UNIVERSITY OF ALBERTA

Injury Prevention in Adolescent Sport

By

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

DEGREE OF DOCTOR OF PHILOSOPHY

in

DEPARTMENT OF MEDICAL SCIENCES
PUBLIC HEALTH SCIENCES

EDMONTON, ALBERTA

SPRING 2004

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ISBN: 0-612-96263-6

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Abstract

Objectives: The objectives of this research are: 1. to systematically review the literature to examine risk factors for injury in adolescent sport, 2. to review the literature to determine if there is a clinical standing balance measurement appropriate for use in sports medicine, 3. to develop and examine the reliability of a static and dynamic clinical balance measurement protocol in healthy adolescents, and 4. to examine the effectiveness of a proprioceptive balance training program in improving static and dynamic balance and reducing sports injury in adolescents.

Methods: We used a prospective longitudinal repeated measures study design to examine intra-rater and inter-rater reliability, concurrent validity, norms and influencing factors of timed static and dynamic unipedal balance measurements in 123 healthy adolescents randomly selected from 10 Calgary high schools. A cluster randomized controlled trial (RCT), in which we randomized 127 subjects to intervention groups by school, was used to examine the effectiveness of a home-based proprioceptive balance training program using a wobble board in healthy adolescents. Outcome measurements included timed eyes-closed static (ECS) and dynamic (ECD) balance (using a foam support surface) and sports injuries.

Results: ECS and ECD balance are appropriate clinical balance measurements for use in healthy adolescents. Adequate intra-rater (ICC = 0.69 and 0.46) and excellent inter-rater (ICC = 0.999 and 0.996) reliability were found for both tests. Previous lower extremity injury was a key factor influencing balance. The cluster RCT provided evidence of a dose-response relationship between a six-week home-based proprioceptive balance training program using a wobble board and improvement in ECS and ECD balance. This program decreased the incidence of injury in adolescent sport five fold (RR= 0.2; 95% CI 0.05-0.88).

Conclusions: The findings of the cluster RCT are consistent with other studies examining multifaceted prevention strategies, including a balance-training component. These results confirm balance training alone, however, as an effective prevention strategy in reducing the incidence of injury in adolescent sport. In addition, the results emphasize the importance of considering cluster randomization in the design and analysis of cluster randomized controlled trials.

DEDICATION

I dedicate this thesis to my parents, Jim and Peggy Stitt, may they rest in peace. They taught me to pursue my dreams but never lose site of what is truly important. As such, I also dedicate this thesis to my family; Kris, Charlie, Jamie and Logan. Without them, my work would have no meaning

ACKNOWLEDGEMENTS

I acknowledge the Calgary Board of Education high school principals and physical education teachers. Without their support, this research would not have been possible. I am especially grateful to the many high school students who consented to participate in this research. I hope they will benefit from the findings of this work.

I would like to thank my PhD Committee at the University of Alberta, Dr. David Cassidy, Dr. Terry Klassen, Dr. Brian Rowe and Dr. Rhonda Rosychuk for their continued support in my academic endeavors. A special thanks to Dr. Winne Meeuwisse at the Sport Medicine Centre, University of Calgary for his ongoing encouragement and support academically, professionally and personally. I also acknowledge the support and encouragement of Dr. Colin Macarthur and Dr. Pat Hessel in the early stages of my PhD. There are many colleagues from the University of Alberta and the University of Calgary to whom I am grateful for their support at various stages of my PhD (Donna Dryden, Peter Faris, Stacey Page, Sarah Rose, Irene Wenger).

I also acknowledge the financial support of the Canadian Institutes of Health Research (CIHR) in partnership with the Physiotherapy Foundation of Canada, the Alberta Heritage Foundation for Medical Research, the CIHR Institute of Musculoskeletal Health and Arthritis, Bone and Joint Training Program, the Walter Johns Graduate Scholarship Fund, University of Alberta, and Dr. Terry Klassen. I would like to thank Fitter International Inc. for their shared vision in the prevention of injury in adolescent sport. Their financial support in providing wobble boards and Airex Balance Pads, at a significantly reduced cost, also made this research possible.

I acknowledge the support and patience of my life partner Kris Loken. Without

her continued support, this work would not have been possible. I acknowledge the support of my children's father, Herb Emery, without his support and encouragement I would not have had the confidence to pursue my PhD. Finally, I acknowledge my children Charlie, Jamie and Logan. I hope they too will pursue their dreams.

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Introduction

1.1 Background

There is a high level of adolescent participation in sport.[2,11,50,54] In Canada, 65% of adolescents participate in regular physical activity at least three times a week.[54] Participation in sport is critical in the future health of our adolescent population. For example, there is significant evidence that decreased physical activity is strongly associated with all-cause morbidity and mortality.[8,51] However, adolescents involved in sport are exposed to the increased risk of sports injury as a result of their participation. The risk of acute trauma sustained in adolescent sport requires special consideration, given factors associated with skeletal immaturity and developmental variability (i.e., size differences) in some sports (i.e., contact sports).[59] In addition, there is growing concern about overuse injury in this population of athletes.[59] This concern likely reflects increased intensity of training and competition in sport at younger ages, increased skill level at younger ages and longer (often year round) training seasons.[59]

Sports injury in adolescents has a reportedly high incidence rate resulting in a significant impact on the individual, their parents and the health care system.[1,5,7,9,23,26,28,29,38,40,42-44,46,48,52,55,60,63,65,68] In Canada, sports injury is the leading cause of injury in adolescents.[38] It is also the leading cause of injury in adolescents leading to a hospital emergency department admission.[6,19,20] This likely reflects the high rates of sport participation in this age group and the predisposition to injury as a result of factors such as skeletal immaturity and developmental variability.[59] There is evidence that sports injury, specifically knee and ankle injury, may result in an increased risk of development of osteoarthritis later on in life.[13,16,25] It is also estimated that 8% of adolescents drop out of recreational sporting activities annually because of injury occurrence.[28] As such, adolescent sports injury could reduce adolescents' future involvement in physical activity leading to less than optimal health in the future. Research that will lead to prevention of sports injury in adolescents is essential in maintaining a healthy lifestyle in young Canadians.

1.2 Research Purpose

The purpose of this research is four fold: 1. to systematically examine the literature to determine known risk factors for injury in adolescent sport,
2. to review the literature to determine if there is an appropriate clinical standing balance measurement appropriate for use in sports medicine, 3. to develop and determine the reliability of a static and dynamic clinical balance measurement protocol, appropriate for use in healthy adolescents, and 4. to examine the effectiveness of a proprioceptive balance training program in healthy adolescents to improve static and dynamic balance and reduce the risk of sports injury.

1.3 Research Rationale

Clearly there is a need for research examining risk factors for injury in adolescent sport and prevention strategies to reduce the immediate and future health impact of sports injury in the adolescent population. Risk factors such as flexibility, strength, endurance, and balance are potentially modifiable by injury prevention strategies to reduce injury rates in sport.[47] Strength of research design in the literature examining modifiable risk factors and prevention strategies for injury in adolescent sport is limited. There are very few strong prospective cohort studies and randomized controlled trials (RCT) reported.[31,32,37,42,44,64] However, in combination with the literature examining risk factors for injury in adult sport, there is some evidence that pre-season conditioning and proprioceptive balance training may be key components in the reduction of some injuries in some sports.[3,10,12,17,18,30,31,33,36,37,42,49,62,64,66]

One may define proprioception as the afferent input of joint position sense (i.e., awareness of joint position or movement). However, many consider it in a broader sense that includes neuromuscular and postural control, including balance.[38] Balance can be defined as the ability to maintain the body's center of gravity over its base of support with minimal sway or maximal steadiness.[35,56] The ability to maintain balance is based on the complex interaction between the somatosensory, vestibular and visual functions and the broader concept of coordination of movements with muscle activity.[30,35] In many sporting activities an athlete's lower extremity joints and soft tissues are subject to significant dynamic forces during running, jumping, landing, rapid stopping and/or pivoting (i.e., sports such as basketball, soccer, volleyball, track, gymnastics and hockey). It is sports involving such forces that are the most relevant in the discussion of standing balance and proprioceptive balance training in sport. The ability of a knee or ankle joint, for example, to remain stable during such activity is referred to as dynamic joint stability.[67] Dynamic proprioceptive balance training leading to the production of more coordinated and consistent movement patterns in athletic participation, may be the key intervention which will improve postural control in athletic situations and prevent some injuries in sport.[41]

Proprioceptive balance training is a significant element of rehabilitation in sports medicine and is recently recognized as an integral component in pre-season injury prevention programs for many athletes, including adolescents.[3,12,32,33,49,58,62,64,66] There is some evidence to suggest that decreased static balance is a risk factor for recurrent ankle sprain injury in soccer.[61] In sport, an athlete is typically visually attentive to the play and relies on joint position sense and muscular control for joint stability. As such, impaired dynamic unipedal balance, minimizing visual feedback to increase reliance on the vestibular and somatosensory feedback systems, may be more relevant as a significant risk factor for injury in sport.[41,57,67]

By improving dynamic postural control and balance and producing more coordinated and consistent movement patterns during athletic participation, some injuries may be prevented.[48] Dynamic proprioceptive balance training may be the key intervention which will improve postural control in athletic situations and prevent some injuries in sport. There is some evidence that static balance does improve following proprioceptive balance training using a wobble board.[3,24,27,34,45,53,61] Most of these studies, however, exclusively examine improvement in static balance following an ankle sprain injury.[27,53,61] Hoffman et al[34] and Balogun et al[4] demonstrate that a proprioceptive balance training program in healthy high school students resulted in significantly improved static balance in the intervention group. However, the dose-response relationship between the amount of training and the effectiveness of training in improving balance remains unclear.

Some studies have demonstrated that training programs, including a proprioceptive balance training component, are an effective prevention strategy for specific injury in specific sport.[3,12,33,49,62,64,66] The relative risks (RR) reported range from 0.06 to 0.46, demonstrating a protective effect of training in the reduction of sports injury.[3,12,33,49,62,64,66] Only one of these studies examines adolescents exclusively.[64] The prevention programs are multifaceted, and there is no measurement of balance reported in any of these trials. In addition, in many of these studies subjects are randomized to intervention groups by cluster (i.e., usually by team), to avoid contamination between intervention groups, and this is not controlled for in the analysis. Individuals within clusters have the tendency to respond similarly and the natural variability in response among clusters exceeds the variability in response within clusters.[14,15] This leads to decreased efficiency of cluster randomization relative to individual randomization and it is critical that this is accounted for in the analysis.[14,15] As a result, the effectiveness of proprioceptive balance training on the improvement of static or dynamic balance and prevention of injury in adolescent sport remains unclear.

Prior to assessing the effectiveness of a proprioceptive balance training program in improving balance and preventing injury in adolescent sport, an appropriate clinical measurement of static and dynamic balance ability needed to be established. A pilot study examining a timed static and dynamic unipedal balance test protocol in healthy adolescents was critical prior to examining the effectiveness of a proprioceptive balance training program in healthy adolescents.

1.4 Specific Research Questions

This research addresses several specific research questions.

1. What are the risk factors and potential prevention strategies for injury in adolescent sport?
2. Is there a clinical standing balance measurement appropriate for use in sports medicine?
3. Are timed unipedal static and dynamic balance tests, appropriate for use in healthy adolescents, reliable clinical measurements of balance?

4. What are the norms for a timed clinical static and dynamic unipedal balance test protocol in healthy adolescents?

5. What is the influence of several factors including age, gender, leg dominance, body-mass index, foot size (length and width), previous injury, sport participation level, sport participation specificity, and visual feedback on static and dynamic balance ability in healthy adolescents?

6. Is a home-based, proprioceptive, balance-training program using a wobble board effective in improving balance based on a timed static and dynamic eyes-closed unipedal clinical balance measurement in healthy adolescents?

7. Is a home-based, proprioceptive, balance-training program using a wobble board effective in reducing injury in healthy adolescents participating in sport?

1.5 Summary of Thesis Format

This thesis is organized in a paper format. Chapters 2 through 5 are separate manuscripts addressing specific research questions. Chapter 2 is a systematic review of the literature examining risk factors for injury in adolescent sport. This paper has been published in the Clinical Journal of Sports Medicine.[19] Chapter 3 is a review of the literature examining clinical standing balance measurements appropriate for use in sports medicine. This paper has been accepted for publication in the Journal of Science and Medicine in Sport.[20] Chapter 4 is original research examining the reliability of a static and dynamic clinical balance measurement protocol in healthy adolescents. This pilot study also addresses norms for a unipedal static and dynamic clinical balance measurement in healthy adolescents as well as factors influencing these balance measurements. The research design used in this pilot study is a longitudinal repeated measures design. Chapter 5 is original research examining the effectiveness of a home-based proprioceptive balance-training program in healthy adolescents in improving balance and reducing the risk of injury in adolescent sport. A cluster RCT is the research design used in this study. Chapter 6 summarizes and draws conclusions about the research presented in all four thesis papers.

References

1. Backx FJG, Erich WBM, Kemper ABA, Verbeek ALM. Sports injuries in school-aged children. An epidemiologic study. *Am J Sports Med* 1989;17:234-240.

2. Backx FJG, Beijer HJM, Bol E, Erich WBM. Injuries in high-risk persons and high-risk sports. A longitudinal study of 1818 school children. *Am J Sports Med* 1991;19:124-130.

3. Bahr R, Lian O. A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports* 1997;7:172-177.

4. Balogun JA, Adesinasi CO, Marzouk DK. The effects of a wobble board exercise training program on sytatic balance perfoprmance and strength of lower extremity muscles. *Physiotherapy Canada* 1992;44:23-30.

5. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child* 1993;68:130-2.

6. Bienfeld M, Pickett W, Carr PA. A descriptive study of childhood injuries in Kingston, Ontario, using data from computerized injury surveillance system. *Chronic diseases in Canada* 1996;17:21-27.

7. Bijur PE, Trumble A, Harel Y, Overpeck MD, Jone D, Scheidt PC. Sports and Recreation Injuries in US Children and Adolescents. *Arch Pediatr Adolesc Med* 1995;149:1009-16.

8. Blair SN, Kohl HW, Barlow CE et al. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. JAMA 1995;273:1093-1098.

9. Brust JD, Leonard BJ, Pheley A, Roberts WO. Children's Ice Hockey Injuries. *AJDC* 1992;146:741-747.

10.Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of highschool football knee injuries. *Am J Sports Med* 1978;6:180-4.

11. Canadian Fitness and Lifestyle Research Institute website 2001; http:www.cflri.ca/cflri/resources/pub.php#98pamrep.

12. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee surg, Sports Traumatol, Arthroscopy* 1996;4:19-21.

13. Daniel DM, Stone ML, Dobson BE et al. Fate of the ACL injured patient. A prospective outcome study. Am J Sports Med 1994;22:632-644.

14. Donner A, Brown KS, Brasher P. A methodological review of non-therapeutic intervention trials employing cluster randomization, 1979-1989. *Int J Epidemiol* 1990;19:795-800.

15. Donner A, Klar N. *Design and Analysis of Cluster Randomization Trials in Health Research.* Oxford University Press, Inc., New York, 2000.

16. Drawer F, Fuller CW. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med* 2001;35:402-408.

17. Emery CA. Does decreased muscle strength cause acute muscle strain injury in sport? A systematic review of the evidence. *Phys Ther Rev* 1999;4:79-85.

18. Emery CA, Meeuwisse WH. Risk factors for groin and abdominal strain injury in the National Hockey League. A Multivariate approach. *Med Sci Sport Exerc* 1999;33:1423-1433.

19. Emery CA. Risk factors for injury in child and adolescent sport: A systematic review of the literature. *Clin J Sports Med* 2003;14:256-268.

20. Emery CA. Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. J Sci Med Sport 2003;in press.

21. Gallagher SS, Guyer B, Kotelchuck M, Bass J, Lovejoy FH, McLoughlin E, Mehta K. A Strategy for the reduction of childhood injuries in Massachusetts: SCIPP. *New Engl J Med* 1982;307:1015-1019.

22. Gallagher SS, Finison K, Guyer B, Goodenough S. The incidence of injuries among 87,000 Massachusetts children and adolescents: results of the 1980-81 statewide childhood injury prevention program surveillance system. *Am J Public Health* 1984;74:1340-1347.

23. Garrick JG, Requa RK. Injuries in High School Sports. *Pediatrics* 1978;61:465-9.

24. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med* 1988;9:141-144.

25. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long term incidence of gonarthrosis. *Sports Med* 1999;27:143-156.

26. Goldberg B, Rosenthal PP, Robertson LS, Nicholas JA. Injuries in Youth Football. *Pediatrics* 1988;81:255-61.

27. Goldie PA, Evans OM, Bach TM. Postural control following inversion injuries of the ankle. *Arch Phys Med Rehabil* 1994;75:969-75.

28. Grimmer KA, Jones D, Williams J. Prevalence of adolescent injury from recreational exercise: an Australian perspective. *J Adolesc Health* 2000;27:1-6.

29. Grubbs N, Nelson RT, Bandy WD. Predictive validity of an injury score among high school basketball players. *Med Sci Sports Exerc* 1997;29:1279-85.

30. Hahn T, Foldspang A, Vestergaard E, Ingermann-Hansen T. One-legged standing balance and sports activity. *Scand J Med Sci Sports* 1999;9:15-18.

31. Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med* 2000;28:659-662.

32. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Am J Sports Med* 1999;27:699-705.

33. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports* 1999;9:104-109.

34. Hoffman M, Payne VG. The effects of proprioceptive ankle disk training on healthy subjects. *J Orthop Sports Phys Ther* 1995;21:90-94.

35. Horak FB. (1987). Clinical measurement of postural control in adults. *Phys Ther* 1987;67:1881-1885.

36. Jones BH, Bovee MW, Harris JM, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993;21:705-710.

37. Junge A, Rosch D, Peterson L, Graf-Baumann T, Dvorak J. Prevention of soccer injuries: a prospective intervention study in youth amateur players. *Am J Sports Med* 2002;30:652-659.

38. King MA, Pickett W, King AJC. Injury in Canadian youth: A secondary analysis of the 1993-94 health behaviour in school-aged children survey. *Can J Public Health* 1998;89:397-401.

39. Laskowski ER, Newcomer-Aney K, Smith J. Refining rehabilitation with proprioceptive training. Expiditing return to play. *Physician and Sportsmed* 1997;25:89-102.

40. Lenaway DD, Ambler AG, Beaudoin DE. The epidemiology of school-related injuries: New perspectives. *Am J Prev Med* 1992;8:193-8.

41. Lephart SM. Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sport Med* 1998;25:149-155.

42. Lysens R, Steverlynck A, van den Auweele Y, Lefevre J, Renson R, Claessens A, Ostyn M. The predictability of sports injury. *Sports Med* 1984;1:6-10.

43. Macnab AJ, Cadman R. Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. *Injury Prevention* 1996;2:286-289.

44. Maffulli N, King JB, Helms P. Training in elite young athletes (the training of young athletes (TOYA) study): injuries, flexibility and isometric strength. *Br J Sports Med* 1994;28:123-136.

45. Mattacola CG, Wills Lloyd J. Effects of a 6-week strength and proprioception training program on mesasures of dynamic balance: A single-case design. *J of Athletic Training* 1997;32:127-135.

46. McLain LG, Reynolds S. Sports injuries in a high school. *Pediatrics* 1989;84:446-450.

47. Meeuwisse WH. Predictability of sports injuries. What is the epidemiological evidence. *Sports Med* 1991;12:8-15.

48. Mummery WK, Spence JC, Vincenten JA, Voaklander DC. A descriptive epidemiology of sport and recreation injuries in a population-based sample: Results from the Alberta Sport and Recreation Injury Survey (ASRIS). *Can J Public Health* 1998;89:53-6.

49. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen O, Bahr R. Prevention of ACL injuries in female handball players: a prospective intervention study over 3 seasons. *Clin J Sports Med* 2003;13:71-78.

50. Northern Sydney Area Health Services. *New South Wales Youth Sports Injury Report.* July 1997.

51. Paffenbarger RS, Kamput JB, Lee IM et al. Changes in physical fitness and other lifestyle patters influence longevity. *Med Sci Sports Exerc* 1994;26:857-865.

52. Roberts WO, Brust JD, Leonard B. Youth ice hockey tournament injuries:rates and patterns compared to season play. *Med Sci Sports Exerc* 1999;31:46-51.

53. Rozzi S, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *J Orthop and Sport Phys Ther* 1999;29:478-486.

54. Statistics Canada, Culture and Tourism Division. *Canada's culture and heritage and identity: A statistical perspective.* Minister of Industry, Ottawa, 1997.

55. Sheps SB, Evans GD. Epidemiology of school injuries: a 2-year experience in a municipal health department. *Pediatrics* 1987;79:69-75.

56. Shumway-Cook A, Anon D, Haller S. Postural sway biofeedback: it's effect on Re-establishing stance stability in hemiplegic patients. *Arch Phys Med Rehab* 1988;69: 395-400.

57. Shumway-Cook A, Woollacott M. *Motor control: Theory and practical applications.* Baltimore,Md: Williams and Wilkins, 1995.

58. Soderman K, Werner S, Pietila T, Engstrom B, Alfredson H. Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surg Sports Traumatol Arthrosc* 2000;8:356-363.

59. Stanitski CL, DeLee JC, Drez D eds. *Pediatric and Adolescent Sports Medicine. Vol 3.* WB Saunders Co:Philadelphia,1994.

60. Sullivan JA, Gross RH, Grana WA, Garcia-Moral CA. Evaluation of injuries in youth soccer. *Am J Sports Med* 1980;8:325-7.

61. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and it's value in predicting injury. *Med Sci Sports Exerc* 1984;16:64-66.

62. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;13:259-62.

63.Watson AWS. Sports injuries during one academic year in 6799 Irish school children. *Am J Sports Med* 1984;12:65-71.

64. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999;9:41-47.

65. Weir MA, Watson AWS. A twelve month study of sports injuries in one Irish school. *IJMS* 1996;3:165-9.

66. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *Journal of Orthopaedic and Sport Physical Therapy* 1996;23:332-336.

67. Williams GN, Chmielewski T, Rudolph KS et al. Dynamic knee stability: Current theory and implications for clinicians and scientists. *J Orthop Sport Phys Ther 2001;*31:546-566.

68. Zaricznyj B, Shattuck LJM, Mast TA, Robertson RV, D'Elia G. Sports-related injuries in school aged children. *Am J Sports Med* 1980;8:318-324.

Chapter 2

Risk Factors for Injury in Child and Adolescent Sport:

A Systematic Review of the Literature

This paper has been published in Clinical Journal of Sports Medicine 2003;13:256-268.

2.1 Introduction

Sports injuries in children and adolescents may be predictable and potentially preventable.[50, 55] Prior to examining potential prevention strategies in child and adolescent sport we must have a good understanding of the extent of the problem (incidence rates for injury), who is at risk (sport participation), and risk factors for injury in this population.

Participation in physical activity by children and adolescents has important implications for individual and public health benefits. There is epidemiological evidence that better levels of physical fitness are associated with lower all cause mortality, morbidity and disease specific morbidity.[13,14,61] Child and adolescent sports injury may reduce present and future involvement in physical activity which may have an impact on future health. Adolescent sport participation rates are high, providing ample opportunity for injury in this population. Based on the 1997 Canadian Population Health Survey, 65% of adolescents reported participation in regular physical activity at least 12 times per month.[75] Similar findings are reported in other countries.[5,10,34,35,60] Canadian adolescents spend on average 14 hours per month participating in physical activity.[19] Though these physical activities may include walking, bicycling and yard-work, a large proportion of Canadian adolescents report participation in sports more prone to injury such as swimming (46%), jogging (44%), basketball (37%), volleyball (26%) and weight training (25%).[19]

Sports injury is the leading cause of injury in adolescents.[9,10,12,26,27,45,82] Incidence rates reported for studies examining all school-aged children (K-12) range from 0.79 to

9.7 injuries/100 children /year.[10,15,21,46,69,85,91] The reported incidence rate for Canadian grade 10 adolescents is 15.8/100 students/year.[45] Studies which have examined only sport injuries reporting to hospital Emergency Departments report rates from 7.03 to 8.55 injuries/100 adolescents/year.[9,26,74,81] Sport-specific injury incidence rates reported in studies examining adolescent sports participants only range from 2.6 to 100+injuries/100participants/year.[5,8,16,17,28,30,36,39,40,50,51,52,53,58,60-63,65,66,76-78,87] In adolescent studies which have examined level of exposure, sport-specific incidence densities reported range from 2.38 to 142.86 injuries/ 1000 participation hours.[3,5,16,41,44,47,48,52,54,59,62,68,85,90] Sport specific rates of injury vary considerably with the highest rates of injury reported for boys participating in hockey,[16,65] basketball[4,5,91] and football[30,52,91] and for girls participating in gymnastics,[9,52,91] basketball[4,5] and soccer.[4,5,44,68] The lowest rates of injury are consistently reported in swimming, tennis and badminton.[4,5,8,91]

Acute trauma is one type of injury sustained in child and adolescent sport. In addition, there is growing concern about overuse injury in this population of athletes.[73] This likely reflects increased intensity of training and competition in sport at younger ages, increased skill level at younger ages and longer (often year round) training seasons.[73]

Risk factors in sport are any factors which may increase the potential for injury.[55] Risk factors may be extrinsic (ie. weather, field conditions) or intrinsic (ie. age, conditioning) to the individual participating in the sport. Modifiable risk factors refer to those which have the potential to be altered by injury prevention strategies to reduce injury rates.[55] Non-modifiable risk factors, which cannot be altered, may affect the relationship between modifiable risk factors and injury. Identification of these factors will assist in defining high risk populations. Potential risk factors (adapted from Lysens et al[50] and Caine et al[18]) are listed in Table 2.1.

