 20-second trials while Sherafat et al. (2013) denied visual feedback to their participants during 30-second trials. Our single limb stance data (Table 2) is consistent with those recorded during 20-second trials [OSI (1.28°), APSI (0.98°), and MLSI (0.66°)] (Arifin et al., 2013). However, Malliou et al. (2004) reported extremely high mean OSI (~7.9°), APSI (~6.7°), and MLSI (~3.9°) scores during a single limb stance on level 1 in young soccer players with eyes open but no information was provided about visual feedback. The extreme variability between our current data and those reported by Malliou et al. (2004) cannot be easily explained but Cachupe et al. (2001) has reported that OSI scores fluctuate between 2.2° to 17.7° on level 2 of the BSS. Our reliability estimates are also similar to those observed in the literature. For example, Sherafat et al. (2013) found good reliability with OSI scores despite significant improvements from pre to post test. Our data also observed significant improvements from the first to second test session while recording poor ICC values in dual limb stance when using a mean score. Single limb stance ICC values (OSI: 0.90, APSI: 0.86, MLSI: 0.76) reported by Cachupe et al. (2001) and are very similar to those observed in the current study for single limb stance (Table 2). Given the cumulative evidence amongst the results of the current study and the literature, it appears that lower stability levels on the BSS may not be appropriate to be used as an objective marker of progression or consistency over time. However, it is important to note that the current results do not condemn the use of a level 1 resistance of the BSS as a training tool.

A limitation of the current investigation was the relatively small sample size of young sedentary but otherwise healthy adults which may affect the generalizability of the findings. Another limitation was the consistent test order that participants underwent (dual limb following by single limb stance). This specific test protocol order may explain the higher reliability of single limb stance scores, relative to dual limb stance scores. While speculative, this pattern could suggest that perhaps as many as 9 familiarization trials (i.e. 6 dual limb and 3 practice single limb trials conducted before the 3 single limb test trials during the first test session) are needed to become proficient at maintaining single limb stance on a level 1 resistance of the BSS over prolonged periods of time (i.e. 10-weeks or greater). Finally, participants were given real-time feedback regarding their center of pressure on the BSS computer interface and allowed to see the balance score associated with each trial. These factors may have artificially shortened the learning curve associated with lower stability levels on the BSS. In other words, without this feedback additional familiarization trials may have been needed. Future research should attempt to address these limitations in a large and more diverse sample size to better capture the true reliability, precision, and MDC score associated with level 1 BSS scores in multiple stances. Future research should also determine the optimal number of practice trials that would result in acceptable test-retest reliability as well as acceptable MDC scores as well as the amount of retention that occurs from different amounts of familiarization trials.

Conclusion

The results of this study showed that a stable within session score on a low stability BSS level can be achieve with as few as 3 practice trials. However, the reliability of low stability level scores over time (i.e. 10-weeks) needs additional practice trials during both test sessions. Therefore the importance of familiarization trials should not be underestimated by researchers/clinicans. This data further suggests that lower stability levels on the BSS may not be appropriate for use as an objective marker of progression due to poor reliability of the scores over time. However, it is important to note that the current results do not condemn the use of a level 1 resistance of the BSS as a training tool.

Practical applications

- At least 3 stance specific familiarization trials are needed to achieve a stable level 1 BSS score within a single test session.
- At least 2 stance specific familiarization trials are needed to achieve a stable level 1 BSS score if participants return for a second test session at least 10 weeks later.
- Over a 10-week period, “best” scores appear to be more reliable than mean scores during dual limb stance but the opposite is true for single limb stance.
- All outcomes (i.e. mean and best score) in both stances are associated with MDC scores greater than the observed mean scores suggesting extremely high variability.
- This result strongly suggests that level 1 BSS scores should not be used as a test setting to assess rehabilitation progress.

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Key points

- Level 1 BSS scores should not be used as a test setting to assess rehabilitation.
- Familiarization trials should not be underestimated by researchers/clinicans.
- Lower stability levels on the BSS may not be appropriate for use as an objective marker of progression due to poor reliability of the scores over time.

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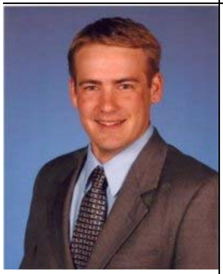

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