Table 2.1: Potential risk factors for injury in child and adolescent sport

Extrinsic Risk Factors	**Intrinsic Risk Factors**
Non-modifiable • Sport played (contact/no contact) • Level of play (recreational/elite) • Position played • Weather • Time of season/ Time of day	Non-modifiable • Previous Injury • Age • Sex
Potentially modifiable • Rules • Playing time • Playing surface (type/condition) • Equipment (protective/footwear)	Potentially Modifiable • Fitness level • Pre-participation sport specific training • Flexibility • Strength • Joint stability • Biomechanics • Balance/Proprioception • Psychological/social factors

Much of the literature addressing child and adolescent sports injury is sport specific and based on descriptive data which portray primarily the extent of the injury problem. Reviews in the literature examining injury risk often have not been systematic in nature (ie. lack presentation of search strategies and/or assessment of study validity), typically address individual sports and include adult studies. Arguably, there is a need for a global comprehensive review of risk factors for injury in child and adolescent sport, to provide direction for further research in injury prevention in this population.

The objective of this systematic review is to identify risk factors for injury in child and adolescent sport as well as potential prevention strategies which may modify risk factors and reduce injury in this population. Studies that have examined an association between risk factor and injury or a prevention strategy and injury in child and adolescent sport are reviewed and assessed regarding their validity, generalizability and strength of scientific evidence (ie. based on study design, validity and causality). Recommendations for future epidemiologic research to assist in determining strategies for prevention of injury in child and adolescent sport are made.

2.2 Methods

2.2.1 Data sources

Seven electronic databases were searched by the author to identify potentially relevant papers. These databases included: MEDLINE (1966-2001), CINAHL (1982-March 2002), Psychinfo (1967-present), Cochrane database for Systematic and Complete Reviews, the Cochrane Controlled Trials Registry, HealthSTAR (1975-present), and sportdiscus (1980-2001). A combination of Medical Subject Headings (MeSH) and text words were used in this search. Medical subject headings and text words included; "athletic injuries", "risk factors", "adolescent", and "child". Additional text word included which is not a MeSH was "sports injury". No limitations were put on articles searched. If 500 articles or less were identified by a given search strategy, the study title and abstract were reviewed to identify potentially relevant articles to subject area. The methods sections of potentially relevant articles were then reviewed to identify studies that met selection criteria.

2.2.2 Study Selection

Inclusion criteria were:

1. Human epidemiological studies that assess the association between any potential injury risk factor or prevention strategy and injury in child and adolescent sport.
2. Outcomes include a measure of injury sustained in sport.
3. Exposure measure includes some objective measurement of risk factor or intervention.
4. Study design includes a comparison group (cross-sectional, case control, cohort, quasi experimental and randomized clinical trial designs all considered).
5. Study contains original data.

Exclusion criteria were:

1. Sport related injury involving the following high speed sports: Bicycling, scootering, skateboarding, inline skating, tobogganing, skiing, snow boarding, and boating.
2. Exclusive examination of head or dental injuries or medical emergencies.
3. Prevention strategy involving protective equipment (ie. helmets, knee braces) to modify risk of sport injury.

The rationale for exclusion criteria were that risk factors and prevention strategies involving particular high speed sports and protective equipment were specialized enough to be addressed independently and beyond the scope of this review.

2.2.3 Data Extraction

The data extracted included study design, study population, exposure(s) of interest measured, outcome measure, and results. Point estimates (including 95% confidence intervals) of odds ratios or relative risks were calculated where study data were adequate to do so, if these were not reported in the reviewed studies. The quality of evidence was assessed based on criteria regarding internal validity, external validity, and Hill's criteria for causal association (Table 2.2).[67]

Table 2.2: Hill's criteria for causality as defined in Rothman[43]

Criteria	Definition
1. Strength	Strong associations more likely to be causal.
2. Consistency	Repeated observation of association in different populations under different circumstances.
3. Specificity	A cause leads to a single effect not multiple effects.
4. Temporality	A cause precedes an effect in time.
5. Biologic gradient	The presence of a unidirectional dose-response curve.
6. Plausibility	Biologic plausibility of the hypothesis.
7. Coherence	No conflict with what is known of the natural history and biology of the disease.
8. Experimental evidence	Basic science and/or epidemiologic human experiments.
9. Analogy	Drawing a parallel with an understood association (provides a source of more elaborate hypotheses about the association under study).

Internal validity of each study was assessed based on the following criteria:

1. Strength of study design.
2. Presence of selection bias.

3. Presence of misclassification bias, including an appraisal of reliability and validity of measurements (exposure and outcome).

4. Control of potential confounding.

2.2.4 Data Synthesis

Characteristics of the studies are summarized including study design, study subjects, exposure measured, outcome measured and results. Assessment of the studies with respect to internal validity, external validity and causal association are summarized. Findings of each study in addition to relative strengths and weaknesses are compared. Comparisons with adult population studies are reviewed. Specific recommendations are made for future research.

2.3 Results

2.3.1 Search Findings

The findings of the Medline search are described in Table 2.3. Twenty-five of the potentially relevant studies identified were included in the review. The findings of the sportdiscus search identified an additional 45 potentially relevant articles, of which five were included. Fifty-four further articles were identified in the CINAHL search, of which seven were included. No further studies were identified in the additional four databases. In total, 37 studies were chosen to be included in this systematic review from the search strategy described. In addition, references from two key sport medicine texts including epidemiological reviews were examined.[2,18] An additional nine relevant articles were included in this systematic review, bringing the total to 46. A summary of research design, subjects, exposure measure(s), outcome measure(s), and results for all 46 studies reviewed are found in Table 2.4.

Table 2.3: MEDLINE strategy and findings

Medical Subject Heading (MeSH) or textword (tw)	MeSH or tw defined	Number of articles identified*	Number of articles determined as potentially relevant** (n/a = not assessed > 500)	Number of articles included in critical appraisal***
1. MeSH or tw	athletic injuries or "athletic injuries"	11889	n/a	n/a
2. MeSH or tw	athletic injuries or "sports injury"	11918	n/a	n/a
3. MeSH or tw	risk factors or "risk factors"	227841	n/a	n/a
4. MeSH or tw	adolescence or "adolescent"	946841	n/a	n/a
5. MeSH or tw	child or "children"	1742010	n/a	n/a
1 and 3 and 4		386	52	19
2 and 3 and 4		387	52	1 additional
2 and 3 and 5		408	48	5 additional

*Number of articles identified by given strategy in MEDLINE search

** Number of articles identified by author as potentially relevant to subject area based on abstract

*** Number of articles identified, following review of methods section in article, as relevant for critical appraisal based on inclusion criteria

2.3.2 Non-modifiable Risk Factors for Injury in Child and Adolescent Sport

In identifying non-modifiable risk factors for injury in child and adolescent sport there is evidence that males are generally at greater risk for injury (OR=1.16-2.4.)[10,21,28,46,75,91] The exception to this is in studies examining specific sports including soccer,[3,21,59,68,78] baseball[64] and basketball[64] where females appear to be at greater risk.

Left-handedness also appears to be a risk factor for injury.[32] Re-injury rates range from 13.1% to 38%.[5,30,50] The risk of re-injury in football is greater than the risk of first time injury (RR=1.4-1.7).[57,66] Sport specific rates of injury vary considerably with the highest rates of injury reported for boys participating in hockey,[16,65] basketball[5] and football[30,52] and for girls participating in gymnastics,[9,52] basketball[5] and soccer.[44,68,90]

Risk of injury consistently increases with age across studies.[3,5,10,16,30,38,49,54,62,66,76,78,89-91] Consistently, in all sports, adolescents (>13 years) are at a greater risk of injury than younger children.[3,5,10,16,30,54,90,91] The peak injury rate is consistently in the oldest adolescent age group studied in studies examining all sports, soccer, hockey, football, baseball and gymnastics.[3,5,10,16,30,54,90,91] Injury rates decrease with increasing skill level in hockey[16] and increase with increasing skill level in wrestling.[62] Risk of injury increases with organized sport versus unorganized sport,[91] amount of time spent doing sporting activity,[28] competition versus practice,[62,63] tournament play versus regular season play,[65,68] increased level of competition,[5] indoor versus outdoor soccer[38] and large field size and reduced number of players in Australian rules football.[54]

There is conflicting evidence regarding anthropometric measurement and risk of injury, which appears to be injury and sport-specific. Brust et al[16] demonstrate an increased risk of injury in lighter hockey players with the same age and experience. In football, however, where age categories are also restricted by weight categorization, heavier players are at higher risk of injury than boys who are lighter.[30,42,54,77] In gymnastics, athletes who are taller or heavier are at an increased risk of injury compared with those shorter or lighter.[76,89] In soccer, Backous et al[3] demonstrate that taller players are at an increased risk of injury compared with shorter players. Lymen et al[49] demonstrate increased risk of elbow symptoms in pitchers who are heavier and taller.

2.3.3. Potentially modifiable risk factors for injury in child and adolescent sport

Twenty of the 46 epidemiological studies reviewed examine potentially modifiable physical intrinsic risk factors specifically for injury in child and adolescent sport.[3,11,17,25,31,33,38,39,49,50,52,54,62,70,71,72,76,86,88,89] Most studies examining biomechanical alignment, flexibility or strength demonstrate no association of these factors with injury in child and adolescent sport.[11,31,33,36,50,52] The exceptions to this are found in sport-specific studies. In gymnastics and figure skating there is some evidence of an association between poor flexibility and injury.[70,89] Woodford-Rogers,[88] also finds that both anterior tibiofemoral laxity and pronation are predictive of anterior cruciate ligament knee injury in adolescents. Pasque et al[62] demonstrate an increased risk of shoulder injury in wrestling with increase shoulder ligament laxity.

There is conflicting evidence that elbow injury in baseball pitchers is related to pitching style.[1,33] Albright et al[1] found an increased risk of elbow injury with a horizontal arm during delivery (particularly with a whipping or snapping motion) in Little League pitchers (≤14 years). Grana et al[33] found no relationship between injury and sidearm delivery or speed of delivery in older pitchers (14-19 years). Fatigue based on number of pitches in a game and number of pitches in a season seems to be associated with an increased risk of elbow injury.[49] Fatigue also appears to play a role in hockey where there is an increased risk of injury in the last 5 minutes of a period and the last period of a game.[63] Lysens et al[50] report an increased risk of injury in young women with decreased endurance fitness. This is consistent with Cahill et al[17] who found that adolescent football players participating in a pre-season conditioning program were at significantly decreased risk of knee injury.

There were only four intervention studies addressing prevention of injuries in adolescent sport that were reviewed. These prevention strategies potentially target risk factors such as limitations in flexibility, strength, endurance and proprioception. Bixler et al[11] show no effect of a half-time warm-up and stretching program in high school football in a quasi-experimental non-randomized trial. Junge et al[41] demonstrate a significant protective effect of a specific education, conditioning and rehabilitation program in adolescent soccer players in the low skilled division only [RR=0.63(0.42-0.94)]. There were only 2 randomized clinical trials (RCT's) examined in this review. Wedderkopp et al[86] demonstrate a significant reduction of injury in adolescent female European handball with the use of a multi-faceted training program which included proprioceptive balance training using a wobble board [RR=0.17 (0.09-0.32)]. Heidt et al[38] also demonstrate a protective effect of a multi-faceted 7 week pre-season training program in female high school soccer players [(RR=0.42(0.2-0.91)].

Psycho-social factors may also be potentially modifiable. Faelker et al[25] demonstrate evidence of a dose-response gradient between decreasing socioeconomic status and increased risk of injury. Smith et al[71,72] demonstrate a high correlation between injury in sport and stressful life events as well as outcomes on the Short Profile of Mood State (ie. low vigour, high fatigue).

2.3.4 Risk Factors for Injury in Adult Sport

As there are relatively few epidemiological studies addressing modifiable risk factors for injury in child and adolescent sport, it is prudent to discuss epidemiological evidence in adult sport prior to making recommendations for future research. There is inadequate evidence to support decreased muscle strength, globally, as a risk factor for injury in sport. Emery[23] concludes, based on a systematic review of the literature, that there is evidence of an association between decreased hamstring strength and hamstring strain injury in sport. In a review of the literature, Gleim et al[29] finds no strong evidence that decreased flexibility is associated with injury in sport. There is significant evidence that decreased sport specific training in the off-season in professional hockey increased the risk of groin strain injury [RR=3.38 (1.45, 7.92)].[24] Poor endurance is a risk factor for injury amongst army trainees during the basic training [RR= 2.8 (1.2, 6.7) for men and 1.69 (1.2, 2.4) for women.][40] Previous injury appears to be the most significant predictor of sports injury in some studies, with relative risks ranging from 2.88 to 9.41.[6,24,84] Tropp et al [80] demonstrate that soccer players with functional ankle instability and decreased balance ability, were at significantly greater risk of ankle sprain re-injury.

Some studies have examined proprioceptive balance training in conjunction with other training strategies (ie. strengthening, endurance training, plyometrics) to reduce injury in sport. These multifaceted training programs have been shown to significantly reduce the incidence of ankle sprain injuries and anterior cruciate ligament injuries in some sports.[7,20,81,86] However, balance, endurance and strength have not been examined as outcome measurements, so it is not clear as to the impact of the training strategies on these potential risk factors.

2.4 Discussion

2.4.1 Non-modifiable Risk Factors

Male children and adolescents participating in sport may be at a greater risk of injury as they may be more aggressive, have larger body mass and experience greater contact compared to girls in the same sports. All of these factors may lead to increased forces in running, jumping, pivoting and contact which may increase susceptibility to injury. In soccer, baseball and basketball studies show an increased risk of injury in girls. The reasons for this may be due to lower skill level or may be physiological in nature. It is hypothesized that left-handed adolescents may be at increased risk of injury because of environmental biases in a right handed world (ie. equipment used in sport) or functional differences related to neurological development.[32] Previous injury clearly increases the risk of injury in sport. This finding may be related to persistent symptoms, underlying physiological deficiencies resulting from the initial injury (ie. ligamentous laxity, muscle strength, endurance, proprioception) and/or inadequate rehabilitation.

It is not surprising that hockey, basketball and football are consistently among the top rated sports for injury in male athletes. There is certainly significant contact involved in two of the three sports (hockey and football) and some contact in basketball also. All three sports involve a high rate of jumping, sprinting and pivoting activity, which are often involved in the mechanism of injury in sport. Backx et al's[6] findings of outdoor sports, high jump rate sports and contact sports increasing the risk of injury are consistent with the high rates of injury in these 3 sports. It is also not surprising that gymnastics, basketball and soccer are consistently among the top rated sports for injury in female athletes. These three sports also involve a high rate of jumping, sprinting and pivoting activity.

Consistency in the findings that risk of injury in child and adolescent sport increases with age is not surprising given that level of competition, contact and size typically increase with age. Time participating in sport also likely increases with age and experience, however, exposure adjusted injury rate (incidence density) is often not examined. Taller and heavier athletes (ie. in football, gymnastics, soccer and baseball) may be more susceptible injury due to greater forces being absorbed through soft-tissue and joints. In hockey, a contact sport where there is no weight classification, it is not surprising that the smaller players are more susceptible to injury.

Injury reporting may be more accurate in studies examining organized sport (ie. levels of competition) and tournament play accounting for higher injury rates than in unorganized sport. In addition, competitors are more likely to be playing at greater intensity and speeds in competition and tournaments than in practice and regular season play, increasing the risk of sustaining an injury. In Australian Rules football, it is not surprising that larger field size and fewer players (ie. likely reducing the risk of contact) appear to be associated with a lower risk of injury.[54]

With rapid skeletal growth occurring in children and adolescents, there are potentially physiological reasons why children and adolescents may be at increased risk of injury.[2] For example, sudden intense muscular traction exerted on an immature skeleton (ie. during a period of rapidly increasing muscular strength) may result in an acute avulsion fracture of a growth plate, an injury not possible in adulthood.[2] Chronic repetitive muscular traction exerted on an immature skeleton, usually at the time of a growth spurt, may result in traction apophysitis (ie. Osgood-Schlatter or Severs' disease).[2] These are both injuries exclusive to children and adolescents.

2.4.2.Potentially Modifiable Risk Factors

Upton et al[83] demonstrate that less than 40% of high school rugby participants (n=2330), completed any pre-season training. High rates of injury may be related to decreased endurance and/or strength associated with limited pre-season training, as indicated in both adolescent[17,38,41,50,86] and adult[7,24,40] study findings. Some athlete populations (ie. low-skill division adolescent female soccer players) may benefit from training programs while others (ie. high-skill division adolescent female soccer players) may not.[41] Decreased flexibility does not appear to be a risk factor generally for injury in adolescent[36,50,52] or adult sport.[29] However, specifically it may be a risk factor for injury in gymnastics and figure skating, both sports that demand a high degree of flexibility for execution of many maneuvers.[70,89] Proprioceptive balance training, in conjunction with other training techniques, may reduce the risk of specific injury in specific sport.[7,20,86] The impact of decreased proprioception as a risk factor for injury remains unclear. The findings that psycho-social factors (ie. low socioeconomic status and high stressful life events) increase the risk of child and adolescent injury in sport are also consistent with the findings for other injury types (ie. home, fall and traffic injury.)[25,71,72]

2.4.3 Study Limitations

One of the fundamental difficulties in comparing research in sports injury epidemiology is the variability in research design, measurements used to assess exposure and injury and the variety of risk factors and sports assessed in studies. The research designs reviewed are almost exclusively observational and intervention studies are not always RCT's. The temporal association between exposure and outcome is often ignored in cross-sectional and case-control studies. For example, Smith et al[70] examine flexibility in figure skaters already presenting with knee pain and the temporal association between knee pain and decreased flexibility is unclear.

Injury definition and methods of injury data collection are extremely variable. One of the major limitations in many studies reviewed is that incidence rates based on number of participants rather than incidence densities based on exposure (ie. hours or sessions of participation) are used to distinguish high risk athletes. Clearly, time spent doing an activity is critical in the assessment of risk of injury. Time loss, medical requirements and re-injury inclusion differ widely between injury definitions. Methods of data collection vary from self-report to therapist or physician report. Only 25-31% of injuries in some studies resulted in a physician consult.[4,5,53] Depending on injury definition, some studies may underestimate injury if only those reporting to an emergency room,[9,26,74,82] physician or therapist[63,68] are included. Other studies may overestimate injury rates if all injuries are reported regardless of reporting source (ie. parent, coach).[4,5] If one relies on self-report, particularly over a longer time frame, incidence rates will likely be underestimated due to recall bias. Bijur et al[10] demonstrate a

51% increase in self-reported injury over a one month recall period compared to a 12 month recall period.

Selection bias is of concern in many studies as there is no random selection of participants. Selection bias in which athletes more likely to be injured (ie. previous injury) and more likely to be in exposure risk group are selected, may lead to an overestimation of association between risk factor and injury. [17,25,50,70-72,76,88,89] If there are unreported drop-outs from the study and the reason for drop-out is related to injury, this may lead to an underestimation of association (another form of selection bias). [11,33,36,50,52] Lack of blinding to exposure status, as with most of the cohort studies examined in this review, may also lead to overestimation of the association.

Poor reliability and validity of exposure measurements (ie. flexibility, strength) resulting in non-differential misclassification of exposure (ie. likelihood of misclassification of exposure is not associated with outcome) will underestimate the association between exposure and injury. This is certainly of concern in studies which found no association.[11,33,36,50,52]

The most significant source of bias in the studies reviewed was a lack of measurement and control for potentially confounding variables. This results most often in an overestimation of association between exposure and injury. When recruitment of subjects is not random, risk factors/ training interventions assessed may not be the only difference between groups. Differences in physiological factors, coaching technique, warm-up routines and equipment may prevail. For example, in Cahill's[14] study, a historical cohort, differences attributed to pre-season conditioning may be a result of equipment differences, coaching differences, rule changes (ie. elimination of below the waist blocking in 1973)[79] or physiologic factors in the two cohorts which were not controlled for in the study.

In some RCT studies examining prevention strategies, the intervention was assigned to a team (ie. cluster) not an individual.[38,41,86] If similarities within a team are greater than similarities between teams, these similarities should be controlled for in the analysis (ie. cluster analysis). When clusters are controlled for in an analysis, the effect measure is less precise (ie. larger 95% CI's) if similarities within each cluster are in fact greater than similarities between clusters.[22] As such, overestimates of the protective effects of training strategies may have been reported as a result of the individual level analyses done in these intervention studies. In addition, the intervention studies examined identify multi-faceted preventative training programs.[11,38,41,86] As a result, it is difficult to identify specific risk factors addressed by the program (ie. flexibility, strength, endurance, proprioception) if measurements of these factors are not examined.

External validity of the results in all of the studies examined is limited due to limitations in internal validity. Certainly generalizability beyond the specific sport, age group, level of competition and specific injury type is limited.

In examining Hill's criteria of causation,[67] many of the studies reviewed are consistent with the findings in adult population studies. The strength of the associations found between pre-participation training programs and injury are convincing based on the magnitude of associations found, despite concerns with internal validity and individual level analysis. Specificity, implying that a specific cause leads to a specific effect is difficult to identify when studies often do not control for other risk factors and injury outcome is often global and poorly defined. Temporal association is clear only in the cohort studies and randomized clinical trials reviewed. The only studies providing a clear indication of a dose-response relationship is Faelker's,[25] in which injury rate increases with increasing level of poverty and the studies examining increased risk of injury with increasing age.[5,10,30,49,66,76] Biological plausibility of risk factors and coherence to existing knowledge has been discussed. Injury prevention studies are few, thus experimental evidence is certainly limited.

2.5 Conclusions

Child and adolescent participation rates in sport are high. High rates of sports injury in this population result in a significant impact on the individual, their parents and the health care system. Sports injury in children and adolescents may also potentially affect future involvement in physical activity and the future health of our population.

The strength of the evidence for potentially modifiable risk factors for injury in children and adolescents is limited by research design and concerns with internal validity. In case-control and cross-sectional study designs, the temporal association between exposure and outcome is unclear. In many of the cohort studies and non-randomized intervention studies reviewed, various sources of bias in the selection of subjects, measurement of exposure and outcome variables and lack of control for other potentially confounding variables threaten the studies' internal validity. There is limited RCT evidence supporting preventative training programs in specific sports in adolescents to reduce the risk of injury. There is certainly more convincing evidence in adult epidemiological studies that decreased endurance, decreased strength, decreased proprioception and decreased pre-season sport-specific training are associated with sports injury. The consistency of the findings between child and adolescent studies reviewed and the adult population studies is encouraging.

These results of this review can be utilized in targeting relevant athlete groups [ie. high risk sports such as hockey, basketball, football, soccer (particularly indoor) and gymnastics], age groups (ie. older adolescents) and skill levels (ie. low skill division in female adolescent soccer) in designing future research examining risk factors and prevention strategies in child and adolescent sport. Future studies examining prevention strategies such as pre-season conditioning and proprioceptive training are warranted. Future clinical trials examining such prevention strategies should quantify and control for potential risk factors for injury in child and adolescent sport.

Table 2.4: Studies examining risk factors for injury in child and adolescent sport

Author (Year)	Study Design (Country and time frame)	Participants (Age)	Risk factor (Exposure variable) (Reference exposure group=R)	Injury Definition	Results (Relative risk= RR, Odds Ratio = OR, provided if adequate information provided)
Albright et al (1978)[1]	Cohort (USA, 1973-4)	109 Little League baseball pitchers (≤ 14 years)	1. Graded pitching form 1 (best form) - 5 (poorest form) based on angle of arm, mechanics, and rhythm 2. Age	Elbow symptoms grades 0 (none) – severe (chronic decreased ROM and marked swelling)	1. Increased risk of injury with horizontal arm during delivery, particularly with whipping or snapping motion 2. No association between age and injury (insufficient data to calculate RR's)
Backous et al (1988)[3]	Cohort (USA, 5 weeks)	1139 soccer players attending summer soccer camp (6-17)	1. Sex (female R) 2. Age 3. Height 4. Grip strength	Injury resulting in time loss ≥1 session	1. RR(male)= 0.69(0.5-0.93) 2. Significantly greater injury rates in ages 14-17, height ≤165 cm, grip strength≤ 25 kg (insufficient data to calculate RR's)
Backx et al (1991)[4]	Cohort (Netherlands, 7 months, 1982-1983)	1818 school children (8-17) 732 Cases 1032 Controls (all sports)	1.Venue (outdoor/indoor) 2.Sport activity (high jump rate) 3.Contact (contact/no)	Physical damage caused by sport-related incident	Multiple regression reveals 1.RR(outdoor)= 1.34(1.19-1.52) 2. RR(high jump rate)= 2.8(2.42-3.23) 3. RR(contact sport)= 3.03(2.69-3.42)

Backx et al (1989)[5]	Case-control (Netherlands, 6 weeks, 1982)	7468 school children (8-17) 732 Cases 1032 Controls (all sports)	1. Level of sport activity (low R, moderate, high) 2. Competitive vs. Recreational (R) 3. Sex (female R) 4. Age (8-10 R) 5.Elementary (R) vs. Secondary 6.Sport (overall R)	Physical damage caused by sport-related incident	1. OR(mod)= 4.62 (3.16-6.76) OR(high)= 7.2 (4.92-10.54) 2. OR(comp)= 1.75 3. OR(male)= 1.38 (1.13-1.67) 4. OR(11-12)= 1.33 (1-1.75) OR(13-14)= 2.05 (1.56-2.7) OR(15-16)= 2.09 (1.53-2.83) 5.OR(secondary) = 1.72 (1.41-2.1) 6.OR(basketball)= 1.99 OR(field hockey)= 1.83 OR(track)= 1.54 OR(korfball)= 1.44 OR(handball)= 1.37 OR(soccer)= 1.24 (insufficient data for 95% CI's) 38% re-injury rate
Bijur et al (1995)[10]	Cross-sectional (USA, 1988)	11840 children (5-17) (all sports)	1. Sex all ages (female R) 2. Sex ages 14-17 (female R) 3. Age (5-9 R)	Medically attended non-fatal injuries occurring in a place of recreation or sports	1. OR(male)= 1.8 (1.5, 2.2) 2. OR(male)= 2.4 (1.8, 3.2) 3. OR(10-13)= 1.88 (1.05-3.36) OR(14-17)= 2.23 (1.6-4.78)

Bixler et al (1992)[11]	Quasi-experimental non-randomized trial (USA)	High school football players (5 teams: 3 intervention, 2 control)	Intervention- ½ time warm-up and stretching exercises Control- no exercises	Injuries requiring medical attention	Injury rates between groups not statistically significant (insufficient data to calculate RR)
Brust et al (1992)[16]	Cohort (USA, 1991-1992)	150 boys (9-15) (hockey)	1.Age (9-13 R) 2.Experience - skill A (R), B, C 3. Weight	Injury in game or practice requiring removal from session	1. RR(13-15)= 2.45 (1.65-3.63) 2. RR(skill BC)= 2.28 (1.23-4.2) 3. Decreased weight within age group based on student t-tests ($p<0.05$) (insufficient data to calculate RR)
Cahill et al (1978)[17]	Historical cohort (USA, 1969-1976)	1. 1254 high-school football players (1969-72) 2. 2481 high-school football players (1973-76)	1.Reference group (no pre-season conditioning) 2. Exposed group pre-season conditioning 80 minutes/day, 3X/week, 4-6 weeks)	Knee injury requiring 2 sessions to be missed	Decreased early season injury RR= 0.33 (0.2-0.53) Decreased injury requiring surgery RR= 0.38 (0.16-0.89) Decreased overall injury RR= 0.6 (0.43-0.84)
de Loes (1995)[21]	Cross-sectional (Switzerland, 1987-89)	689,374 youth (14-20) (all sports)	1.Sex (female R) 2.Sex (top 10 sports except soccer R) 3. Sport	Acute sporting injuries	1. OR(male)= 1.77 (1.07-2.98) 2. OR(male no soccer) = 1.03 (0.61-1.75) 3. Top 3 incidence rates in handball, soccer, basketball

Faelker et al (2000)[25]	Case-control (Canada, 1996)	35,380 children (< 19)	Socio-economic status (Grade 1-5 poverty level, poor-rich) (Grade 1 R = highest poverty level)	All injury reporting to emergency	OR(grade 5)= 1.67(1.48-1.89) OR(grade 5 adolescent only 14-19)= 2.33 (1.92-2.82) Evidence of dose response with increased injury risk by increased poverty grade
Garrick et al (1978)[28]	Cross-sectional (USA, 1973-75)	3049 high school sports participants (all sports)	1. Sex (female R) 2. Sport	Sports injury resulting in removal from session or missing subsequent session	1. OR(male) = 2.09 (1.83-2.39) 2. Top 3 incidence rates for males in football, wrestling, track. Top 3 incidence rates in females in softball, gymnastics, track
Goldberg et al (1988)[30]	Cohort (USA, 1987)	5128 football players (8-15) (football)	Level of play (youngest and smallest R= Jr Peewee 8-11/ 22.5-38.3 kg) (oldest and biggest= bantam 12-15 /49.5-67.5 kg)	Injury occurring in football requiring > 6 days activity restriction	RR(peewee)= 1.45 (0.79-2.68) RR(jr.midget)= 2.92 (1.64-5.19) RR(midget)= 4.45 (2.51-7.88) RR(bantam)= 5.11(2.53-10.33) 13.1% re-injury rate

Grace et al (1984)[31]	Cohort (New Mexico)	172 male high school football players (13-18)	Isokinetic strength imbalance 1.ipsilateral/ contralateral imbalance ≥10% 2. hamstring/ quads imbalance ≥10% mean	Knee injury requiring missing at least 1 game or practice	No association found between isokinetic strength imbalances 1 or 2 (insufficient data to calculate RR)
Graham et al (1995)[32]	Cross-sectional (USA 1994)	634 junior and senior high-school athletes (mean=13.6)	Left handedness	Injury sustained in sport in the last year requiring physician consult	OR(left)= 2.15 (1.22-3.79)
Grana et al (1978)[33]	Cohort (USA, 1973-75)	73 high school baseball pitchers (14-19)	1. # seasons played 2. pitching traits 3. asymmetry on physical exam 4. asymmetry on x-ray exam	Elbow symptoms graded 1 (acute episode impairing performance) to 4 (no symptoms or history of injury)	No association between occurrence of symptoms and risk factors 1-4 (insufficient data to calculate RR)
Grubbs et al (1997)[36]	Cohort (USA, 1996)	62 high school basketball players (mean=15)	Injury score based on Q-angle and weight-bearing asymmetry	Injury requiring missing 1 game or 2 practices	Injury score not predictive of injury Se=16.7%, Sp=66.1%, PPV=5%, NPV=86.2% No association

Heidt et al (2000)[38]	RCT (USA)	300 female high school soccer players (14-18)	1. Intervention (I) 7 week preseason Frappier acceleration program (cardio-vascular, plyometrics, strength and flexibility) 2. Control- no preseason program	Injury requiring missing at least 1 game or practice	RR(I)= 0.42(0.2-0.91)
Hoff et al (1986)[39]	Cohort (USA, 1984-1985)	455 outdoor and 366 indoor soccer players (U8 - U16)	1. Field type (outdoor R) 2. Age (U10 R)	Injury requiring player to miss next session or limited playing ability	1. RR(indoor)= 6.1(4.17-9.03) 2. RR(10-16)= 2.66(1.6-4.67)
Junge et al (2002)[41]	Quasi-experimental non-randomiz-ed trial (Switzer-land, 1999-2000)	194 soccer players (mean = 16.5)	1. Intervention (I) included coach and player education, rehab + conditioning program including cardio-vascular, strength, flexibility and plyometrics training) 2. Control - ill-defined	Injury resulting in physical complaint >2 weeks or missed session	1. RR(I)= 0.82(0.58-1.15) 2. RR(I) high skilled divisions= 0.94(0.58-1.5) 3. RR(I) low skilled divisions= 0.63 (0.42-0.94)

Kaplan et al (1995)[42]	Cohort (USA)	98 high-school football players (mean = 16.6)	1. Body weight (≤90 kg R) 2. BMI (≤75%ile)	Injury requiring player to miss next session	1. RR(>90 kg)= 2.53(1.41-4.55) 2. RR(>75%ile)= 2.78(1.05-7.39)
Lenaway et al (1992)[46]	Cohort (USA, 1998-1999)	5518 school students (5-19) (all sports)	Sex (female R)	Injury occurring during sporting activity	RR(male)= 2.13 (1.41, 3.21)
Lyman et al (2001)[49]	Cohort (USA, 1997-1998)	298 baseball pitchers (9-12)	Age, weight, height,# pitches in game,# pitches in season, arm fatigue, self perceived performance, weight-lifting, baseball outside league)	Symptoms in the elbow or shoulder during or after a league game	Multivariate analysis (GEE) revealed: 1. Risk factors for elbow symptoms:↑age, ↑weight, ↓height, lifting weights, baseball outside league, ↓self satisfaction, arm fatigue and throwing <300 or >600 pitches in season 2. Risk factors for shoulder symptoms:↓self satisfaction, arm fatigue, throwing >75 pitches in game, throwing <300 pitches in season

Lysens et al (1984)[50]	Cohort (Netherlands, 1980-1983)	138 physical education students over 4 years (17-18) (all sports)	Re-injury, endurance fitness, alignment, flexibility, ligamentous laxity	Not well defined	Decreased endurance fitness increased risk of injury in females only. ($p<0.05$). No association between alignment, flexibility or ligamentous laxity and injury. (insufficient data to calculate RR's) 27% reinjury rate
Maffulli et al (1994)[52]	Cohort (UK, 1992-1993)	453 elite athletes (9-18) Football, gymnastics, swimming, tennis	Strength and flexibility	Injury not well defined	No association found between flexibility or strength and injury ($p<0.05$) (insufficient data to calculate RR's)
McMahon (1993)[54]	Cohort (Australia 1992)	1253 Australian Rules football players (U10-U15)	1. Age (U10 R) 2. Training (R) vs. Game 3. Rule modification in U-10 only (R) (↓contact, ↓Field size, ↓Player numbers) vs. Conventional (Conv)	Injury causing pain or disability. Functional impairment (FI) injuries interfered with normal function or consult of a health professional(HP)	1. RR (U15) = 1.52(1.17-1.99) RR (FI U15) = 2.2(1.58-3.1) RR (HP U15) = 7.58(3.6-18.36) 2. RR(Game) = 15.1(9.3-24.7) 3.RR(Conv)= 2.1 (1.2-3.6) for FI injuries only

Messina et al (1999)[56]	Cohort (US 1996/97)	1863 high-school basketball players	Sex (female R)	Injury requiring time loss or medical consult	RR(male)= 1.14 (1.04-1.24) RR(male)= 0.49 (0.36-0.68) knee injury alone
Mueller et al (1974)[57]	Cohort (USA, 1968-1972)	8776 high school football players (13-19)	1. Previous injury (none R)	Injury requiring time loss ≥1 day or medical attention	1. RR(previous injury) = 1.43 (1.29-1.58)
Nilsson (1978)[59]	Case-Control (Norway, 1975-1977)	25,000 soccer players attending international tournament (11-18)	1. Sex (female R) 2. Age (11-14 R)	All injuries other than minor skin abrasions and blisters reporting to first aid station	1. RR(male)= 0.52(0.3-0.88) 2. RR(15-18)= 1.0(0.56-1.77)
Pasque et al (2000)[62]	Cohort (USA)	418 male high school wrestlers (14-19)	1.Ligamentous laxity 2. Age 3. Experience 4. Practice/ Competition	Injury requiring time loss and trainer or physician consult	1. ↑Risk of injury: ↑age, ↑experience, competition 2. ↑Risk of shoulder injury: ↑ligamentous laxity (insufficient data to calculate RR)

Pinto et al (1999)[63]	Cohort (USA)	22 Junior A hockey players (16-20)	1. Position (Goalie R) vs. Forward or Defense 2. Practice(R) vs.Game 3. Time of season (last ½ R) 4. Time of period and game	Injury requiring medical attention	1. RR(F or D)= ↓ RR(D game)=1.1 2. RR(Game)=75 3. RR(1st ½ season) = 2.52 (insufficient data to calculate 95% CI's) 4. 46% of injuries in 3rd period, 47% of injuries in final 5 minutes of period
Powell et al (2000)[64]	Cohort (US, 1995-1997)	39,032 high-school basketball, baseball and soccer player seasons	Sex (female R)	Injury requiring time loss or medical consult	RR(male)= 0.79 (0.73-0.86) baseball, 0.88 (0.82-0.93) soccer, 0.96 (0.93-1.04) basketball, 0.7 (0.58-0.83) basketball knee injury only
Roberts et al (1999)[65]	Cross-sectional (USA 1993/94)	807 hockey players (9-19)	Tournament/ Regular season play(R)	Significant injury resulting in cessation of play, missing next day or medical attention	OR(tournament) = 4-6 (insufficient data to calculate 95% CI's)
Robey et al (1971)[66]	Cohort (USA 1968)	2252 high school football players (13-19)	1. Age (13-14 R) 2. Previous season injury (none R)	Injury requiring time loss or medical consult	1. RR(15)= 1.13(0.85-1.5) RR(16)= 1.54(1.17-2.04) RR(≥17)= 2.24(1.71-2.95) 2. RR(Previous Injury)= 1.66(1.35-2.03)

Schmidt-Olsen et al (1985)[68]	Cross-sectional (Denmark, 1984)	6600 soccer players attending 2 tournaments	Sex (female R)	Injury requiring medical attention	ORmale= 0.49 (0.4-0.61)
Smith et al (1991)[70]	Cross-sectional (US, 1986-1987)	46 elite junior figure skaters	Flexibility (quadriceps, hamstrings, ITB, ileopsoas)	Anterior knee pain (AKP)	Skaters with AKP had ↓quadriceps and hamstring flexibility compared to those without AKP ($p<0.05$) (insufficient data to calculate RR)
Smith et al (1997)[71]	Cohort (US, 1996)	86 male high-school ice hockey players	Physical, situational and psycho-social factors	Injury requiring medical attention or time loss >24 hours	High playing time, low vigor and high fatigue as per (Short Profile of Mood States) significantly predicted injury (insufficient data to calculate RR's)
Smith et al (1990)[72]	Cohort (US, 1988)	451 high school athletes	Psycho-social factors (stressful life events, social support, coping skills)	Injury requiring time loss>1 day	Stressful life events accounted for 30% of injury variance in subjects with low social support and coping skills (insufficient data to calculate RR's)
Sorensen et al (1996)[74]	Cross-sectional, (Denmark, 1988-1992)	63,017 school aged children (6-17) (all sports)	1.Sex (female R)	Injury resulting from sport activity presenting to the hospital Emergency Dept	1. OR(male)= 1.13 (1.07-1.18)

Steele et al (1986)[76]	Cohort (Britain 1985)	40 elite female gymnasts (10-21)	Anthropometric variables, hypermobility, flexibility and spinal curvature	Injury score 1 (head injury, fracture or dislocation) to 8 (minor injury - modified training < 1 week)	Multiple regression yields accurate prediction of high (40+) and low (0-15) injury score with 5 variables 1. lordosis 2. mesomorphy 3. weight 4. age 5. height
Stuart et al (2002)[77]	Cohort (USA, 1997)	915 football players (9-13)	1. Age (School grade 4 R) 2. Weight	Injury preventing participation and requiring medical attention.	1. RR(grade5)= 2.07(1.43-2.71) RR(grade6)= 2.31(1.59-2.74) RR(grade7)= 2.19(1.56-2.83) RR(grade8)= 4.13(3.49-4.77) 2. Weight not predictive of injury.
Sullivan (1980)[78]	Cohort (USA)	1272 soccer players (7-18)	1. Sex (female R) 2. Age (U14 R)	Injury preventing participation	1. RR(male)= 0.46 (0.22-0.98) 2. RR(14-18)= 9.3(4.29-21.78)

Wedderkopp et al (1999)[86]	Randomized Clinical Trial (Denmark, 1995/96)	237 female European team handball players (16-18)	1. Intervention: practice session training program (warm-up with 2 or more functional large muscle group exercises and proprioceptive ankle disk activity) 2. Control: non-specific practice session training	Injury requiring player to miss next session or unable to participate without considerable discomfort	RR(intervention) =0.17(0.09-0.32)
Woodford-Rogers et al (1994)[88]	Matched Case-control (US)	44 football, basketball and gymnasts	Pronation and anterior knee joint laxity measurement	ACL knee ligament injury (complete tear)	Discriminant analysis correctly predicts 87.5% all females and 70.5% all cases (insufficient data to calculate OR's)
Wright et al (1998)[89]	Cross-sectional (UK)	15 female competitive gymnasts (8-18)	1. Age 2. Height 3. Mass 4. Somatotype 5. Years experience 6. Strength 7. Flexibility	4 year injury history (classified as "high" or "low" injury status based on # injuries and time loss	High injury group significant ↑age, ↑height, ↑mass, ↑years experience and ↑flexibility (ankle dorsiflexion and back extension) in univariate analysis only. Strength and somatotype not significant.

Yde et al (1990)[90]	Cohort (Denmark, 1985-1986)	302 soccer, handball and basketball players (< 18 years)	1. Age (<14 R) 2. Sport played (handball + basketball R)	Injury requiring player to miss next session	1. RR(≥14) =3.14(2.49-4.77) 2. RR(soccer<14)= 6.47(2.06-20.33) RR(soccer ≥14)= 1.79(1.35-2.37)
Zaricznyj et al (1980)[91]	Cross-sectional (USA, 1974-1975)	25,512 school aged children in one community (all sports)	1.sex (female R) 2.junior high (R) vs high school 3.organized (R) vs. physical education and non-organized sports	Injury occurring in sport requiring medical treatment or filing of school/ insurance forms	1. OR(male)= 2.1 (1.9-2.33) 2. OR(high-school)= 2.74 (2.48-3.02) 3. OR(PE + non-organized) = 0.4 (0.35-0.46)

References

1. Albright JA, Jokl P, Shaw R, Albright JP. Clinical study of baseball pitchers: correlation of injury to the throwing arm and method of delivery. *Am J Sports Med* 1978;6:15-21.

2. Armstrong N, van Mechelen W eds. *Paediatric exercise science and medicine.* Oxford University Press: NewYork,2000.

3. Backous DD, Friedl KE, Smith NJ, Parr TJ, Carpine WD. Soccer injuries and their relation to physical maturity. *Am J Dis Child* 1988;142:839-842.

4. Backx FJG, Beijer HJM, Bol E, Erich WBM. Injuries in high-risk persons and high-risk sports. A longitudinal study of 1818 school children. *Am J Sports Med* 1991;19:124-30.

5. Backx FJG, Erich WBM, Kemper ABA, Verbeek ALM. Sports injuries in school-aged children. An epidemiologic study. *Am J Sports Med* 1989;17:234-40.

6. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scand J Med Sci Sports* 1997;7(3):166-71.

7.Bahr R, Lian O. A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports* 1997;7(3):172-177.

8. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Disease Child* 1993;68:130-2.

9. Bienfeld M, Pickett W, Carr PA. A descriptive study of childhood injuries in Kingston, Ontario, using data from computerized injury surveillance system. *Chronic Disease in Canada* 1996;17:21-7.

10. Bijur PE, Trumble A, Harel Y, Overpeck MD, Jone D, Scheidt PC. Sports and Recreation Injuries in US Children and Adolescents. *Arch Pediatr Adolesc Med* 1995;149:1009-16.

11. Bixler B. Jones RL. High school football injuries: effects of a post-halftime warm-up and stretching routine. *Family Practice Research Journal* 1992;12:131-9.

12. Bjornstig U, Larsson TJ. Persistent medical problems and permanent impairment: injuries associated with work, vehicles and sport. *Accid Anal and Prev* 1994;26:41-8.

13. Blair SN, Kohl HW, Barlow CE et al. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. JAMA 1995;273:1093-8.

14. Blair SN. Physical activity, physical fitness and health. *Res Q Exerc Sport* 1993;64:365-76.

15. Briscoe JHD, Sports injuries in adolescent boarding school boys. *Practitioner* 1978;221:751-5.

16. Brust JD, Leonard BJ, Pheley A, Roberts WO. Children's ice hockey injuries. *AJDC* 1992;146:741-7.

17.Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of highschool football knee injuries. *Am J Sports Med* 1978;6:180-4.

18. Caine DJ, Caine CG, Lindner KJ eds. *Epidemiology of Sports Injuries.* Human Kinetics Publishers, Inc:Illinois, 1996.

19. Canadian Fitness and Lifestyle Research Institute website 2001; http:www.cflri.ca/cflri/resources/pub.php#98pamrep.

20. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee Surg Sports Traumat Arthrosc* 1996;4:19-21.

21.de Loes M. Epidemiology of Sports Injuries in the Swiss Organization "Youth and Sports" 1987-1989. Injuries, Exposure and Risks of Main Diagnoses. *Int J Sports Med* 1995;16:134-8.

22. Donner A, Klar N. *Design and Analysis of Cluster Randomization Trials in Health Research.* Oxford University Press, Inc., New York, 2000.

23. Emery CA. Does decreased muscle strength cause acute muscle strain injury in sport? A systematic review of the evidence. *Phys Ther Rev* 1999;4:79-85.

24. Emery CA, Meeuwisse WH. Risk factors for groin and abdominal strain injury in the National Hockey League. A Multivariate approach. *Med Sci Sport Exerc* 1999;33:1423-1433.

25. Faelker T, Pickett W, Brison RJ. Socioeconomic differences in childhood injury: a population based epidemiologic study in Ontario, Canada. *Injury Prev* 2000;6(3):203-8.

26. Gallagher SS, Finison K, Guyer B, Goodenough S. The incidence of injuries among 87,000 Massachusetts children and adolescents: results of the 1980-81 statewide childhood injury prevention program surveillance system. *Am J Pub Health* 1984;74:1340-7.

27. Gallagher SS, Guyer B, Kotelchuck M, Bass J, Lovejoy FH, McLoughlin E, Mehta K. A Strategy for the reduction of childhood injuries in Massachusetts: SCIPP. *NEJM* 1982;307:1015-9.

28. Garrick JG, Requa RK. Injuries in high school sports. Pediatrics 1978;61:465-9.

29. Gleim GW, McHugh MP. Flexibility and its effects on sports injury and performance. *Sports Med* 1997;24:289-99.

30. Goldberg B, Rosenthal PP, Robertson LS, Nicholas JA. Injuries in youth football. *Pediatrics* 1988;81:255-61.

31. Grace TG, Sweetser ER, Nelson MA, Ydens LR, Skipper BJ. Isokinetic muscle imbalance and knee-joint injuries. *JBJS* 1984;66A:734-740.

32. Graham CJ. Cleveland E. Left-handedness as an injury risk factor in adolescents. *J of Adolesc Health* 1995;16:50-52.

33. Grana WA, Rashkin A. Pitcher's elbow in adolescence. *Am J Sports Med* 1980;8:333-336.

34. Grimmer KA, Jones D, Williams J. Prevalence of adolescent injury from recreational exercise: an Australian perspective. *J Adolesc Health* 2000;27:1-6.

35. Grimmer KA. *Young people's participation in sports and recreational activities, and associated injury.* Centre for Allied Health Research, University of South Australia and Sports Medicine Australia, South Australia 1999, August.

36. Grubbs N, Nelson RT, Bandy WD. Predictive validity of an injury score among highschool basketball players. *Med Sci Sports Exerc* 1997;29:1279-85.

37. Halpern B, Thompson N, Walton W et al. High school football injuries: Identifying risk factors. *Am J Sports Med* 1987:15;S113-S117.

38. Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med* 2000;28:659-662.

39. Hoff GL, Martin TA. Outdoor and indoor soccer: injuries among youth players. *Am J Sports Med* 1986:14:231-233.

40. Jones BH, Bovee MW, Harris JM, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993;21:705-10.

41. Junge A, Rosch D, Peterson L, Graf-Baumann T< Dvorak J. Prevention of soccer injuries: a prospective intervention study in youth amateur players. *Am J Sports Med* 2002;30:652-659.

42. Kaplan TA, Digel SL, Scavo VA, Arellana SB. Effect of obesity on injury risk in high school football players. *Clin J Sports Med* 1995;5:43-47.

43. Keller CWS, Noyes FR, Buncher CR. The medical aspects of soccer injury epidemiology. *Am J Sports Med* 1987;15:S105-S112.

44. Kibler WB. Injuries in adolescent and preadolescent soccer players. *Med Sci Sports and Exerc* 1993:25:1330-32.

45. King MA, Pickett W, King AJC. Injury in Canadian youth: A secondary analysis of the 1993-94 health behaviour in school-aged children survey. *Can J Pub Health* 1998;89:397-401.

46. Lenaway DD, Ambler AG, Beaudoin DE. The epidemiology of school-related injuries: New perspectives. *Am J Prevent Med* 1992;8:193-8.

47. Lindenfeld TN, Schmitt DJ, Hendy MP, Mangine RE, Noyes FR. Incidence of injury in indoor soccer. *Am J Sports Med* 1994;22:364-71.

48. Lindqvist KS, Timpka T, Bjurulf P. Injuries during leisure activity in a Swedish municipality. *Scand J Soc Med* 1996;24:282-292.

49. Lyman S, Fleisig GS, Waterbor JW, Funkhouser EM, Pulley L, Andrews JR, Osinski ED, Roseman JM. Longitudinal stgudy of elbow and shoulder pain in youth baseball pitchers. *Med Sci Sports Exerc* 2001;33:1803-1810.

50. Lysens R, Steverlynck A, van den Auweele Y, Lefevre J, Renson R, Claessens A, Ostyn M. The predictability of sports injuries. *Sports Med* 1984;1:6-10.

51. Macnab AJ, Cadman R. Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. *Injury Prevention* 1996;2:286-289.

52. Maffulli N, King JB, Helms P. Training in elite young athletes (the training of young athletes (TOYA) study): injuries, flexibility and isometric strength. *Br J Sports Med* 1994;28:123-36.

53. McLain LG, Reynolds S. Sports injuries in a high school. *Pediatrics* 1989;84:446-50.

54. McMahon KA, Nolan T, Bennett CM, Carlin JB. Australian Rules football injuries in children and adolescents. *Med J Austral* 1993;159;301-306.

55. Meeuwisse WH. Predictability of sports injuries. What is the epidemiological evidence. *Sports Med* 1991;12:8-15.

56. Messina DF, Farney WC, DeLee JC. The incidence of injury in Texas high school basketball: a prospective study among male and female athletes. *Am J Sports Med* 1999;27:294-299.

57. Mueller FO, Blyth CS. North Carolina high school football injury study. Equipment and prevention. *J Sports Med* 1974;2:1-10.

58. Mummery WK, Spence JC, Vincenten JA, Voaklander DC. A descriptive epidemiology of sport and recreation injuries in a population-based sample: Results from the Alberta Sport and Recreation Injury Survey(ASRIS).*Can J Pub Health* 1998;89:53-6.

59. Nillson S, Roaas A. Soccer injuries in adolescents. *Am J Sports Med* 1978;6:358-361.

60. Northern Sydney Area Health Services. *New South Wales Youth Sports Injury Report.* Northern Sydney Area Health Services 1997; July.

61. Paffenberger RS, Kamput JB, Lee IM et al. Changes in physical activity and other lifestyle pattern influencing longevity. *Med Sci Sports Exerc* 1994;26:857-865.

62. Pasque CL, Hewett TE. A prospective study of high school wrestling injuries. *Am J Sports Med* 2000;28:509-515.

63. Pinto M, Kuhn JE, Greenfield MLV, Hawkins RJ. Prospective analysis of ice hockey injuries at the Junior A level over the course of a season. *Clin J Sports Med*1999;9:70-74.

64. Powell JW. Barber-Foss KD. Sex-related injury patterns among selected high school sports. *Am J Sports Med* 2002;28:385-91.

65. Roberts WO, Brust JD, Leonard B. Youth ice hockey tournament injuries: rates and patterns compared to season play. *Med Sci Sports Exerc* 1999;31:46-51.

66. Robey JM, Blyth CS, Mueller FO. Athletic injuries: application of epidemiologic methods. *JAMA* 1971;217:184-189.

67. Rothman KJ, Greenland S. *Modern Epidemiology, 2nd edition.* Philadelphia, PA: Lippincott-Raven Publishers, 1998.

68. Schmidt-Olsen S, Bunemann LKH, Lade V, Brassoe JOK. Soccer injuries of youth. *Br J Sports Med* 1985;19:151-4.

69. Sheps SB, Evans GD. Epidemiology of school injuries: a 2-year experience in a municipal health department. *Pediatrics* 1987;79:69-75.

70. Smith AD, Stroud L, McQueen C. Flexibility and anterior knee pain in adolescent elite figure skaters. *J Pediatric Orthop* 1991;11:77-82.

71. Smith RE. Smoll FL. Ptacek JT. Conjunctive moderator variables in vulnerability and resiliency research: life stress, social support and coping skills, and adolescent sport. *J of Personal & Social Psych* 1990;58:360-370.

72. Smith AM. Stuart MJ. Wiese-Bjornstal DM. Gunnon C. Predictors of injury in ice hockey players: a multivariate, multidisciplinary approach. *Am J Sports Med* 1997;25:500-507.

73. Stanitski CL, DeLee JC, Drez D eds. *Pediatric and Adolescent Sports Medicine. Vol 3.* WB Saunders Co:Philadelphia,1994.

74. Sorensen L, Larsen SE, Rock ND. The epidemiology of sports injuries in school aged children. *Scand J Med Sci Sports* 1996;6:281-6.

75. Statistics Canada, Culture and Tourism Division. *Canada's culture and heritage and identity: A statistical perspective.* Minister of Industry, Ottawa, 1997.

76. Steele VA, White JA. Injury prediction in female gymnasts. *Br J Sports Med* 1986;20:31-33.

77. Stuart MJ, Morrey MA, Smith AM, Meis JK, Ortiguera CJ. Injuries in youth football: a prospective observational cohort analysis among players aged 9-13 years. *Mayo Clin Proceed* 2002;77:317-322.

78. Sullivan JA, Gross RH, Grana WA, Garcia-Moral CA. Evaluation of injuries in youth

soccer. *Am J Sports Med* 1980;8:325-7.

79. Thompson N, Halpern B, Curl WW, Andrews JR, Hunter SC, McLeod WD. High school football injuries: Evaluation. *Am J Sports Med* 1987;15:S97-S104.

80. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and it's value in predicting injury. *Med Sci Sport Exerc* 1984;16:64-66.

81. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;13:259-62.

82. Tursz A, Crost M. Sports related injuries in children. A study of their characteristics, frequency, and severity, with comparison to other types of accidental injury. *Am J Sports Med* 1986;14:294-9.

83. Upton PAH, Roux CE, Noakes TD. Inadequate pre-season preparation of school-boy rugby players - a survey of players at 25 Cape Province high schools. *South African Med J* 1996;86:531-3.

84. Van Mechelen W, Twisk J, Molendijk A, Blom B, Snel J, Kemper HCG. Subject-related risk factors for sports injuries: a one year prospective study in young adults. *Med Sci Sports Exerc* 1996;28:1171-9.

85.Watson AWS. Sports injuries during one academic year in 6799 Irish school children. *Am J Sports Med* 1984;12:65-71.

86. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999;9:41-7.

87. Weir MA, Watson AWS. A twelve month study of sports injuries in one Irish school.

IJMS 1996; :165-9.

88. Woodford-Rogers B, Cyphert L, Denegar CR. Risk factors for anterior cruciate ligament injury in high school and college athletes. *J Athletic Train* 1994;29:343-6,376-7.

89. Wright KJ, De Cree C. The influence of somatotype, strength and flexibility on injury occurrence among female competitive olympic style gymnasts - a pilot study. *J Phys Ther Sci* 1998;10:87-92.

90. Yde J, Nielsen AB. Sports injuries in adolescents' ball games: soccer, handball and basketball. *Br J Sports Med* 1990;24:51-54.

91. Zaricznyj B, Shattuck LJM, Mast TA, Robertson RV, D'Elia G. Sports-related injuries in school aged children. *Am J Sports Med* 1980;8:318-24.

Chapter 3

Is there a clinical standing balance measurement appropriate for use in sports medicine?

A review of the literature

This paper has been published in

Journal of Science and Medicine in Sport 2003;6(4):492-504639..

3.1 Introduction

Proprioceptive balance training has become a major component of rehabilitation in sports medicine and is quickly gaining recognition as an important element in pre-season injury prevention programs for many athletes.[3,4,14,20,36,48,58,88,104,106108] As such, the ability to measure standing balance using an appropriate clinical measurement tool is essential in further examining the effectiveness of proprioceptive balance training in rehabilitation and injury prevention programs in sports medicine.

The objectives of this review of the literature are:

1. To define proprioception and balance in the context of sport.
2. To review the evidence examining decreased balance as a risk factor for injury in sport and balance training as a sports injury prevention strategy.
3. To examine the reliability and validity of clinical balance measurements described in the literature.
4. To examine factors potentially influencing balance in a healthy population.
5. To discuss the implications for future research in identifying clinical balance measurement tools appropriate for use in sports medicine rehabilitation and injury prevention.

3.2 Proprioception and Balance in the Context of Sport

One may define proprioception as the afferent input of joint position sense (ie. awareness of joint position or movement).[58] However, many consider it in a broader sense that includes neuromuscular and postural control including balance.[58] Balance can be defined as the ability to maintain the body's center of gravity over its base of support with minimal sway or maximal steadiness.[54,94] The center of gravity refers to a point in the body at which the total force of gravity is considered to act and that is projected vertically onto the support surface.[74] The ability to maintain balance is based on the complex interaction between the somatosensory, vestibular and visual functions and the broader concept of coordination of movements with muscle activity.[43,54]

There are several postural control strategies identified in the literature to maintain balance in a variety of activity circumstances (both static and dynamic).[63] The ankle strategy restores stability through body movement centered primarily around the ankle joint when perturbation to equilibrium is small and the support surface firm.[54,72] The hip strategy is used when larger perturbations are experienced and the ankle strategy doesn't provide enough force to maintain postural stability and the movement is focused primarily at the hip joint.[53,54] When the perturbation is large enough to displace the center of gravity outside the person's base of support, the stepping or hopping strategy is used to regain balance.[94] Unique muscle synergies are used to adapt these postural strategies to a variety of dynamic circumstances.[94]

In many sporting activities an athlete's lower extremity joints and soft tissues are subject to significant dynamic forces during running, jumping, landing, rapid stopping and/or pivoting (ie. basketball, soccer, volleyball, track, gymnastics and hockey). It is sports involving such forces that are the most relevant in the discussion of standing balance and proprioceptive balance training in sport. The ability of a knee or ankle joint, for example, to remain stable during such activity is referred to as dynamic joint stability.[110] Excessive loads applied to these joints during athletic activities may result in joint or soft-tissue injury if the loads exceed the strength of the stabilizing structures (ie. ligaments, muscles, joint capsule, cartilage, articular structure). The ability of an athlete to maintain dynamic joint stability and avoid injury or re-injury is based on a complex interaction of numerous neuromuscular mechanisms involving sensory organs (ie. mechanoreceptors), neural pathways at three levels (spinal cord, brainstem and cerebellum, and the cerebral cortex) and muscle.[110]

Preventing injury in a dynamic sporting situation will depend on: 1. the direction and magnitude of destabilizing force, 2. the rate at which loads are applied to the stabilizing structures (ie. ligament), 3. the amount of muscle activity present as the event unfolds, 4. the joint position and activity performed, and 5. anticipation of the ensuing injury mechanism.[110] If an athlete could anticipate occurrence of an injury, the coordinated muscular response could begin prior to the injury mechanism onset to reduce its impact in an effort to prevent the injury.[92] Theoretically, the odds of injury may be reduced by the presence of preprogrammed movement strategies that could be triggered when receptors detected an impending injury.[63] By improving dynamic postural control and balance and producing more coordinated and consistent movement patterns during athletic participation, some injury may be prevented.[63] Dynamic proprioceptive balance training may be the key intervention which will improve postural control in athletic situations and prevent some injuries in sport.

3.3 Is Decreased Balance a Risk Factor or Balance Training a Prevention Strategy for Injury in Sport?

There have been few studies examining balance as a risk factor or balance training as a prevention strategy for injury in sport. Tropp et al[101] demonstrate that soccer players with functional ankle instability and poor balance, based on abnormal stabilometric values, were at significantly greater risk of ankle sprain re-injury. There have been other studies examining a balance training program as a prevention strategy for specific re-injury in sport. There is randomized controlled trial (RCT) evidence that athletes with previous history of ankle sprain injury were at significantly decreased risk of re-injury following a balance training program using a wobble board [Relative Risks (RRs)= 0.24-0.46].[52,104,108] There was no measurement of balance reported in any of these trials, hence the effectiveness of proprioceptive training in improving balance ability remains unclear. Gauffin et al[36] and Rozzi et al[88] demonstrate an improvement in balance in athletes post ankle sprain injury following wobble board training but do not examine re-injury rates. Hoffman & Payne[48] demonstrate an improvement in balance in healthy subjects following a balance training regime.

There is limited RCT evidence that proprioceptive balance training reduces the risk of specific injury (ie. ankle sprain, anterior cruciate ligament) in specific sports (ie. soccer, volleyball, European handball) with RR's ranging from 0.13 to 0.51.[3,20,106] The training programs in these studies have included other training components such as strength and agility. There is no measurement of balance examined in these studies at baseline or following the intervention. As a result, it is unclear in these studies whether or not the intervention directly affected balance ability. The effectiveness of balance training in rehabilitation to reduce re-injury or as a preseason prevention strategy remains unclear. An appropriate and reliable clinical measurement of balance must be defined before the effectiveness of balance training in the sports medicine setting will be well understood.

3.4 Balance measurements

Traditionally, many tests of balance consisted of measures of the length of time subjects can maintain a particular equilibrium position.[1933,41] These were originally used to assess balance in a population of patients with neurological disorders. In these tests, visual inputs were often minimized to assess the control of balance, dependent on the vestibular and somatosensory functions.

Many tests appropriate for use in a clinical setting have been developed for measurements of standing balance (Table 3.1). A simple unipedal static balance test is a widely used method to measure standing balance.[4,12,30,43,84,95] The relevance of static (ie. fixed base of support) testing conditions to the functional dynamic nature of sporting activity in adolescents is largely unknown. Static conditions may potentially fail to present enough challenge to elicit balance deficiencies in healthy active athletes.[85]

The concept of maintaining balance during dynamic conditions is not well understood. It is the point at which postural sway exceeds the ability to maintain postural control in a dynamic situation is important with respect to sports injury. Some clinical measurement tools have been developed in an attempt to measure dynamic balance. One such tool is the multiple single-leg hop-stabilization test.[85] This tool was developed to assess balance during a functional performance task in normal participants. Foam has been used to alter the proprioceptive feedback of the support surface in assessing dynamic balance.[24,85,92,107] The use of a tiltboard has been developed for assessing dynamic balance in children.[2,17,66] Functional reach tests have been used in children and the elderly to examine dynamic balance, not by an external force, but rather a self motivated reach.[16,26,65]

There are other functional tests used to measure balance, typically in the elderly and neurologically impaired population. [7-9,15,16,28,29,65,71,81,92,98,99,109] The Berg Balance Test involves tasks which are scored according to quality of performance or time to complete task (ie. sit to stand, transfers, standing eyes closed, turning 360 degrees, standing on one foot).[7-9,83,97] Other similar tests include the Postural Assessment Scale for Stroke patients, the Functional Independence Measure and the Continuous- scale Physical Function Performance test.[6,14,22] These tests will not be examined further, as they are inappropriate for use in sports medicine, based on the simplicity of the tasks assessed.

Many laboratory techniques including force platforms (ie. stabilometry, posturography), electromyography, and motion analysis (ie. accelerometry, three dimensional motion analysis) are expensive, complicated and often non-portable, hence, unsuitable for clinical settings and population based field studies.[1,9,18,25,34,35,38,39,49,53,55,56,60,66,69,80,89,101-103,111] Some of these laboratory measurement techniques examine dynamic balance with the addition of internal or external perturbation. An example of internal perturbation is through electrical stimulus to the tibial nerve as described by Hoffman & Koceja.[49] External perturbation has been described using a pulley weight system or a platform tilt system.[28,44,64,66] The equipment and variables measured to quantify balance across laboratory techniques vary greatly between studies (ie. postural sway velocities in various planes, maximum excursion of centre of pressure, ground reaction forces, acceleration of postural sway movements.)

3.4 Reliability of Clinical Balance Measurements

Measurement reliability is the degree of stability exhibited when a measurement is repeated under identical conditions or the degree to which the results obtained by a measurement procedure can be replicated.[59] Test-retest reliability of a balance measurement refers to the reproducibility of a test result upon repetition under identical conditions. If one wishes to use a clinical balance measurement as an outcome measure in rehabilitation or injury prevention setting, the reliability of the test used is crucial. It is also essential to examine inter-tester reliability of an outcome measurement to ensure the findings are generalizable to multiple examiners. In examining the reliability of clinical balance measurements in the literature, the most common methods of statistical analysis to describe test-retest reliability are Pearson correlation coefficients (r) and intraclass correlation coefficients (ICC's).[91] Excellent reliability is often used to describe an ICC>0.75.[32]

The results of studies examining clinical balance measurements are summarized in table 3.1. Unipedal static timed balance measurements examined in various age groups demonstrate variable test-retest reliability on eyes open testing (ICC= 0.68-0.95) and eyes closed testing (ICC=0.44-0.95).[2,4,13,95] Inter-rater reliability, however, for timed balance testing (eyes-open and closed) is more consistent across studies (ICC=0.93-0.96).[2,84] Test-retest reliability of a static functional reach test reported are also consistent across studies (ICC=0.75-0.99).[16,26,65] Dynamic balance testing using a wobble board and a scoring system has been examined, demonstrating consistently poor test-retest reliability (ICC=0.45-0.54) but good inter-rater reliability (ICC=0.91-0.96).[2,17] Riemann et al[84] demonstrate no difference in repeated testing of dynamic balance on a foam surface using an error scoring system and good inter-rater reliability (ICC=0.92). Riemann et al[85] developed a hop stabilization test on a numbered floor pattern in an attempt to measure dynamic balance using a balance and landing error scoring system. Again, though inter-rater reliability of balance error scoring system was good (ICC=0.92), test-retest reliability was poor.

Table 3.1: Studies examining reliability of clinical measurements of balance

Clinical Balance Test	Outcome measure	Test-retest Reliability	Inter-rater Reliability	Validity
Static unipedal stance (Eyes open)	Maximum time maintained	Atwater (1990):[2] (r=0.91) Balogun (1992):[4] (ICC=0.95) Stones (1987):[95] (r=0.68)	Atwater (1990):[2] (r=0.96)	Nil
Static unipedal stance (Eyes closed)	Maximum time maintained	Atwater (1990):[2] (r=0.59-0.77) Balogun (1992):[4] (ICC=0.95) Bohannon (1993):[13] (ICC=0.44-0.75) Stones (1987):[95] (r=0.68)	Atwater (1990):[2] (r=0.96)	Ekdahl (1989):[30] (r= -0.31--0.42) Stabilometry sway path measurements (length, velocity, area)
	Error scoring system	Riemann (1999[1]):[84] (F(1,10)=0.71, p=0.503)	Riemann (1999[1]):[84] (ICC=0.93)	Riemann (1999[1]):[84] (r = 0.42) Stabilometry sway path measurements (area)

Dynamic bipedal stance tiltboard tests (Eyes open)	Error scoring system	Atwater (1990):[2] (r=0.45)	Atwater (1990):[2] (r=0.96-1.0)	Nil
	Angle of tilt (major postural adjustment)	Broadstone (1993):[17] (ICC=0.49-0.54)	Nil	
	Error scoring system		Mattacola (1997): (ICC=0.91-0.92)	
Dynamic stance using foam surface	Error scoring system (bipedal)	Deitz (1991):[24] (r = 0.05-0.83)	Crowe (1991):[23] (r=0.82-0.92)	
	Error scoring system (unipedal)	Riemann (1999^1):[84] (F(1,10)=1.08, p=0.358)	Riemann (1999^1):[84] (ICC=0.92)	Riemann (1999^1):[84] (r = 0.79) Stabilometry sway path measurements (area)
Functional Reach test	Maximum lateral distance reached maintaining balance (cm)	Brauer (1999):[16] (ICC=0.99)	Nil	Nil
	Maximum anterior distance reached maintaining balance (cm)	Donahoe (1994):[26] (ICC=0.83) Mackenzie (1999):[65] (ICC=0.79)	Donahoe (1994):[26] (ICC=0.98)	
Multiple single-leg hop stabilization test on numbered floor pattern	Scoring system for balance and landing errors	Riemann (1999^2):[85] (F(2,28)=4.32, p=0.023)	Riemann (1999^2):[85] (ICC=0.92)	Nil

3.6 Validity of Clinical Balance Measurements

Last[59] defines measurement validity as the degree to which a measurement measures what it purports to measure. Concurrent validity is examined by comparing one measurement to another (often the gold standard).[82] There are some studies that examine concurrent validity by comparing a clinical balance measurement to a laboratory balance measurement (table 3.1). Ekdahl et al[30] demonstrate significant negative correlations between sway path measurements (length, velocity and area) using stabilometry in blindfolded unipedal stance and timed balance measurement in the same position. Riemann et al[84] examined eyes closed unipedal balance ability on both a flat surface and a medium density foam surface using a balance error scoring system and a force plate target sway measure based on maximal excursion of the center of pressure. There was a significant association found between sway measures and error scores.

Predictive validity describes the extent to which the outcome on a target test can be used to predict a future outcome. Balance measurements have been used to predict injury in the athlete and falls and other functional measures in the elderly. There have been some studies described previously, examining balance training as a prevention strategy for injury in sport. Tropp et al[101] demonstrate that soccer players with functional ankle instability and poor balance, were at significantly greater risk of ankle sprain re-injury. Other studies have examined predictive validity of balance measurements in the elderly and neurological populations. Some study findings, for example, include positive correlations between balance measurements and gait velocity, stride length and physical activity or mobility levels.[31,47,64,77] Topper et al[100] demonstrate force platform balance measurements to be predictive of falls in the elderly and O'Brien et al[75] demonstrate an association between several clinical balance measurements and falls in the elderly.

3.7 Factors Potentially Influencing Balance:

Consideration of factors which may potentially influence balance is critical in examining any balance measurement as an outcome measure in rehabilitation or injury prevention research. Factors which may potentially influence balance ability are age, gender, leg dominance, height, weight, foot size, footwear, previous injury, sport participation level, sport participation specificity, visual feedback, learning effects and fatigue.

Postural sway (length, velocity and/or area of sway path) has been shown to increase with age.[5,21,27,30,31,46,57,70,90] Timed unipedal balance has been shown to decrease with age.[12,30,95] Most of these studies examine this relationship over a wide age range (ie. adolescent to elderly). Hahn et al[43] failed to demonstrate this relationship in competitive athletes aged 14 to 24 years. Peeters et al[79] demonstrated that stability increased with age in both boys and girls ages 6 to 15. Studies measuring functional reach in children also found age to be a predictor of functional reach.[26,29,42]

Some studies have demonstrated a relationship between gender and postural sway (length, velocity and/or area of sway path) and/or timed unipedal balance, with women demonstrating better balance ability.[30,68,7] Peeters et al[79] demonstrated that girls ages 6 to 10 demonstrated better postural stability than boys in the same age group, however, boys ages 11-15 demonstrated better postural stability than girls in the same age group. Others fail to demonstrate any significant relationship between balance ability and gender in adults.[10,11,21,43,96]

All studies examining leg dominance failed to demonstrate a difference in balance ability between the dominant and non-dominant legs in healthy subjects.[12,38,39,43,95,96,102]

In theory, factors which lower the centre of gravity (ie. sitting, decreased height) and increase the base of support (ie. bipedal, foot size) will increase postural stability.[94] Odenrick et al[76] found both height and weight to be predictors of increased postural sway in boys and girls ages 5 to 15. Habib & Westcott[42] found that increased base of support (foot length) was a significant predictor of balance ability in children. Peeters et al[79] and Ekdahl et al,[30] however, demonstrated that height and weight had no direct influence on stability parameters measured using posturography and stabilometry respectively. Robbins et al[86] and Robbins et al[87] demonstrate that balance is also related to footwear sole properties. It was demonstrated that balance improved with increasing mid-sole hardness and decreasing mid-sole thickness.

In examining balance as an outcome measurement in sports medicine, it is important to consider activity level and specificity. Ekdahl et al[30] failed to demonstrate an association between postural stability and work or leisure activities. Hahn et al[43] demonstrated that timed unipedal balance was not associated with type of sport as such, but was positively associated with hours per week of basketball and number of years of basketball and negatively associated with hours of swimming.

In development of a clinical balance measurement tool, testing conditions may include variable visual feedback and repetitive testing. As such, visual conditions, potential fatigue and learning effects should be considered. Diminishing visual feedback with eyes closed or blindfolded conditions consistently demonstrate decreased postural stability in comparison to eyes opened conditions.[1,12,30,38,39,43,57,62,95,96] Geurts et al[37] failed to demonstrate a significant learning effect between stabilometry measures in bipedal stance over 5 measurement sessions at biweekly intervals. Balogun et al[4] and Ekdahl et al[30] demonstrated similar findings at weekly measurement intervals, however, demonstrated learning effects after one trial session on the same day. This learning effect over repeated trials on the same day was also demonstrated by Holliday & Fernie[51] and Ageberg et al.[1] Nawoczenzi et al[73] reported a learning effect using a Stability Testing and Rehabilitation Station (STARStation ®) over the first three of six trials on the same day, with plateauing of measurement variability following the third trial. Thus, no evidence of fatigue was demonstrated over 6 trial sessions using this protocol.

In sports medicine, one must always consider the impact of previous injury on any outcome measurement. Previous ankle and knee injury appears to decrease postural control. Significant differences in balance measurements between previously injured and uninjured athletes are consistently reported.[34,40,45,50,60,61,102,103,105,111] However, failure to demonstrate differences in unipedal balance between the injured and uninjured extremity in the same athlete suggests some carry over effect between extremities.[34,45,50,102]

3.8 Discussion

Impaired dynamic unipedal balance may be a significant risk factor for injury in sport. There is limited evidence to support decreased static unipedal balance ability as a risk factor for ankle injury in soccer. Other studies have demonstrated proprioceptive balance training as an effective prevention strategy for specific injury in specific sports, however, no measurement of static or dynamic balance is examined in these studies at baseline or following the intervention. It is unclear in these studies, whether or not the intervention directly affected balance ability. It is necessary to determine the effectiveness of a proprioceptive balance training program in improving unipedal dynamic balance, prior to establishing it's effectiveness as an injury prevention strategy in sport. This cannot be accomplished without reliable clinical dynamic balance measurement tools appropriate for use in specific athletic populations.

Laboratory measurement techniques for balance use costly, highly technical, and often non-portable equipment and hence are not appropriate for use in a clinical setting or for research in a large field based clinical trial. Some clinical tools for measurement of balance have been developed for use in the clinical setting. Many clinical balance tools which have been developed for use in the elderly and neurologically impaired populations are not appropriate for use in the healthy active population, as they are not challenging enough or they are static balance measures.

Good test-retest reliability and inter-rater reliability of a timed static unipedal balance test (eyes open and eyes closed tests) and dynamic unipedal balance test (eyes open and eyes closed test), using a foam support surface, based on an error scoring system have been established (see table 1). The studies which have demonstrated poor reliability of a timed static unipedal balance test either used an inappropriate length of time between measurements (ie. 1 year), evaluated a neurologically impaired population or allowed for an inadequate length of time for measurement trial, resulting in skewed data.[12,13,95] Attempts to establish adequate test-retest reliability of a dynamic unipedal balance test using a tilt board in children or a hop-stabilization test have not been successful to date.[2,17,85] Though functional reach tests are consistently reliable, it could be argued that the nature of the tool does not replicate the dynamic nature of sporting activity and is likely more appropriate in an elderly or neurologically impaired population. The reported use of a foam support surface for the measurement of balance has been reliant on an observer scoring system (based on observed sway, movement strategy and time) and variable test-retest reliability has been demonstrated.[24,84]

Validity of clinical balance measurements has been examined in the elderly and neurologically impaired populations to predict functional outcomes and falls. These studies use clinical balance measurements which are not appropriate for use in a healthy athletic population. There is minimal research examining balance as a risk factor or balance training as a prevention strategy for injury in sport, using balance also as an outcome measurement.

Factors which may influence balance ability in the athletic population must be considered in examining balance as an outcome measurement in rehabilitation or a risk factor for injury in sport. A review of these factors will assist the researcher in determining which factors should be assessed in conjunction with any research in sports medicine examining balance as an outcome measurement. Factors to be considered should include: age, gender, height, weight, foot length, footwear, physical activity level and type, and previous lower extremity injury.

3.9 Conclusions

There is likely not one dynamic balance measurement tool appropriate for use globally in sports medicine, given the complexity of dynamic balance and the sport specificity of dynamic forces acting on the joints and soft tissues. However, development of a suitable clinical balance measurement to examine dynamic balance in sports with similar dynamic forces (ie. basketball, soccer, volleyball) would be appropriate. Any such measurement should be simple to administer, inexpensive and feasible for use in large populations by multiple examiners. Perhaps further development of a timed unipedal dynamic balance measurement, with the use of foam to alter proprioceptive feedback from the support surface, may be appropriate to consider for measurement of dynamic balance in sports medicine. Reliability, concurrent validity with a static balance test, norms and influencing factors need to be examined in the development of such a clinical balance tool prior to its use in research examining balance as an outcome measurement in rehabilitation or sports injury prevention.

References

1. Ageberg E, Zatterstrom R, Moritz U. Stabilometry and one-leg hop test have high test reliability. *Scand J Med Sci Sport* 1998;8:198-202.

2. Atwater SW, Crowe TK, Deitz JC, Richardson PK. (1990) Inter-rater and test-retest reliability of two pediatric balance tests. *Phys Ther* 1990;70:79-87.

3. Bahr R, Lian O. (1997) A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports Sport* 1997;7: 172-177.

4. Balogun JA, Adesinasi CO, Marzouk DK. The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada* 1992;44:23-30.

5. Baloh RW, Fife TD, Zwerling L, Socotch T, Jacobson K, Bell T, Beykirch K. Comparison of static and dynamic posturography in young and older normal people. *J Am Ger Soc* 1994;42:405-12.

6. Benaim B, Perennou A, Villy J et al. Validation of a standardized assessment of postural control in stroke patients. *Stroke* 1999;30:1862-1868.

7. Berg K, Wood-Daphinee S, Williams JI, Gayton D. Measuring balance in the elderly.: Preliminary development of an instrument. *Physiotherapy Canada* 1989;41:304.

8. Berg K, Wood-Daphinee S, Williams JI, Maki B. Measuring balance in the elderly:Validation of an instrument. *Can J Pub Health* 1992;83:S7-11.

9. Berg K, Wood-Daphinee S. The balance scale: Reliability assessment with elderly residents and patients with an acute stroke. Scand J Rehab Med 1995;27:27-36.

10. Black FO, Wall C, Rockette HE, Kitch R. Normal subject postural sway during the Romberg Test. *Am J Otolaryng* 1982;3:309-318.

11. Brocklehurst JC, Robertson D, James-Groom P. Clinical correlates of sway in old age-sensory modalities. Age and Ageing 1982;16:1-10.

12. Bohannon RW, Larkin PA, Cook AC, Gear J, Singer J. Decrease in timed balance test scores with aging. Phys Ther 1984;64:1067-70.

13. Bohannon RW, Walsh S, Joseph MC. Ordinal and timed balance measurements: reliability and validity in patients with stroke. *Clin Rehab* 1993;7:9-13.

14. Bohannon RW, Leary KM. Standing balance and function over the course of acute rehabilitation. *Arch Phys Med Rehab* 1995;76:994-996.

15. Bonanni M, Newton R.Test-retest reliability of the Fukuda Stepping Test. *Phys Res Int* 1998;3:58-68.

16. Brauer S, Burns Y, Galley P. Lateral reach: a clinical measure of medio-lateral postural stability. *Phys Res Int* 1999;4:81-88.

17. Broadstone BJ, Westcott SL, Deitz JC. Test-retest reliability of two tiltboard tests in children. *Phys Ther* 1993;73:618-25.

18. Brouwer B, Culham EG, Liston RAL, Grant T. Normal variability of postural measures: Implications for the reliability of relative balance performance outcomes. *Scand J Rehab Med* 1998;30:131-137.

19. Bruininks RH. *Bruininks-Oseretsky Test of Motor Proficiency: Examiner's Manual.* American Guidance Service, Circle Pines, MN 1998.

20. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. Knee Surg Sport Traumatol Arthrosc 1996;4: 19-21.

21. Colledge NR, Cantley P, Peaston I, Brash H, Lewis S, Wilson JA. Ageing and balance: the measurement of spontaineous sway by posturography. Gerontol 1994;40:273-278.

22. Cress ME, Buchner DM, Questad KA et al. Continuous-scale physical functional performance in healthy older adults: a Validation study. Arch Phys Med Rehab 1996;77:1243-1250.

23. Crowe TK, Deitz JC, Richardson PK, Atwater SW. Interrater reliability of the pediatric clinical test of sensory interaction for balance. *Phy Occup Ther Pediatr* 1991;10:1-27.

24. Deitz JC, Richardson P, Atwater SW, Crowe TK, Odiorne M. Performance of normal children on the Clinical Test of Sensory Interaction for Balance. Occ Ther J of Res 1991;11:336-356.

25. Dickstein R, Dvir Z. Quantitative evaluation of stance balance performance in the clinic using a novel measurement device. *Physiotherapy Canada* 1993;45 (2):102-108.

26. Donahoe B, Turner D, Worrell T.The use of functional reach as a measurement of balance in boys and girls without disabilities ages 5 to 15 years. *Ped Phys Ther* 1994;6:189-193.

27. Dornan J, Fernie GR, Holiday PJ.Visual input: its importance in the control of postural sway. *Arch Phys Med Rehab 1978;59*:586-591.

28. Duncan PW, Studenski S, Chandler J, Bloomfeld R, LaPointe LK. Electromyographic analysis of postural adjustments in two methods of balance testing. *Phys Ther* 1990;70: 88-96.

29. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional Reach: A new clinical measure of balance. J Gerontol 1990;45:M192-7.

30. Ekdahl C, Jarnlo G-B, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. *Scand J Rehab Med* 1989;21:187-195.

31. Era P, Heikkinen E. Postural sway during standing and unexpected disturbance in balance in random samples of men of different ages. *J Gerontol* 1985;40:287-295.

32. Fleiss JL. *The design and analysis of clinical experiments.* John Wiley and Sons, New York 1986.

33. Fregly A, Graybiel A. An ataxia test battery not requiring rails. *Aerospace Med 1968;39*:277-282.

34. Friden T, Zatterstrom R, Lindstrand A, Moritz U. A stabilometric technique for the evaluation of lower extremity instabilities. *Am J Sport Med* 1989;17:118-122.

35. Furman JMR, Baloh RW, Barin K. Assessment: Posturography. *Neurol* 1993;43:1261-1264.

36. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sport Med* 1988;9:141-144.

37. Geurts ACH, Nienhuis B, Mulder TW. Intrasubject variability of selected force-platform parameters in the quantification of postural control. Arch Phys Med Rehab 1993;74:1144-50.

38. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: Reliability and validity. *Arch Phys Med Rehab* 1989;70:510-517.

39. Goldie PA, Evans OM, Bach TM. Steadiness in one-legged stance: Development of a reliable force-platform testing procedure. *Arch Phys Med Rehab* 1992;73:348-54.

40. Goldie PA, Evans OM, Bach TM. (1994) Postural control following inversion injuries of the ankle. *Arch Phys Med Rehab* 1994;75:969-75.

41. Graybiel A, Fregly A. A new quantitative ataxia test battery. *Acta Otolaryng (Stockholm)* 1966;61:292-321.

42. Habib Z, Westcott S. Assessment of anthropometric factors on balance tests in children. Ped Phys Ther 1998;10:101-109.

43. Hahn T, Foldspang A, Vestergaard E, Ingermann-Hansen T. One-legged standing balance and sports activity. *Scand J Med Sci Sport* 1999;9:15-18.

44. Harburn KL, Hill KM, Kramer JF et al. Clinical applicability and test-retest reliability of an external perturbation test of balance in stroke subjects. *Arch Phys Med Rehab* 1995;76:317-323.

45. Harrison EL, Duenkel N, Dunlop R, Russell G. Evaluation of single-leg standing following anterior cruciate ligament surgery and rehabilitation. *Phys Ther* 1994;74:245252.

46. Hasselkus BR, Shambes GM. Aging and postural sway in women. *J Gerontol* 1975;30:661-667.

47. Hill KD, Bernhardt J, McGann AM. A new test of dynamic standing balance for stroke patients: reliability, validity and comparison with healthy elderly. *Physiotherapy Canada* 1996;Fall:257-262.

48. Hoffman M, Payne VG. The effects of proprioceptive ankle disk training on healthy subjects. J Orthop Sport Phys Ther 1995;21:90-94.

49. Hoffman MA, Koceja DM. Dynamic balance testing with electrically evoked perturbation: a test of reliability. *Arch Phys Med Rehab* 1997;78:290-3.

50. Hoffman M, Schrader J, Koceja D. An investigation of postural control in postoperative anterior cruciate ligament reconstruction patients. *J Athlet Train* 1999;34:130-136.

51. Holliday PJ, Fernie GR. Changes in the measurement of postural sway resulting from repeated testing. *Agressologie* 1979;20:225-8.

52. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sport* 1999;9: 104-109.

53. Horak FB, Nashner LM. Central programming of postural movements: Adaptation to altered support surface configurations. *J Neurophysiol* 1986;55:1369-81.

54. Horak FB. Clinical measurement of postural control in adults. Phys Ther 1987;67:1881-1885.

55. Kamen G, Patten C, Duke Du C, Sison S. An accelerometry based system for the assessment of balance and postural sway. *Gerontol* 1998;44:40-45.

56. Kejonen P, Kauranen K, Vanharanta H. Body movements in postural balance with motion analysis. *Europ J Phys Med Rehab* 1998;8:39-43.

57. Kolleger H, Baumgartner C, Wober C, Ober W, Deecke L. Spontaneous body sway as a function of sex, age, and vision: Posturographic study in 30 healthy adults. *European Neurol* 1992;32:253-259.

58. Laskowski ER, Newcomer-Aney K, Smith J. Refining rehabilitation with proprioceptive training. Expiditing return to play. *Physician and Sportsmed* 1997;25: 89-102.

59. Last, JM (ed). *A Dictionary of Epidemiology (3rd Ed).* Oxford University Press, New York, 1995.

60. Leanderson J, Wykman A, Eriksson E. Ankle sprains and postural sway in basketball players. *Knee Surg Sport Traumatol Arthrosc* 1993;1:203-205.

61. Leanderson J, Eriksson E, Nilsson C, Wykman A. Proprioception in classical ballet dancers. A prospective study on the influence of an ankle sprain on proprioception in the ankle joint. *Am J Sport Med* 1996;24:370-373.

62. Lee DN, Lishman JR. Visual proprioceptive control of stance. *J Hum Mov Stud* 1975;1:87-95.

63. Lephart SM. Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sport Med* 1998;25:149-155.

64. Liston RAL and Brouwer BJ. Reliability and validity of measures obtained from stroke patients using the balance master. *Arch Phys Med Rehab* 1996;77: 425-430.

65. Mackenzie M. A simplified measure of balance by functional reach. *Phys Res Int* 1999;4:233-236.

66. Mattacola CG, Lebsack DA, Perrin DH. Intertester reliability of measuring postural sway using the Chattecx Balance System. *J Athlet Train* 1995;30:237-242.

67. Mattacola CG, Wills Lloyd J. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: A single-case design. J Athlet Train 1997;32:127-135.

68. Mechling RW. Objective assessment of postural balance through the use of the variable resistance balance board. *Phys Ther* 1986;66:685-688.

69. Moe-Nilssen R.Test-retest reliability of trunk accelerometry during standing and

walking. *Arch Phys Med Rehab* 1998;79:1377-1385.

70. Murray MP, Seireg AA, Sepic SB. Normal postural stability and steadiness; quantitative assessment. *JBJS* 1975;57A:510-516.

71. Nakamura DM, Holm MB, Wilson A. Measures of balance and fear of falling in the elderly: A review. *Phys Occ Ther Ger* 1998;15 (4):17-32.

72. Nashner LM. Fixed patterns of rapid postural responsses among leg muscles during stance. Exp Brain Res 1977;30: 13-24.

73. Nawoczenski DA, Sharp WB, Maiers DJ, Patterson JE, Soderberg GL. Reliability of performance measurements obtained using the Stability Testing and Rehabilitation Station (STARStation®). *Phys Ther* 1991;71:706-714.

74. Nichols DS, Glenn TM, Hutchinson KJ. Changes in the mean center of balance during balance testing in young adults. *Phys Ther* 1995;75 (8):699-706.

75. O'Brien K, Pickles B, Culham E. Clinical measures of balance in community-dwelling elderly female fallers and non-fallers. *Physiotherapy Canada* 1998;Summer:212-221.

76. Odenrick P, Sandstedt P. Development of postural sway in the normal child. *Human Neurobiol* 1984;3:241-244.

77. Ostir GV, Markides KS, Black SA and Goodwin JS. Lower body functioning as a predictor of subsequent disability among older Mexican Americans. *J Gerontol Med Sci* 1998;53A: M491-M495.

78. Overstall PW, Exton-Smith AN, Imms FJ, Johnson AL. Falls in the elderly related to postural imbalance. *BMJ* 1977;8:261-264.

79. Peeters H, Breslau E, Mol J, Caberg H. (1984) Analysis of posturographic measurements on children. *Med Biol Eng Comp* 1984;22:317-321.

80. Pincivero D, Lephart SM, Henry T. Learning effects and reliability of the Biodex Stability System. *J Athlet Train* 1995;30:S35.

81. Podsiadlo D, Richardson S. The Timed "Up and Go": A test of basic functional mobility for frail elderly persons. *J Am Geriatric Society* 1991;34:119-26.

82. Portney LG, Watkins MP. *Foundations of Clinical Research.* Appleton & Lange, Stamford,CT, 1993.

83. Riddle DL, Stratford PW. Interpreting validity indexes for diagnostic tests: An illustration using the Berg Balance Test. *Phys Ther* 1999;79:939-948.

84. Riemann BL, Guskiewicz KM, Shields EW. Relationship between clinical and forceplate measures of postural stability. *J Sport Rehab* 1999[1];8:71-82.

85. Riemann BL, Caggiano NA, Lephart SM. (Examination of a clinical method of assessing postural control during a functional performance task. *J Sport Rehab* 1999[2];8:171-83.

86. Robbins S, Waked E, Gouw GJ, McClaran J. Athletic footwear affects balance in men. *BJSM* 1994;28:117-22.

87. Robbins S, Waked E, Allard P, McClaran J, Krouglicof N. Foot position awareness in younger and older men: the influence of footwear sole properties. *J Am Geriatr Soc* 1997;45:61-66.

88. Rozzi S, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *J Orthop Sport Phys Ther* 1999;29:478-486.

89. Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J Sport Rehab* 1998;7:95-101.

90. Sheldon JH. The effect of age on the control of sway. *Gerontol Clin* 1963;5:129-138.

91. Shrout PE and Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psych Bull* 1979;86:420-428.

92. Shumway-Cook, Horak FB. Assessing the influence of sensory interaction of balance. Suggestions from the field. *Phys Ther* 1986;66:1548-50.

93. Shumway-Cook A, Anon D, Haller S. Postural sway biofeedback: it's effect on reestablishing stance stability in hemiplegic patients. *Arch Phys Med Rehab* 1988;69: 395-400.

94. Shumway-Cook A, Woollacott M. *Motor control: Theory and practical applications.* Williams and Wilkins, Baltimore,Md,1995.

95. Stones MJ, Kozma A. Balance and age in the sighted and blind. *Arch Phys Med Rehab* 1987;68:85-9.

96. Stribley RF, Albers JW, Tourtellotte WW, Cockrell JL. A quantitative study of stance in normal subjects. *Arch Phys Med Rehab* 1974;55:74-80.

97. Thorbahn LDB, Newton RA. Use of the Berg Balance Test to predict falls in the elderly. *Phys Ther* 1996;76:576-585.

98. Tinetti ME. Performance oriented assessment of mobility problems in elderly patients. *J Am Geriatr Soc* 1986;39:142-8.

99. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *New Engl J Med* 1988;319:1701-7.

100. Topper AK, Maki BE, Holliday PJ. Are activity-based assessments of balance and gait in the elderly predictive of risk of falling and/or type of fall? *J Am Geriatr Soc* 1993;41:479-487.

101. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recording of single leg stance. *Am J Sport Med* 1984^1;12:185-188.

102. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and its value in predicting injury. *Med Sci Sport Exerc* 1984^2;16: 64-66.

103. Tropp H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. *Int J Sport Med* 1985^1;6:180-182

104. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sport Med* 1985^2;13:259-62.

105. Tropp H, Odenrick P. Postural control in single-limb stance. J Orthop Res 1988;6:833-839.

106. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sport* 1999;9: 41-47.

107. Westcott SL, Crowe TK, Deitz JC. Test-retest reliability of the Pediatric Clinical Test of Sensory Interaction for Balance. *Phys Occ Ther Ped* 1994;14:1-22.

108. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *J Orthop Sport Phys Ther* 1996;23: 332-336.

109. Whitney SL, Poole JL, Cass SP. A review of balance instruments for older adults. *Am J of Occup Ther* 1998;52:666-671.

110. Williams GN, Chmielewski T, Rudolph KS et al. Dynamic knee stability: Current theory and implications for clinicians and scientists. *J Orthop Sport Phys Ther* 2001;31:546-566.

111. Zatterstrom R, Friden T, Lindstrand A, Moritz U. The effect of physiotherapy on standing balance in chronic anterior cruciate ligament insufficiency. *Am J Sport Med* 1994;22:531-536.

Chapter 4

Development of a clinical static and dynamic standing balance measurement tool appropriate for use in healthy adolescents

4.1 Introduction

Proprioceptive balance training is a key component of rehabilitation following sports injury. [32,35,66,76] It is quickly gaining recognition as a vital component of injury prevention programs for many athletes, including adolescents.[4,21,41,80-82] Currently, there is no "reference standard" for the measurement of standing balance in a young active population. Measurement of standing balance using an appropriate clinical measurement tool is essential in further examination of the effectiveness of proprioceptive balance training. Development of such a measurement tool in healthy adolescents has not been previously reported.

Balance can be defined as the ability to maintain the body's center of gravity over it's base of support with minimal sway or maximal steadiness.[42,70] There is some evidence to suggest that decreased static unipedal balance is a risk factor for ankle sprain re-injury in soccer.[77] In sport, an athlete is typically visually attentive to the play and the activity is dynamic in nature at the time of injury. As such, impaired dynamic unipedal balance may be more relevant as a significant risk factor for injury in sport.[49,65]

There is some evidence from both RCT and non-randomized prospective studies that static balance does improve following proprioceptive balance training including a wobble board.[5,32,35,38,51,66,76] Most of these studies, however, exclusively examine improvement in static balance following ankle sprain injury. Other studies have demonstrated proprioceptive balance training to be effective in preventing specific injury in specific sport.[4,21,41,80-82] No measurement of static or dynamic balance is examined in these studies at baseline or following intervention. As such, the effect of these training programs on balance ability remains unclear.

Numerous measurement techniques have been described to measure a combination of static, dynamic, bipedal, and unipedal standing balance with varying levels of challenge in various populations. Stabilometry and accelerometry demonstrate extremely variable reliability on many different parameters measured.[20,29,34,43,61,67,25,52,56,82] There is little evidence of correlation between these parameters (i.e., center of pressure and ground reaction force measurements).[34] As such, there is no 'reference standard' laboratory balance measurement. There is limited evidence of significant correlation between clinically timed unipedal balance and sway path measurements using stabilometry.[29,64]

Laboratory measurement techniques use costly, highly technical, and often non-portable equipment. As such, they are not appropriate for use in many clinical or sporting settings. Furthermore, their reliability and validity in the measurement of dynamic balance remains unclear. Nevertheless, some tools for measurement of balance have been developed for use in the clinical setting. Many of these, which were developed for use in the elderly and neurologically impaired population, are not dynamic or challenging enough for use in the healthy adolescent population.[6-8,16,17,27,28,50,56,62,69,74,75,83] Adequate intra-rater and inter-rater reliability for timed static unipedal balance has been established in both children and adults.[3,5] The studies, which have demonstrated poor reliability of timed static unipedal balance, used an inappropriate length of time between measurements, evaluated a neurologically impaired population, or allowed for an inadequate length of time for measurement trials (i.e., many subjects reached the allowed maximum trial time).[14,15,72] Attempts to establish adequate reliability of a dynamic unipedal balance test using a tilt board in children or a hop-stabilization test have not been successful to date.[3,18,65] The reported use of a foam support surface for the measurement of balance has been reliant on an observer scoring system including observed sway (ie., minimal, moderate, large), movement strategy (ie., control of balance primarily initiated at the ankle, hip or trunk) and time.[23,24,64] Inter-rater reliability of these tests is excellent (ICC=0.82-0.92), however, variable intra-rater reliability (ICC or $r = 0.05-0.83$) has been reported.[23,24,64] The use of foam to alter proprioceptive feedback from the support surface and create a more dynamic task, may be an appropriate tool for measurement of timed dynamic unipedal balance in healthy adolescents.

The goals of this study are: 1.to determine the intra-rater, test-retest reliability and inter-rater reliability of a timed unipedal static and dynamic balance test, appropriate for use in healthy adolescents, 2. to examine the relationship between a timed dynamic unipedal balance test and a timed static unipedal balance test in healthy adolescents, 3. to develop norms for a timed static and dynamic unipedal balance test protocol in healthy adolescents, and 4.to determine the influence of age, gender, leg dominance, body-mass index, foot size (length and width), previous injury, sport participation level, sport participation specificity, and visual feedback on static and dynamic balance ability in healthy adolescents.

4.2 Methods

4.2.1 Study Design

This is a longitudinal repeated measures study design

4.2.2 Subjects

The sampling frame included 15 Calgary Board of Education high schools. We randomly selected ten schools using computer generation of random numbers using the

Stata statistical software package.[71] Consent was requested from the school principal and physical education (PE) coordinator prior to stratified random recruitment of students from grades 10, 11 and 12 PE classes. We randomly approached four subjects, two male and two female, from each of grades ten to twelve PE program rosters at each school. If a subject declined participation or dropped-out at the time of the baseline assessment, another student (from the same school, grade, and gender) was recruited.

Subjects were included if they were between the ages of 14 and 19 years and participating in PE class. Subjects were excluded from the study if they reported a previous history of a musculoskeletal injury (requiring medical attention and time loss from sporting activity of one or more days) in the six-weeks prior to recruitment, a previous history of a serious musculoskeletal disorder (fracture, rheumatological disease, systemic disease or surgery) in the six-months prior to recruitment or an ongoing medical condition (including high blood pressure or fainting/dizziness spells) or disability.

4.2.3 Procedures

Both the subject and their parent/guardian completed a written informed consent. Each subject was asked to complete a baseline questionnaire prior to the initial assessment (Appendix A). These were reviewed with the primary examiner. At baseline, the examiner also measured height (metres), weight (kilograms), and foot length and width (centimetres). Body-mass index was calculated by the formula, BMI = weight (kg)/ height $(m)^2$.

Each subject completed both a timed static unipedal balance test protocol on the gym floor surface and two timed dynamic unipedal balance test protocols on an Airex Balance Pad®. This is a high density (50 kilogram/cubic metre) closed cell foam pad (50 x 41 x 6 centimetres, 0.7 kilograms), manufactured by the L-group (St. Louis, Missouri). We randomly selected the order of leg examination for each subject for each test protocol (eyes closed static = ECS, eyes open dynamic = EOD and eyes closed dynamic = ECD). We randomized the order of testing of all three protocols by block randomization, with blocks of size six. A 30-second rest between protocols was provided. The timed measurements were completed using a stopwatch and recorded concurrently by two examiners.

For the static balance protocol (ECS), each subject completed three trials on each leg on the flat surface (Figure 4.1). A 15-second rest was allowed between trials. For the two dynamic balance protocols (EOD and ECD), the identical procedure was followed using the Airex Balance Pad® for the support surface (Figure 4.2). A 15-second practice session on the foam pad was allowed prior to the start of the test session to allow subjects some familiarity with this support surface.

To identify leg dominance, the subject was asked to kick a ball hard prior to balance testing. Hands were placed on the hips for both the static and dynamic trials. The testing foot was placed in the center of the foam. For the EOD trials, the stopwatch was started immediately upon elevation of the opposite foot from the floor. The subject focused on a target placed on a wall at eye level, four meters in front. For both the ECS and ECD trials, eyes were closed prior to elevation of the opposite foot from the floor. The examiners had no physical contact with the subject. Once the stopwatch had been started, no further verbal cues were given to the subject prior to loss of balance. The maximum time allowed for each test was 180 seconds. This was based on the findings of Hahn et al[5] in which only 1% of their healthy participants (ages 14-24 years) achieved this maximum time on the eyes-closed static unipedal balance test.

The stopwatch was stopped upon loss of balance or eyes opening in the eyes closed trials. Loss of balance included removal of one hand from the hip, touching the foam or floor with the non-weightbearing foot, movement of the weightbearing foot from its original position on the floor or foam, or movement of the foam from its original position in the dynamic balance tests.

The testing procedure was completed a second time with each subject, by the primary examiner, seven days following the initial test. All times were recorded on a record sheet (Appendix B).

Figure 4.1: Eyes-closed static balance

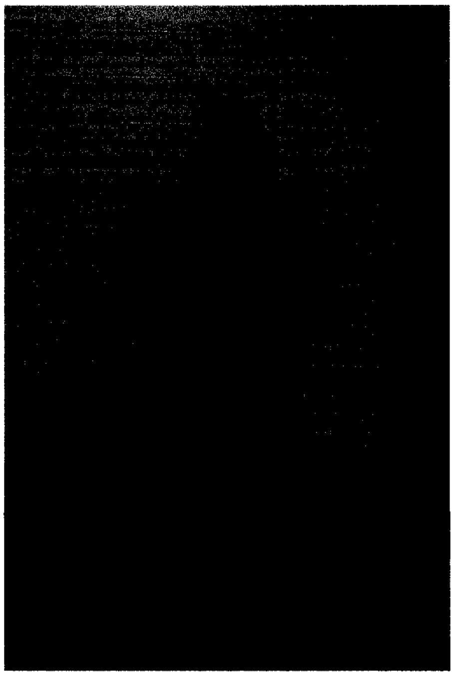
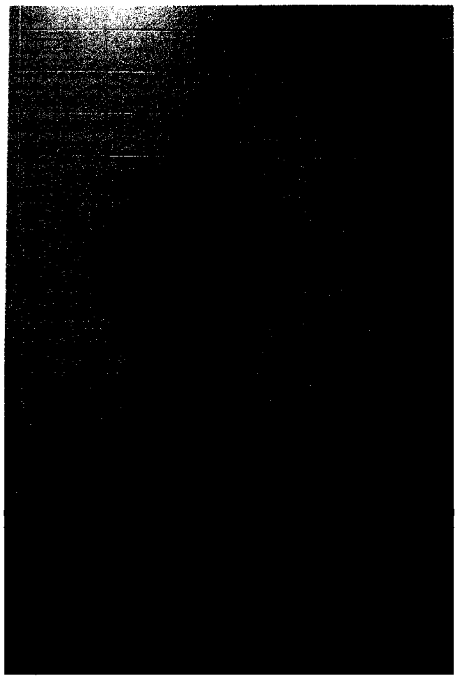


Figure 4.2: Eyes-closed dynamic balance



4.2.4 Analysis

Data analysis was performed using the Stata statistical software package.[71] Descriptive statistics are used to describe the sample of subjects participating in this study. Data were logarithmically transformed if the assumptions of normality and equal variance were not met for statistical tests.

4.2.4.1. Intra-rater test-retest reliability

For intra-rater test-retest reliability, all analyses were based on the primary examiners measurements at baseline and follow-up. The preferred technique for measuring agreement between two techniques or repeatability of a measurement is described by Bland and Altman.[10,13] This technique involves plotting the individual subject differences between test sessions against the individual mean scores for both test sessions.[2] There should be not be any graphical evidence of an association between the differences and the magnitude of the measurement (i.e., uniform scatter of points around the mean difference) in order to examine agreement using Bland and Altman methods. Heteroscedacity results when the differences between two measurements in examining repeatability are related to the magnitude of the measurement.[10] In this case, when log transformations are done to meet the assumptions of normality, the back-transformed results are described by a geometric mean ratio with 95% limits of agreement.[10] The interpretation of the geometric mean ratio is a ratio of the follow-up balance measurement to the initial balance measurement. The 95% limits of agreement describe the upper and lower limits of the expected ratio, 95% of the time.[10] Intra-class correlation coefficients (ICC) are also reported. The ICC (3,1)[*] and 95% confidence interval (95% CI) using the method described by Shrout and Fleiss, were calculated to assess intra-rater reliability with multiple scores from the same rater.[30,63,68] Intra-rater reliability was examined for each of three unipedal balance stances (ECS, EOD and ECD). Common

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[*] ICC (3,1) is based on Shrout and Fleiss model 3 (based on repeated measures ANOVA where tested raters are the only raters of interest), form 1 (single measurement is the unit of analysis rather than a mean). Calculations are based on a repeated measures ANOVA with one fixed effect for one rater.

guidelines for the interpretation of reliability based on ICC scores are; < 0.4 (poor), 0.4-0.75 (moderate), 0.75-0.9 (good), and >0.9 (excellent).[30,63]

4.2.4.2. Inter-rater reliability:

For inter-rater reliability, all analyses were based on both examiners measurements for all three primary outcome measurements at baseline. The preferred technique for measuring agreement between two examiners is described by Bland et al.[10] This technique involves plotting the individual subject differences between examiners against the respective individual mean scores from both examiners.[2] Again, there should not be any graphical evidence of an association between the differences and the magnitude of the measurement (i.e., uniform scatter of points around the mean difference) in order to examine agreement using Bland and Altman methods. As for intra-rater reliability, when log transformations were performed, a geometric mean ratio with 95% limits of agreement was calculated.[10] The interpretation of the geometric mean ratio in this case is a ratio of the second examiner's balance measurement to the primary examiner's balance measurement. The 95% limits of agreement describe the expected ratio of the two measurements, 95% of the time.[10] The ICC (2,1)[*] and 95% CI's were calculated using the method described by Shrout and Fleiss, where single ratings from all subjects are measured by raters who are representative of a larger population of similar raters.[63, 68]

4.2.4.3. Relationship between static and dynamic balance measurements:

The predictive validity of timed static unipedal balance for timed dynamic unipedal balance with the same visual conditions (eyes-closed) was examined using

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[*] ICC (2,1) is based on Shout and Fleiss model 2 (based on repeated measures ANOVA where raters are considered representative of a larger population of raters), form 1 (single measurement, not mean). Calculations are based on a repeated measures ANOVA with random effects for multiple raters.

baseline measurements by the primary examiner. Linear regression, was used to examine this relationship.[26]

4.2.4.4. The influence of intrinsic and extrinsic factors on timed dynamic unipedal balance measurement in healthy adolescents:

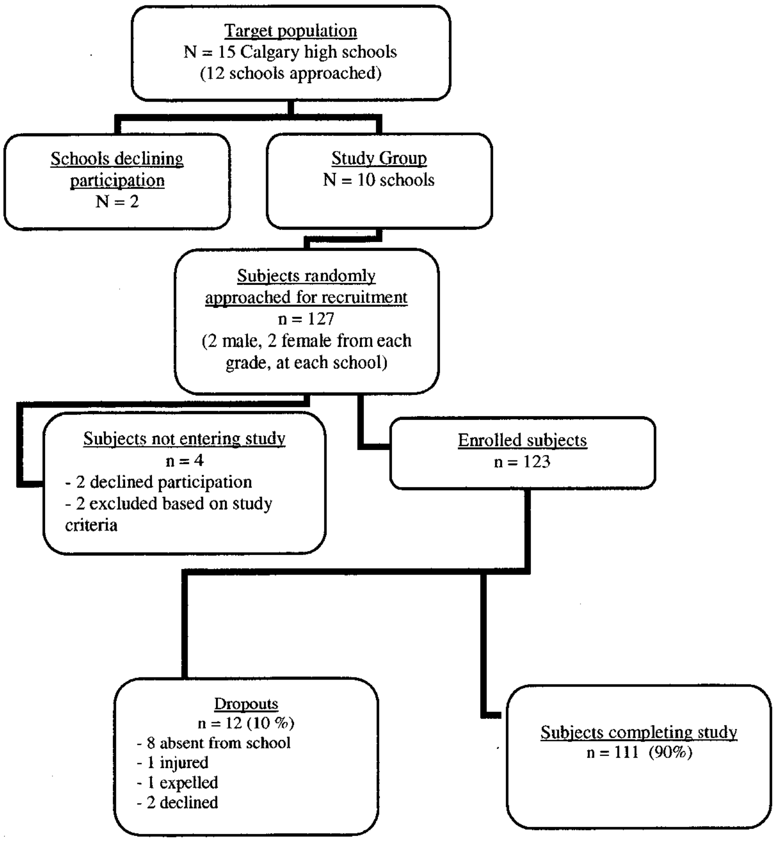
The influence of several factors including leg dominance, order of testing (block one to six), age (years), gender, body mass index (kg/m^2), foot length (cm), foot width (cm), previous lower extremity injury within one year, sport participation level (estimated hours/week in previous six week period) and sport participation specificity on static and dynamic balance in healthy adolescents was examined using multiple regression analysis. The effects of learning and/or fatigue were examined using repeated measures analyses of variance. Mean log time for unipedal balance on the right for each of ECS, EOD and ECD was compared across three trials at baseline.

4.3 Results

4.3.1 Descriptive Statistics

School and subject recruitment is summarized in Figure 4.3. A dropout included any subject who did not participate in both assessments (baseline and 1-week follow-up).

Figure 4.3: Flow Diagram summarizing recruitment of subjects



There were no significant differences between baseline covariates in subjects completing the study and dropout subjects (Appendix C [Table 4.i]). Baseline co-variables by gender are outlined in Appendix C (Table 4.ii + 4.iii).

The main outcome measurements included maximum time achieved over three trials for each of two legs on each of three tests (ECS, EOD and ECD). The maximum time allowed for each trial in all three tests was 180 seconds. On the ECS test, two of 123 subjects reached 180 seconds at the baseline assessment and 3 of 111 subjects reached 180 seconds at follow-up. Dropouts included one subject whom reached 180 seconds at baseline. As a result, four subjects were excluded from the analysis involving ECS balance based on achieving the maximum (180 seconds), 12 were dropouts and 107 subjects remained in analysis of reliability for ECS balance. On the EOD test, 22 of 123 subjects reached 180 seconds at the baseline assessment, and 27 of 111 subjects reached 180 seconds at the follow-up. As a result, 33 subjects were excluded from the data (n=78) in analysis of reliability for EOD balance.

A logarithmic transformation was required for all three tests in order to compare maximum time achieved on left and right legs, as maximum time achieved was right skewed and did not meet assumptions of normality (Appendix D [Figure 4.i]). Combining right and left leg results was considered appropriate based on paired t-tests examining the difference between legs based on the log maximum time of three trials for all three tests (paired t-tests: ECS t_{120}= -0.96,p=0.34; EOD t_{100}= -0.32, p=0.75; ECD t_{122}= -0.64,p=0.53) (Appendix D [Figure 4.ii]). The primary outcome measurement for further analyses was log maximum of six trials (three on each leg) for ECS, EOD and ECD balance. For all three tests, there was no difference in log maximum times between males and females (two-tailed Student's t-tests: ECS t_{119}= 1.72,p=0.09; EOD t_{99}= -0.06, p=0.96; ECD t_{121}= -0.28,p=0.78) (Table 4.ii). As such, the norms for all three balance tests (ECS, EOD, and ECD) based on the geometric mean are summarized in Table 4.1. Based on one-way ANOVA analyses, there were also no significant differences that could be detected between log balance measurements by age or school (Appendix D [Figure 4.iii-v]).The difference of five between age means (ages 14-18) was not statistically significant for any of the three tests (ECS $F_{4,116}$ = 0.99, p=0.41; EOD $F_{4,96}$ = 1.31, p=0.27; ECD $F_{4,118}$ = 0.41, p=0.81).The difference of 10 between school means was not statistically significant for any of the three tests (ECS $F_{9,111}$ = 0.7,p=0.71; EOD $F_{9,91}$ = 0.73, p=0.68; ECD $F_{9,113}$ = 0.64, p=0.76).

Table 4.1: Study norms for ECS, EOD and ECD balance tests
(based on back transformed log-balance at baseline)

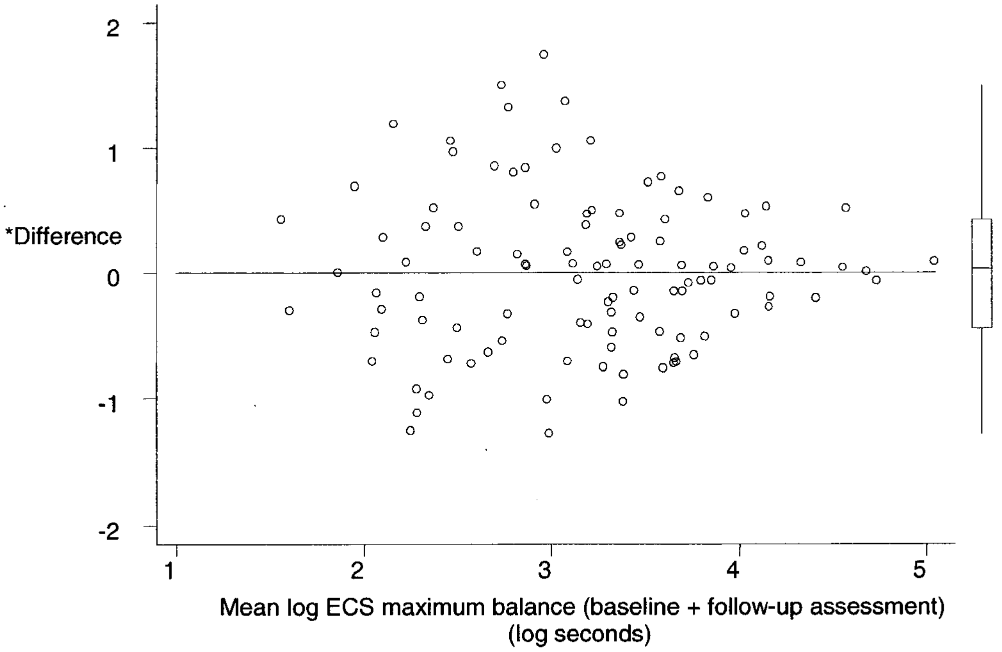
Balance Test	Geometric Mean in seconds (95% CI)
Eyes closed static balance (ECS)	**25.43 (22.06, 29.31)**
Eyes open dynamic balance (EOD)	**54.4 (47.3, 62.61)**
Eyes closed dynamic balance (ECD)	**5.32 (4.98, 5.68)**

4.3.2 Test-Retest Intra-rater Reliability

Eyes Closed Static Balance (ECS)

Maximum balance for ECS measurement did not meet assumptions of normality; however, the difference between follow-up and baseline assessment ECS balance did meet these assumptions (Appendix D [Figure 4.vi]). A Bland and Altman plot examining agreement demonstrates heteroscedacity (Appendix D [Figure 4.vii and 4.viii]). Log transformation was highly successful in producing differences unrelated to the magnitude of the measurement of maximum time achieved (Figure 4.4). The mean difference on the log scale was -0.05 log seconds (95% limits of agreement, -1.26 to 1.16). The back-transformed results relate to the ratios of the measurements at baseline and follow-up assessments. The geometric mean ratio was 0.95 (95% limits of agreement, 0.28 to 3.2). This means that the one-week follow-up measurement yielded an ECS maximum on average of 0.95 times the baseline value. The limits of agreement tell us that 95% of the time the follow-up measurement will be between 0.28 and 3.2 times the baseline measurement.

Figure 4.4: Difference between follow-up and baseline log transformed ECS maximum balance plotted against their mean (95% limits of agreement) (n=107)

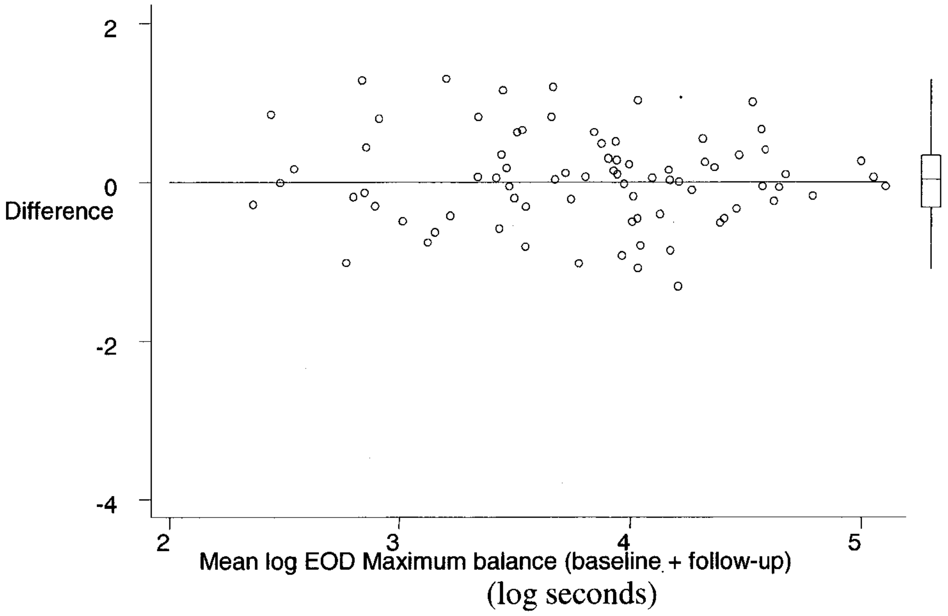


* Difference between follow-up and baseline assessments for log transformed ECS Maximum Balance
The mean difference is -0.05 log seconds (mean difference is the midpoint and 95% limits of agreement superimposed as upper and lower limits on box-plot figure).

Eyes Open Dynamic Balance (EOD)

Maximum balance for EOD balance did not meet assumptions of normality. However, the difference between follow-up and baseline assessment EOD balance did meet these assumptions (Appendix D [Figure 4.ix]). As for ECS balance, a Bland and Altman plot examining agreement demonstrates heteroscedacity or increased variability as the maximum balance time increases (Appendix D [Figures 4.x and 4.xi]). Logarithmic transformation was highly successful in producing differences unrelated to the mean (Figure 4.5). The mean difference on the log scale was -0.12 log seconds (95% limits of agreement, -1.4 to 1.15). The geometric mean ratio is 0.88 (95% limits of agreement, 0.25 to 3.2). This means that the one-week follow-up measurement yielded an EOD maximum on average of 0.88 times the baseline value. The limits of agreement tell us that 95% of the time the follow-up measurement will be between 0.25 and 3.2 times that at baseline.

Figure 4.5: Difference between follow-up and baseline log transformed EOD maximum balance plotted against their mean (95% limits of agreement) (n=78)

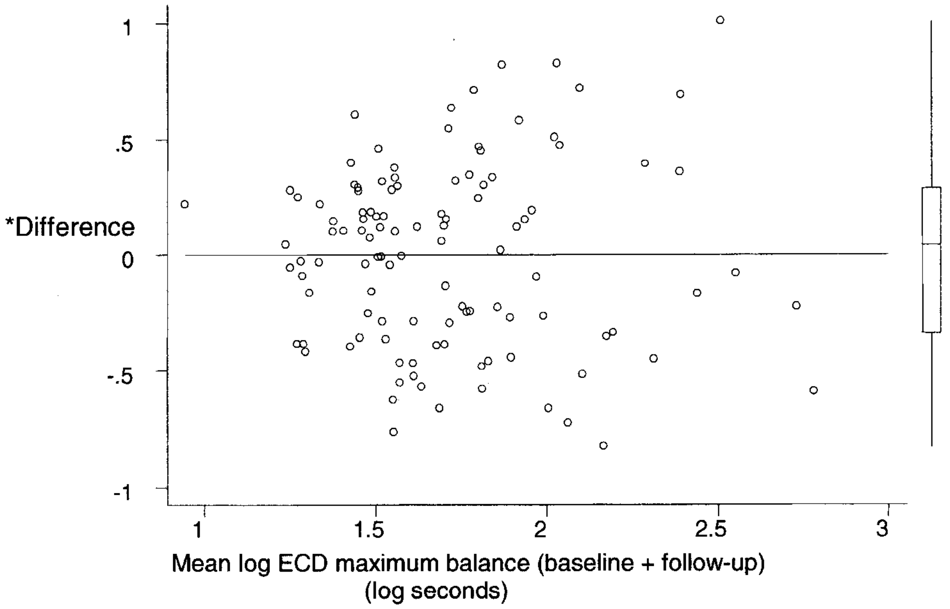


* Difference between follow-up and baseline assessments for log- transformed EOD maximum balance The mean difference is -0.12 log seconds (mean difference is the midpoint and 95% limits of agreement superimposed as upper and lower limits on box-plot figure).

Eyes-closed dynamic (ECD) balance

Maximum balance for ECD balance measurement did not meet assumptions of normality, however, the difference between follow-up and baseline assessment ECD balance did meet these assumptions (Appendix D [Figure 4.xii]). As for ECS and EOD balance, a Bland and Altman plot examining agreement demonstrates heteroscedacity (Appendix D [Figures 4.xiii and 4.iv]). Log transformation was highly successful in producing differences unrelated to the mean (Figure 4.6). The mean difference on the log scale was 0.05 log seconds (95% limits of agreement, -0.73 to 0.83). The geometric mean ratio is 1.05 (95% limits of agreement, 0.48 to 2.29). This means that the one-week follow-up measurement yielded an ECD maximum on average of 1.05 times the baseline value. The limits of agreement tell us that 95% of the time the final measurement will be between 0.48 and 2.29 times that at baseline.

Figure 4.6: Difference between follow-up and baseline log transformed ECD maximum balance plotted against their mean (95% limits of agreement) (n=111)



* Difference between follow-up and baseline assessments for log- transformed ECD maximum balance
The mean difference is 0.05 log seconds (mean difference is the midpoint and 95% limits of agreement superimposed as upper and lower limits on box-plot figure).

For all three balance tests (ECS, EOD and ECD) intra-class correlation coefficients [ICC (3,1)] and 95% CI's were calculated based on log transformed maximums for baseline and one-week follow-up assessments. The results of all analyses examining reliability are summarized in Table 4.2.

Table 4.2: Intra-rater test-retest reliability

Balance Measurement	Bland and Altman Geometric Mean Ratio (95% limits of agreement)	ICC (3,1) (95% CI)
Eyes Closed Static Balance (n = 107)	0.95 (0.28 to 3.2)	0.69 (0.57, 0.78)
Eyes Open Dynamic Balance (n = 78)	0.88 (0.25 to 3.2)	0.59 (0.43, 0.71)
Eyes Closed Dynamic Balance (n = 111)	1.05 (0.48 to 2.29)	0.46 (0.31, 0.59)

4.3.3 Inter-rater reliability

Inter-rater reliability was examined in a similar fashion to intra-rater reliability. Failure to meet assumptions again led to logarithmic transformation of maximum balance measurements for further analyses. A summary of the results of the Bland and Altman agreement methodology (including the geometric mean ratio and 95% limits of agreement) and the intra-class correlation and 95% confidence intervals based on ICC (2, 1) are found in Table 4.3.

Table 4.3: Inter-rater reliability based on baseline measurements by two examiners

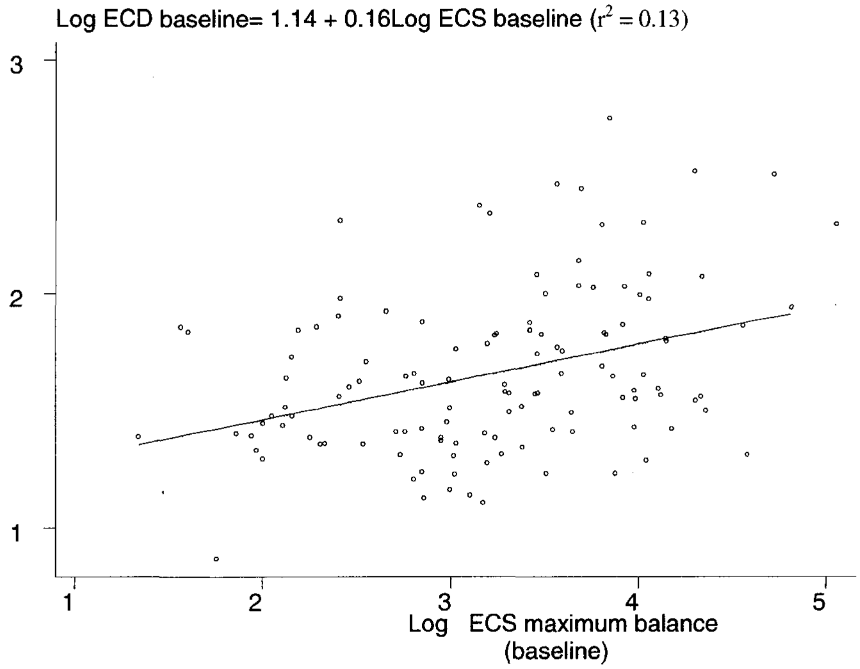
Balance Measurement	Bland and Altman Geometric Mean Ratio (95% limits of agreement)	ICC (2,1) (95% CI)
Eyes Closed Static Balance	1.0 (0.98 to 1.02)	0.999 (0.984,1.0)
Eyes Open Dynamic Balance	1.0 (0.996 to 1.007)	1.0 (0.997, 1.0)
Eyes Closed Dynamic Balance	1.0 (0.958 to 1.048)	0.996 (0.981, 1.0)

Interpretation of the geometric mean ratios above is that the measurement of ECS, EOD, and ECD by examiner 2 were on average the same (geometric mean ratio = 1.0) as the measurement by examiner 1 at baseline. The limits of agreement, for example based on ECS balance, tell us that 95% of the time the second examiner's measurement will be between 0.98 and 1.02 times the first examiner's measurement.

4.3.4 Relationship Between Static and Dynamic Eyes-Closed Balance

A simple linear regression model, which met the assumptions for linear regression, describes the predictive validity between ECS balance and ECD balance (Figure 4.7). The slope of the regression line was significantly greater than zero (0.16, 95% CI = 0.08, 0.24), indicating that dynamic balance tends to increase as static balance increases. This describes a significant relationship between static and dynamic balance measurements, where ECD balance can be predicted based on ECS balance.

Figure 4.7: Simple linear regression comparing ECS and ECD balance at baseline



4.3.5 The Influence of Other Factors on Static and Dynamic Balance Measurements

There is no evidence to support learning or fatigue based on order of testing the three test protocols (ECS, EOD and ECD) based on one-way ANOVAs (ECS $F_{5,115}$ = 0.51, p=0.77; EOD $F_{5,95}$ = 1.6, p=0.17; ECD $F_{5,117}$ = 0.65 p=0.66). (Appendix D [Figures 4.xv – 4.xvii]). A repeated measures ANOVA was used to examine a potential learning effect over three trials, for each of three tests. For purposes of analysis, right leg was chosen and trial 1, 2 and 3 were compared based on log transformed maximum balance measurements. There were no significant differences found between trials 1, 2 and 3 for ECS or EOD balance (ECS $F_{2,242}$ = 0.18, p=0.83; EOD $F_{2,217}$ = 0.01, p=0.99). (Appendix D [Figures 4.xviii and 4.xix]). There was an apparent learning effect over three trials for ECD balance (ECD $F_{2,244}$ = 4.69, p=0.01) (Appendix D [Figure 4.xx]).

A multivariable linear regression model was used to examine the influence of various factors (leg dominance, age, order of testing, height, weight, BMI, length of foot, width of foot, previous lower extremity injury within one year, and estimated hours/week of sport participation in the previous six-weeks) on ECS balance and ECD balance. EOD balance was not used as an outcome measurement due to the number of students achieving the maximum of 180 seconds on this test. A stepwise elimination was performed in order to determine factors that had a significant influence on balance. The results of the multivariate regression models can be found in Appendix E.

The final regression model for ECS balance, which met the assumptions for linear regression, was: **logECS = 3.309 – 0.514(Injury)** ($r^2 = 0.056$), where logECS denotes the log-transformed ECS balance maximum at baseline, and Injury indicates previous lower extremity injury within one year (0=no injury and 1=injury). The coefficient associated with previous injury was significantly less than 0, indicating that static balance at baseline in adolescents with a previous one year history of lower extremity injury was less than those without a history of previous lower extremity injury (-0.514, 95% CI = -0.899 , - 0.13).

The final regression model for ECD balance, which met the assumptions for linear regression was: **logECD = 1.699 – 0.193(Injury)** ($r^2 = 0.035$), where logECD = log-transformed ECD balance maximum at baseline. The coefficient associated with previous injury was significantly less than 0, indicating that static balance at baseline in adolescents with a previous one year history of lower extremity injury was less than those without a history of previous lower extremity injury (-0.193, 95% CI = -0.376,- 0.01).

The only significant influencing factor for both ECS and ECD balance was previous lower extremity injury. The relationship between log transformed ECS or ECD balance and history of previous injury did not change significantly when controlling for all other covariates. The predicted log-transformed ECS and ECD balance from this regression were back transformed to estimate the predicted ECS balance and ECD balance in adolescents with a history of lower extremity injury within one year, compared to those adolescents with no previous history of lower extremity injury. These results are summarized in Table 4.4.

Table 4.4: Predicted ECS and ECD balance (back-transformed from logECS and logECD) across previous injury groups based on regression models: logECS = 3.309 – 0.514(Injury) and logECD = 1.699 – 0.193(Injury)

Balance Test	Subjects reporting no previous LE injury (95% CI) (95% Prediction Interval)	Subjects reporting previous LE injury (95% CI) (95% Prediction Interval)
Eyes Closed Static Balance (seconds)	27.35 (23.58, 31.73) (6.03, 124.15)	16.36 (10.52, 25.43) (3.12, 85.68)
Eyes Closed Dynamic Balance (seconds)	5.47 (5.1, 5.87) (2.66, 11.24)	4.51 (3.66, 5.56) (2.05, 9.92)

In examining sport specificity, subjects were grouped by their number one sport for estimated hours spent per week in the past one year beyond PE class. Based on 23 different sports reported, there was no significant difference found between groups for log transformed ECS or ECD balance based on a one-way ANOVA [ECS $F_{23,97} = 1.26$, p=0.21; ECD $F_{23,99} = 1.41$, p=0.1].

4.4 Discussion

This study is the first of its kind to examine timed dynamic balance measurements using an Airex Balance Pad® for a support surface as a measure of proprioceptive balance. Using 111 adolescents times for ECS, EOD, and ECD timed balance, we determined that ECS and ECD timed balance were both appropriate and reliable clinical measurements of standing balance in adolescents.

Other studies have examined timed unipedal static eyes closed balance in healthy subjects.[15,29,37] Hahn et al[37] assessed 339 active competitive athletes, ages 14-24 years, from sports clubs in Denmark. They found that 1.8% reached the maximum time of 180 seconds, which is similar to the findings in this study (1.6%).[37] The geometric mean of the maximum balance attained in this study for ECS balance was 25.43 seconds (95% CI, 22.06, 29.31). This is in accordance with Hahn et al[37] who demonstrated a mean of 29 seconds based on maximum time achieved over two trials. Ekdahl et al[29] examined timed eyes closed static balance in adults ages 20-64 years. For the 20-29 year old age group the mean time, based on maximum times achieved over three trials, was 44 seconds. In Bohannon et al.'s study[15] the maximum time set was 30 seconds. Only 25% of subjects, ages 20-29 years, did not achieve the 30 second maximum. In this study 55% did not achieve 30 seconds at the baseline assessment. The difference between studies may be related to balance ability in adolescents compared to adults.

Variable intra-rater test-retest reliability of a timed static eyes-closed unipedal balance test (measurements one week apart) has been demonstrated previously using the ICC alone. Atwater et al[3] examined children ages 4 to 6 years (ICC = 0.59-0.77), Balogun et al[5] examined healthy young adults (ICC = 0.96) and Bohannon et al[15] examined adults following stroke (ICC=0.44-0.75). Differences between studies include age and disability. The present study demonstrates adequate intra-rater reliability for ECS balance, based on ICC alone, consistent with these other studies [ICC = 0.69 (95% CI, 0.57, 0.78)]. Riemann et al[64] demonstrated no significant difference ($F_{1,10}$=1.08, p=0.358) in repeated testing of dynamic balance on a foam surface using an error scoring system measured one day apart. In this study, dynamic balance measurements (EOD and ECD) appear to have moderate and poor reliability with test sessions one week apart, based on the ICC alone [ICC= 0.59 (0.43, 0.71) for EOD and ICC=0.46 (0.31, 0.59) for ECD].

One of the weaknesses of the ICC in determining reliability is that as the between subject variability of a measurement increases, the estimated ICC also increases.[11] Greater between subject variability clearly does not indicate increased reliability of that measurement.[11] As such, in this study, between subject variability of the ECD measurement is very small (range = 2.38 to19.63 with only 3 subjects exceeding 12 seconds). This may have contributed to a poor ICC for ECD balance in this study.

Analysis using ICC's does not examine whether or not the variability of the measurement, and as a result the estimated reliability, is independent of the magnitude of the measurement.[13] In addition, use of ICC in estimating reliability of a measurement fails to use the units of measurement in question.[2,13] It is thus extremely difficult to make decisions regarding clinical relevance of measurement differences. As such, results based on Bland and Altman's methods of agreement were examined in this study.[13] Based on the 95% limits of agreement, examples of baseline measurement for each of ECS, EOD and ECD balance (based on minimum, 25th percentile, median, 75th percentile and maximum< 180 seconds for this study data) and expected measurements one week later are given in Table 4.5.

Table 4.5: Examples of expected one-week follow-up ECS, EOD and ECD balance measurements based on 95% limits of agreement

Balance Measurement	95% limits of agreement (i.e., expected one-week follow-up based on baseline measurement)	Baseline Measurement (seconds)	Expected one week follow-up measurement (seconds)
Eyes Closed Static	0.28 to 3.2 times baseline measurement	3.8	1.06 to 12.2
		15.4	4.31 to 49.28
		26.4	7.39 to 84.5
		46.4	12.99 to 148.5
		166.2	46.53 to 180
Eyes Open Dynamic	0.25 to 3.2 times baseline measurement	8.6	2.15 to 27.5
		35.7	8.93 to 114.2
		58.4	14.6 to 180
		94.7	23.68 to 180
		174.1	43.53 to 180
Eyes Closed Dynamic	0.48 to 2.28 times baseline measurement	2.4	1.15 to 5.5
		4	1.92 to 9.1
		4.9	2.35 to 11.2
		6.4	3.07 to 14.6
		19.6	9.41 to 44.7

In examining the example measurements calculated, ECD appears to be the most reliable of the three measurements. This contradicts the ICC results, because of the small between subject variability for ECD. The reliability of these measurements, based on assessments one week apart, appears to be greater for relatively low balance and decreases as balance ability improves.

The results show adequate reliability for both ECS and ECD tests, based on ICC for ECS balance and Bland and Altman agreement analysis for ECD balance. In the EOD test 18 and 24% of subjects achieved the maximum of 180 seconds in each of two test sessions. As such, these subjects were excluded from further analyses and reliability was based on the remaining 78 subjects. This ceiling maximum of 180 seconds limits our ability to examine changes in EOD balance over time, following an intervention, in adolescents with the best balance ability. EOD balance may not be the most suitable clinical examination for dynamic balance in this population, unless the maximum time was extended and reliability further examined. The reliability found for ECS testing was not as good, based on ICC's, as that found by Balogun et al[5] (ICC=0.96) in 17 healthy male university students. The reasons for this may be that dynamic balance testing was done in conjunction with ECS balance test and motivation to achieve maximum balance potential in adolescents in this study may have been inferior to that in university students.

There are other limitations that may have contributed to the test-retest reliability found for the clinical balance measurements in our study. The selection of one week between assessments, allows time for potential practicing of balance activity by the subjects. Testing was performed on the same weekday and time of day, for each subject, at baseline and follow-up; however, there is the possibility that physical activities extraneous to the study may have affected balance measurement outcomes at one session and not the other. In addition, adolescents may be influenced by boredom during the testing session, peer-pressure, or limited attention span, which may influence the reliability of timed balance measurements.

Inter-rater reliability for timed ECS balance testing is consistent across studies (ICC=0.93-0.96).[3,64] Excellent inter-rater reliability for dynamic unipedal balance tests (eyes open and eyes closed), using a foam support surface, based on an error scoring system have been established (ICC=0.92).[64] Excellent inter-rater reliability has also been established in this study based on all three timed balance methods used for ECS, EOD and ECD tests. This is not surprising given the nature of a timed balance measurement done by two examiners at the same time. In examining intra-rater reliability, measurements are done seven days apart. The artifact of time likely contributes to moderate reliability.

Testing conditions in the measurement of balance may include variable visual feedback. Diminishing visual feedback with eyes closed or blindfolded consistently demonstrates decreased postural stability in comparison to eyes opened conditions.[14,29,33,34,35,37,45,48,72,73] This study is consistent in its findings that ECD balance was less than EOD balance. Other studies examining leg dominance also failed to demonstrate a difference in balance ability between the dominant and non-dominant legs in healthy subjects.[14,33,34,37,72,73,76]

There was no association seen between static or dynamic balance measures and age in this study. Hahn et al[37] reported a similar relationship in competitive athletes aged 14 to 24 years. Most of the studies demonstrating that timed unipedal balance decreases with age, examined this relationship over a wider age range (i.e., adolescent to elderly).[14,29,72] Peeters et al[60] demonstrated that stability increased with age, but they examined children ages 6 to 15 years.

Consistent with our findings, others have not demonstrated any significant relationship between balance ability and gender in adolescents and adults.[9,19,22,29,37,73] Peeters et al[60] demonstrated that girls ages six to ten years demonstrated better postural stability than boys in the same age group, however, boys ages eleven to fifteen years demonstrated better postural stability than girls in the same age group.

Some studies have demonstrated a relationship between gender and postural sway (length, velocity and/or area of sway path) and/or timed unipedal balance in the elderly, with women demonstrating better balance ability.[29,53,59]

In theory, factors which lower the centre of gravity (i.e., sitting and decreased height) and increase the base of support (i.e., bipedal and foot size) will increase postural stability.[70] Odenrick et al[58] found both height and weight to be predictors of increased postural sway in boys and girls ages 5 to 15 years. Habib and Westcott[36] found that an increased base of support (i.e., foot length) was a significant predictor of balance ability in children. The age of their subjects differs considerably from our study. Consistent with our study, however, Peeters et al[60] and Ekdahl et al[29]demonstrated that height and weight had no direct influence on stability parameters measured using posturography and stabilometry respectively.

Our study fails to demonstrate an association between estimated hours per week of sports activity and static or dynamic balance. Static and dynamic balance also did not differ significantly between groups when adolescents were grouped by sport (i.e., the sport in which the largest number of hours was reported in the previous one year). Ekdahl et al[29] also failed to demonstrate an association between postural stability and leisure activities. Hahn et al[37] demonstrated that timed unipedal balance was not associated with type of sport as such, but was positively associated with hours per week of basketball and number of years of basketball, and negatively associated with hours of swimming.

We found no learning or fatigue effects demonstrated over repeated trials on the same day for ECS and EOD balance. There was evidence of a learning effect over three trials, however, for ECD balance. This may be related to the increased difficulty of ECD balance compared to ECS and EOD balance. There was no indication that order of test (based on six possible orders of ECS, EOD and ECD tests) was a factor in balance maximum achieved in any of the three tests. Thus, no evidence of fatigue was demonstrated. Other studies have demonstrated learning effects over repeated trials for static balance measurements on the same day using stabilometry.[1,29,40] Nawoczenzi et al[57] reported a learning effect measuring dynamic balance using a Stability Testing and Rehabilitation Station (STARStation ®) over the first three of six trials on the same day, with a decrease of measurement variability following the third trial.

In sports medicine, one must always consider the impact of previous injury on any outcome measurement. Previous lower extremity injury appears to decrease both static and dynamic eyes closed balance measurements in this study. Significant differences in balance measurements between previously injured and uninjured athletes are also consistently reported in the literature. .[31,35,38,46,47,77-79,84] In this study, previous injury was determined based on self-report of previous one-year injury history.

One of the major strengths of our study is the random recruitment of schools and subjects, which increases the generalizability of the study results. Other strengths of our study include the high rate of consent to participate (greater than 98%). In addition, the dropout rate was extremely low (less than 10%). Both of these factors limit selection bias. This study also confirms the need to consider alternate and more appropriate statistical methods, in addition to the commonly used ICC in the assessment of reliability of outcome measurements in sports medicine.

4.5 Conclusions

Timed eyes closed static balance and eyes closed dynamic balance (using an

Airex Balance Pad for base of support), with a 180 second maximum for each test, are appropriate clinical balance measurements for use in healthy adolescents. Excellent inter-rater reliability was consistently found across all three test examined in this study (ECS, EOD and ECD). Intra-rater reliability was moderate for EOD test; however, more than 24% of subjects achieved the maximum of 180 seconds on this test. Consequently, EOD balance would be considered inappropriate for use as a clinical balance measurement in healthy adolescents. In future research examining balance, it is critical to consider previous lower extremity injury as a key factor influencing balance in adolescents.

References

1. Ageberg E, Zatterstrom R, Moritz U. Stabilometry and one-leg hop test have high test-retest reliability. *Scand J Med Sci Sports* 1998;8:198-202.

2. Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med* 1998;26:217-238.

3. Atwater SW, Crowe TK, Deitz JC, Richardson PK. Interrater and test-retest reliability of two pediatric balance tests. *Phys Ther* 1990;70:79-87.

4. Bahr R, Lian O. A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports* 1997;7:172-177.

5.Balogun JA, Adesinasi CO, Marzouk DK. The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada* 1992;44:23-30.

6. Berg K, Wood-Daphinee S, Williams JI, Gayton D. Measuring balance in the elderly.: Preliminary development of an instrument. *Physiotherapy Canada* 1989;41:304.

7. Berg K, Wood-Daphinee S, Williams JI, Maki B. Measuring balance in the elderly:Validation of an instrument. *Can J Pub Health* 1992;83:S7-11.

8. Berg K, Wood-Daphinee S. The balance scale: Reliability assessment with elderly residents and patients with an acute stroke. *Scand J Rehab Med* 1995;27:27-36.

9. Black FO, Wall C, Rockette HE, Kitch R. Normal subject postural sway during the Romberg Test. *Am J Otolaryngol* 1982;3:309-318.

10. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986;Feb:307-310.

11. Bland JM, Altman DG. Measurement error and correlation coefficients. *BMJ* 1996;313:41-2.

12. Bland JM, Altman DG. Measurement error proportional to the mean. *BMJ* 1996;313:106.

13. Bland JM, Altman DG. Measuring agreement in method comparison studies. *Statistical Methods in Medical Research* 1999;8:135-160.

14. Bohannon RW, Larkin PA, Cook AC, Gear J, Singer J. Decrease in timed balance test scores with aging. *Phys Ther* 1984;64:1067-70.

15. Bohannon RW, Walsh S, Joseph MC. Ordinal and timed balance measurements: reliability and validity in patients with stroke. *Clin Rehabil* 1993;7:9-13.

16. Bonanni M, Newton R. Test-retest reliability of the Fukuda Stepping Test. *Physiotherapy Research International* 1998;3:58-68.

17. Brauer S, Burns Y, Galley P. Lateral reach: a clinical measure of medio-lateral postural stability. *Physiotherapy Research International* 1999:4:81-88..

18. Broadstone BJ, Westcott SL, Deitz JC. Test-retest reliability of two tiltboard tests in children. *Phys Ther* 1993;73:618-25.

19. Brocklehurst JC, Robertson D, James-Groom P. Clinical correlates of sway in old age-sensory modalities. *Age Ageing* 1982;16:1-10.

20. Brouwer B, Culham EG, Liston RAL, Grant T. Normal variability of postural measures: Implications for the reliability of relative balance performance outcomes. *Scand J Rehab Med* 1998;30:131-137.

21. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee surg, Sports Traumatol, Arthroscopy* 1996;4:19-21.

22. Colledge NR, Cantley P, Peaston I, Brash H, Lewis S, Wilson JA. Ageing and balance: the measurement of spontaineous sway by posturography. *Gerontol* 1994;40:273-278.

23. Crowe TK, Deitz JC, Richardson PK, Atwater SW. Interrater reliability of the pediatric clinical test of sensory interaction for balance. *Phy Occup Ther Pediatr* 1991; 10:1-4.

24. Deitz JC, Richardson P, Atwater SW, Crowe TK, Odiorne M. Performance of normal children on the Clinical Test of Sensory Interaction for Balance. *Occ Ther J of Res* 1991; 11:336-356.

25. Dickstein R, Dvir Z. Quantitative evaluation of stance balance performance in the clinic using a novel measurement device. *Physiotherapy Canada* 1993;45:102-108.

26. Donner A, Klar N. *Design and Analysis of Cluster Randomization Trials in Health Research.* Oxford University Press, Inc., New York, 2000.

26. Dornan J, Fernie GR, Holiday PJ. Visual input: its importance in the control of postural sway. *Arch Phys Med Rehabil* 1978;59:586-591.

27. Duncan PW, Weiner DK, Chandler J, Studenski S. Functional Reach: A new clinical measure of balance. *J Gerontol* 1990;45:M192-7.

28. Duncan PW, Studenski S, Chandler J, Prescott B. Functional Reach: Predictive validity in a sample of elderly male veterans. *J Gerontol* 1992;47:M193-8

29. Ekdahl C, Jarnlo G-B, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. *Scand J Rehab Med* 1989;21:187-195.

30. Fleiss JL. The design and analysis of clinical experiments. New York, John Wiley and Sons, 1986, pp 1-32.

31. Friden T, Zatterstrom R, Lindstrand A, Moritz U. A stabilometric technique for the evaluation of lower extremity instabilities. *Am J Sports Med* 1989;17:118-122.

32. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med* 1988;9:141-144.

33. Goldie PA, Bach TM, Evans OM. Force platform measures for evaluating postural control: Reliability and validity. *Arch Phys Med Rehabil* 1989;70:510-517.

34. Goldie PA, Evans OM, Bach TM. Steadiness in one-legged stance: Development of a reliable force-platform testing procedure. *Arch Phys Med Rehabil* 1992;73:348-54.

35. Goldie PA, Evans OM, Bach TM. Postural control following inversion injuries of the ankle. *Arch Phys Med Rehabil* 1994;75:969-75.

36. Habib Z, Westcott S. Assessment of anthropometric factors on balance tests in children. *Pediatr Phys Ther* 1998;10:101-109.

37. Hahn T, Foldspang A, Vestergaard E, Ingermann-Hansen T. One-legged standing balance and sports activity. *Scand J Med Sci Sports* 1999;9:15-18.

38. Hoffman M, Payne VG. The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopaedic and Sports Physical Therapy* 1995;21:90-94.

39. Hoffman M, Schrader J, Koceja D. An investigation of postural control in postoperative anterior cruciate ligament reconstruction patients. *J Athletic Training* 1999;34:130-136.

40. Holliday PJ, Fernie GR. Changes in the measurement of postural sway resulting from repeated testing. *Agressologie* 1979;20:225-8.

41. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports* 1999;9:104-109.

42. Horak FB. Clinical measurement of postural control in adults. *Phys Ther* 1987;67:1881-1885.

43. Kamen G, Patten C, Duke Du C, Sison S. An accelerometry based system for the assessment of balance and postural sway. *Gerontol* 1998;44:40-45.

44. Kejonen P, Kauranen K, Vanharanta H. Body movements in postural balance with motion analysis. *Eur J Phys Med Rehabil* 1998;8:39-43.

45. Kolleger H, Baumgartner C, Wober C, Ober W, Deecke L. Spontaineous body sway as a function of sex, age, and vision: Posturographic study in 30 healthy adults. *Eur Neurol* 1992;32:253-259.

46. Leanderson J, Wykman A, Eriksson E. Ankle sprains and postural sway in basketball players. *Knee Surgery, Sport Traumatology, Arthroscopy* 1993;1:203-205.

47. Leanderson J, Eriksson E, Nilsson C, Wykman A. Proprioception in classical ballet dancers. A prospective study on the influence of an ankle sprain on proprioception in the ankle joint. *Am J Sports Med* 1996;24:370-373.

48. Lee DN, Lishman JR. Visual proprioceptive control of stance. *J Human Movement Studies* 1975;1:87-95.

49. Lephart SM. Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sport Med* 1998;25:149-155.

50. Mackenzie M. A simplified measure of balance by functional reach. *Physiotherapy Research International* 1999:4:233-236.

51. Mattacola CG, Wills Lloyd J. Effects of a 6-week strength and proprioception training program on mesasures of dynamic balance: A single-case design. *J of Athletic Training* 1997;32:127-135.

52. Mattacola CG, Lebsack DA, Perrin DH. Intertester reliability of measuring postural sway using the Chattecx Balance System. *J Athletic Train ing* 1995;30:237-242.

53. Mechling RW. Objective assessment of postural balance through the use of the variable resistance balance board. *Phys Ther* 1986;66:685-688.

54. Moe-Nilssen R. Test-retest reliability of trunk accelerometry during standing and walking. *Arch Phys Med Rehabil* 1998;79:1377-1385.

55. Murray MP, Seireg AA, Sepic SB. Normal postural stability and steadiness; quantitative assessment. *J Bone Joint Surg* 1975;57A:510-516.

56. Nakamura DM, Holm MB, Wilson A. Measures of balance and fear of falling in the elderly: A review. *Physical & Occupational Therapy in Geriatrics* 1998;15:17-32.

57. Nawoczenski DA, Sharp WB, Maiers DJ, Patterson JE, Soderberg GL. Reliability of performance measurements obtained using the Stability Testing and Rehabilitation Station (STARStation®). *Phys Ther* 1991;71:706-714.

58. Odenrick P, Sandstedt P. Development of postural sway in the normal child. *Human Neurobiol* 1984;3:241-244.

59. Overstall PW, Exton-Smith AN, Imms FJ, Johnson AL. Falls in the elderly related to postiral imbalance. *Br Med J* 1977;1:261-264.

60. Peeters H, Breslau E, Mol J, Caberg H. Analysis of posturographic measurements on children. *Med & Biol Eng & Comp* 1984;22:317-321.

61. Pincivero D, Lephart SM, Henry T. Learning effects and reliability of the Biodex Stability System. *J Athletic Training* 1995;30:S35.

62. Podsiadlo D, Richardson S. The Timed "Up and Go": A test of basic functional mobility for frail elderly persons. *J Am Geriatric Society* 1991;34:119-26.

63. Portney LG, Watkins MP. Foundations of Clinical Research. Applications to Practice. New Jersey: Prentice-Hall, Inc., 2000.

64. Riemann BL, Guskiewicz KM, Shields EW. Relationship between clinical and forceplate measures of postural stability. *J Sport Rehabil* 1999;8:71-82.

65. Riemann BL, Caggiano NA, Lephart SM. Examination of a clinical method of assessing postural control during a functional performance task. *J Sports Rehabil* 1999;8:171-83.

66. Rozzi S, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *Journal of Orthopaedic and Sport Physical Therapy* 1999;29:478-486.

67. Schmitz R, Arnold B. Intertester and intratester reliability of a dynamic balance protocol using the Biodex Stability System. *J Sport Rehabil* 1998;7:95-101.

68. Shrout PE and Fleiss JL. Intraclass correlations: uses in assessing rater reliability. *Psych Bull* 1979;86:420-428.

69. Shumway-Cook, Horak FB. Assessing the influence of sensory interaction of balance. Suggestions from the field. *Phys Ther* 1986;66:1548-50.

70. Shumway-Cook A, Woollacott M *Motor control: Theory and practical applications.* Baltimore,Md: Williams and Wilkins, 1995.

71. StataCorp. Stata Statistical Software [computer program]. Release 5.0 College Station (TX): Stata Corporation;1997.

72. Stones MJ, Kozma A. Balance and age in the sighted and blind. *Arch Phys Med Rehabil* 1987;68:85-9.

73. Stribley Rf, Albers JW, Tourtellotte WW, Cockrell JL. A quantitative study of stance in normal subjects. *Arch Phys Med Rehabil* 1974;55:74-80.

74. Tinetti ME. Performance oriented assessment of mobility problems in elderly patients. *J Am Geriatric Society* 1986;39:142-8.

75. Tinetti ME, Speechley M, Ginter SF. Risk factors for falls among elderly persons living in the community. *New England J Med* 1988;319:1701-7.

76. Tropp H, Ekstrand J, Gillquist J. Factors affecting stabilometry recordings of single leg stance. *Am J Sports Med* 1984;12:185-188.

77. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and it's value in predicting injury. *Med Sci Sports Exerc* 1984;16:64-66.

78. Tropp H, Odenrick P. Postural control in single-limb stance. *J Orthop Res* 1988;6:833-839.

79. Tropp H, Odenrick P, Gillquist J. Stabilometry recordings in functional and mechanical instability of the ankle joint. *Int J Sports Med* 1985;6:180-182.

80. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;13:259-62.

81. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999;9:41-47.

82. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *Journal of Orthopaedic and Sport Physical Therapy* 1996;23:332-336.

83. Whitney SL, Poole JL, Cass SP. A review of balance instruments for older adults. *Am J Occ Ther* 1998;52:666-671.

84. Zatterstrom R, Friden T, Lindstrand A, Moritz U. The effect of physiotherapy on standing balance in chronic anterior cruciate ligament insufficiency. *Am J Sports Med* 1994;22:531-536.

Chapter 5

The effectiveness of a proprioceptive balance-training program in healthy adolescents: A cluster randomized controlled trial.

5.1 Introduction

Adolescent participation rates in sport are high .[4,16,58,63] In Canada, 65% of adolescents participate in regular physical activity at least twelve times per month.[63] The incidence of sports injury in adolescents is high, resulting in a significant impact on the individual, their parents and the health care system.[3,7,10,13,31,34,36,37,43,46,48-50,52,54,61,64,69,74,76,80] In Canada, sports is the leading cause of injury in adolescents.[43] It is also the leading cause of injury in adolescents leading to a hospital emergency department admission.[9,29,30] There is evidence that sports injury, specifically knee and ankle injury, may result in an increased risk of development of osteoarthritis (OA).[20,25,33] It is also estimated that 8% of adolescents drop out of recreational sporting activities annually because of injury occurrence.[28] Adolescent sports injury may also reduce adolescents' future involvement in physical activity. Decreased physical activity is strongly associated with multiple cause morbidity and mortality.[11,60] Hence, sports injury may also impact the future health of our population. Research that will lead to prevention of injury in adolescent sport should be a top priority in maintaining a healthy lifestyle in young Canadians.

Proprioceptive balance-training is a significant component of rehabilitation in sports medicine and is rapidly becoming recognized as an important element in pre-season injury prevention programs for many athletes, including adolescents.[6,17,39,40,56,72,75,77] There is some evidence to suggest that decreased static balance is a risk factor for ankle sprain re-injury in soccer.[71] In sport, an athlete is typically visually attentive to the play and the activity is dynamic in nature at the time of injury. As such, impaired dynamic unipedal balance, minimizing visual feedback to increase reliance on the vestibular and somatosensory feedback systems, may be more relevant as a significant risk factor for injury in sport than static balance.[47,65,78]

In sport, a participant running, jumping or pivoting on one leg is visually attentive to the play and relies on joint position sense and muscular control for joint stability. By improving dynamic postural control and balance and producing more coordinated and consistent movement patterns during athletic participation, some injury may be prevented.[47] Dynamic proprioceptive balance training may be the key intervention which will improve postural control in athletic situations and prevent some injuries in sport. There is some evidence that static balance does improve following proprioceptive balance-training using a wobble board[7,32,35,41,51,62,67,71] Most of these studies, however, exclusively examined improvement in static balance following an ankle sprain injury. Hoffman et al[41] and Balogun et al[8] provide experimental evidence from randomized controlled trials (RCTs) that a wobble board balance-training program in healthy subjects significantly improved static balance. They did not examine dynamic balance.

Some RCT studies have demonstrated that prevention programs, including a proprioceptive balance-training component using a wobble board, are effective in reducing specific injury (i.e., anterior cruciate ligament and ankle sprain) in specific sports (i.e., soccer, European handball, and volleyball).[6,17,40,56,72,75,77] The relative risks (RRs) reported in these studies support the protective effect of such training programs (i.e., RR = 0.06 - 0.51).[6,17,40,56,72,75,77] The prevention programs examined in the literature are multifaceted (i.e., include warm-up, flexibility, jump training, strength, rehabilitation and/or sport specific technical components) and there is no measurement of balance reported in any of these trials. As such, the effectiveness of the proprioceptive balance-training component alone, on the improvement of dynamic balance and prevention of injury in sport, remains unclear.

The purpose of this cluster-RCT is three-fold: 1. to determine the effectiveness of a home-based, proprioceptive, balance-training program in improving static and dynamic timed eyes-closed unipedal balance in healthy adolescents; 2. to examine the impact of this balance-training program on functional strength and endurance; and 3. to determine the feasibility of future cluster-RCTs in examining the effectiveness of injury prevention programs in adolescent sport

5.2 Methods

5.2.1 Design

This is a cluster-randomized controlled trial design. Randomization by individual was not practical because randomizing adolescents within the same school setting would likely result in information sharing regarding the specific training intervention and unwanted crossover of intervention.[12,21,23,66] In addition, since a pre-season training program is often offered at a group level (i.e., team), cluster randomization has advantages in terms of external validity of the trial results.[66]

5.2.2 Subjects

We randomly recruited ten schools from a potential 15 Calgary Board of Education high schools to participate in our study. We used computer generation of random numbers for all randomization (i.e., random recruitment of schools, students and allocation to intervention) in this study using the Stata statistical software package.[68] We obtained the consent of the school principals and physical education (PE) coordinators, prior to randomly recruiting students from PE classes and randomly allocating schools to intervention group. There was allocation concealment, in that schools were randomly allocated to treatment group following initial subject recruitment. We randomly approached four subjects, two male and two female, from each of grades ten to twelve PE program rosters. If a subject declined participation or dropped-out after the baseline assessment but prior to a follow-up assessment, another student (from the same school, grade, and gender) was recruited.

In order to be included in this study, the subject had to be between the ages of 14 and 19 years, attend high school (grade ten to twelve) in Calgary, and participate in PE class. Subjects were excluded if there was a previous history of a musculoskeletal injury requiring medical attention and/or time loss from sporting activity of at least one day in the six weeks prior to recruitment, a previous history of serious musculoskeletal disorder (e.g., fracture, rheumatological disease, systemic disease or surgery) in the six months prior to recruitment and those with an ongoing medical condition (e.g., high blood pressure or fainting/dizziness spells).

5.2.3 Procedures:

5.2.3.1 Baseline Assessment

Both the subject and their parent/guardian completed informed consent prior to screening. We asked each subject to complete a baseline questionnaire prior to the initial assessment (Appendix A). At the initial assessment the examiner measured each participant's height and weight. Body-mass index (BMI) was calculated by the formula of: BMI = weight (kg)/ height $(m)^2$. All study measurements were recorded on a measurement record sheet (Appendix F).

Each subject completed both a timed eyes-closed static unipedal balance (ECS) test on the gym floor surface and a timed eyes-closed dynamic unipedal balance (ECD) test on an Airex Balance Pad® (Figure 5.1 and 5.2). Three trials were performed on each leg following determination of leg dominance. These tests were previously examined in a pilot study and adequate intra-rater reliability and excellent inter-rater reliability were demonstrated.[28] An Airex Balance Pad®, manufactured by the L-group (St. Louis, Missouri), is a high-density (50 kilogram/cubic meter) closed cell foam pad (50 x 41 x 6 centimetres, 0.7 kilograms). A 30-second rest between protocols and 15-second rest between trials was given. A 15-second practice session was allowed, using the foam prior to the start of the test session, to help subjects become familiar with this support surface.

To identify leg dominance the subject was asked to kick a ball hard. Hands were placed on the hips for both the static and dynamic trials. The testing foot was placed in the center of the foam. For both the ECS and ECD trials, eyes were closed prior to elevation of the opposite foot from the floor. The examiners had verbal, yet no physical contact with the subject. Once the stopwatch had been started, no further verbal cues were given to the subject prior to loss of balance. The maximum time allowed for each test was 180 seconds. The stopwatch was stopped upon loss of balance or eyes opening. Loss of balance included removal of one hand from the hip, touching the floor or foam with the non-weight-bearing foot, movement of the weight-bearing foot from its original position on the floor or foam, or movement of the foam from its original position in the dynamic balance tests.

Figure 5.1: Eyes-closed static balance

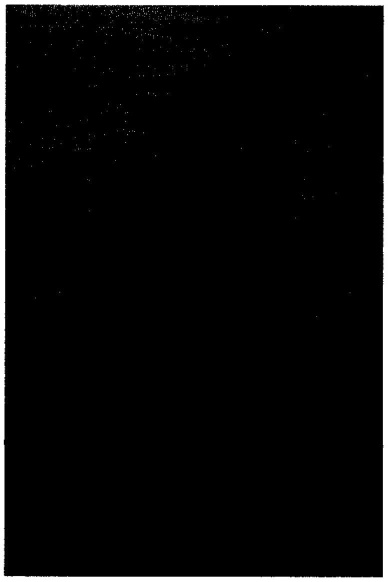
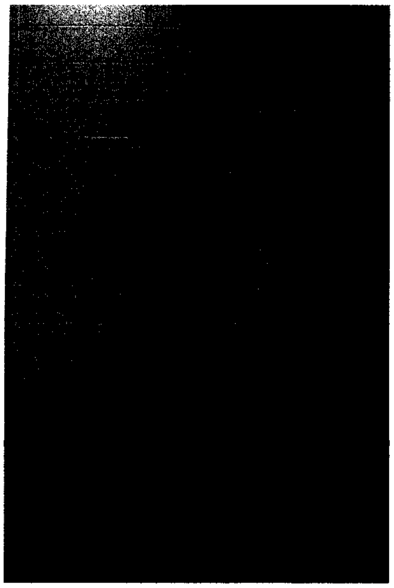


Figure 5.2: Eyes-closed dynamic balance



The baseline assessment also included a vertical jump test and a shuttle run endurance test. The vertical jump test[57] is a functional strength measurement that assesses the maximum height attained over three jump trials (Figure 5.3). We used the Canadian version of the 20-metre shuttle run test to assess endurance(Figure 5.4).[44,45] We recorded the number of shuttles completed, keeping in time with a pre-recorded time signal.

Figure 5.3: Vertical jump test

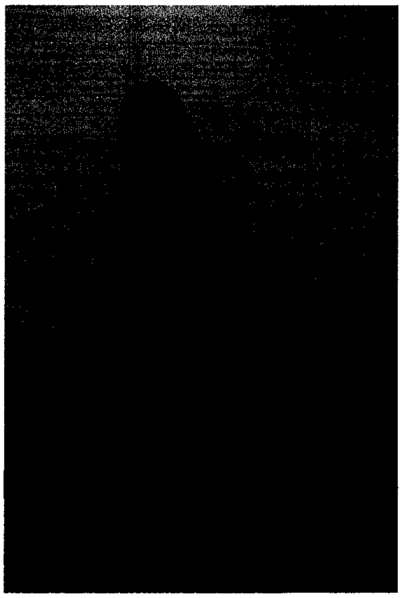
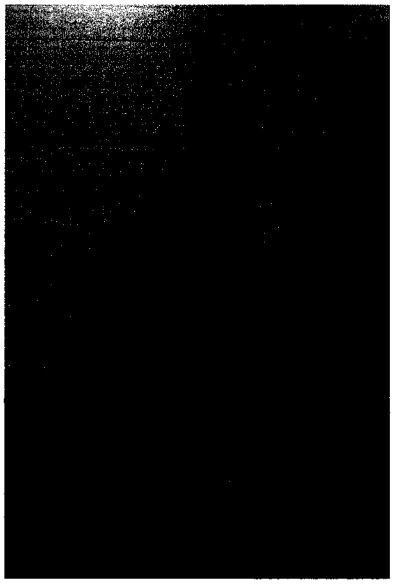


Figure 5.4: 20-metre shuttle run test



5.2.3.2 Follow-up Assessments

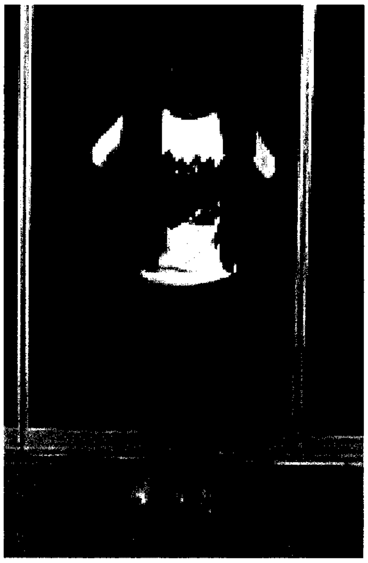
We assessed each subject at baseline, two, four, and six weeks. Each study subject was asked to complete a static (ECS) and dynamic (ECD) balance test, vertical jump test, and shuttle run test at each assessment. We also asked each study participant to complete a sport participation record sheet (Appendix G) and an injury report form (Appendix H) as required for six months following the baseline assessment. An athletic injury was defined as any injury occurring during a sporting activity, which required medical attention and/or loss of at least one day of sporting activity. Biweekly phone calls were made to all study participants for the six-month follow-up period to facilitate completion of injury report forms and sport participation journals. These forms were to be returned to the school PE department in a sealed envelope.

5.2.3.3 Intervention

Following baseline assessment, the study coordinator taught each participant in the intervention group a progressive program that consisted of a six-week, home-based, proprioceptive, balance-training program using a 16-inch diameter wobble board supplied by Fitter International Inc. (Figure 5.5 and Appendix I). Progression of this program was taught after each follow-up assessment. Each daily session was expected to be 20 minutes. We asked the participant to complete the session five times per week. Each participant in an intervention school was provided with a wobble board for their use at home. In addition, each participating school was provided with two wobble boards for their school gym, to aid participants in completing their daily balance training session.

The balance-training program was adapted from two published protocols designed by Hoffman et al[41] and Wester et al.[77] In addition, it included an emphasis on "core stabilization" exercises, including isometric contraction of the transverse abdominus and gluteus medius muscles.

Figure 5.5: Wobble board training program



Compliance of the intervention group with the balance training was assessed by completion of a daily record (Appendix J) by each participant. Weekly telephone follow-up by the research coordinator was done to verify compliance and address any specific questions regarding progression of the training program. Compliance with the six-week balance-training program was considered met if the participant completed, on average, a minimum of three training sessions per week.

5.2.3.3 Outcome measurements

Our primary outcome measurements of interest are the time (in seconds) that unipedal balance is maintained for each of the static and dynamic balance tests (ECS and ECD). The measurements are based on the maximum of six trials, three for each leg. We pooled the leg measurements because there is no evidence that sides differ for static or dynamic balance ability.[28,38,71]

Our outcome measurement of interest for the vertical jump test is the maximum height attained (in centimeters) over three jump trials. Our outcome measurement of interest for endurance is an estimation of maximal oxygen uptake (VO_2Max), which was calculated based on level achieved in the 20-metre shuttle run test.[44]

The primary injury outcome measurements were relative risks of injury based on cumulative incidence, including all reported sports injuries meeting study criteria. The secondary injury outcome measurements were relative risks of injury based on cumulative incidence, including only ankle sprain injuries meeting study criteria.

5.2.4. Statistical Issues

5.2.4.1 Sample Size Considerations:

The sample size chosen for this study accounted for the necessity to assess the treatment effect against the between-group variance (Appendix K).[21,23,24,55] Individuals within clusters have the tendency to respond similarly and the natural variability in response among clusters exceeds the variability in response within clusters.[21,24] This leads to decreased efficiency of cluster randomization relative to individual randomization.[21,24] To ensure similar power to a study randomizing individuals, the calculated sample size must be adjusted by an "inflation factor" associated with an intra-cluster correlation factor (ρ).[21,23] The intra-cluster correlation reflects the within cluster resemblance anticipated.[21,23]

5.2.4.2 Analytic Considerations:

We used the Stata statistical software package to analyze our data.[68] Information on baseline characteristics (age, previous injury, previous lower extremity injury, sports participation, height, weight, body mass index, balance [ECS and ECD], vertical jump test and predicted VO_2Max) are reported as means, geometric means, or counts and percentages (with 95% CIs), where appropriate. Variables were examined for both the intervention and control groups, as well as for the dropout subjects who initiated the baseline assessment.

We calculated the mean difference in the maximum static and dynamic balance (ECS and ECD) between baseline and six weeks for each study participant. To examine the effectiveness of the six-week balance-training program in improving ECS and ECD balance, these mean differences in the intervention group were compared to those in the control group. To do this, we used a two-sample independent t-test and a cluster-adjusted analysis.[23,24] Because the number of clusters randomized to each study arm is small and the study groups may not be entirely comparable with respect to the baseline covariates, we did a cluster-adjusted two-sample independent t-test, which uses the individual as the unit of analysis and adjusts for clustering effects in the estimation of variability.[21,23,24]

Where the assumptions of normality and equal variance were not met, we transformed our data.[1] We did a similar analysis to examine between-group comparisons for change in functional strength and predicted VO_2Max. Our analyses are based on the intent-to-treat principal.

To examine a potential dose-response relationship between training program duration and improvement of balance, we also examined between week differences at baseline to two weeks, two to four weeks and four to six weeks. Bonferroni adjustment for multiple tests is considered in the interpretation of results, however, given the small sample size the unadjusted results are presented.[1]

We performed further analyses to examine vertical jump test scores and predicted VO_2Max in a similar fashion. We examined the dose-response relationship between reported compliance and change in ECS and ECD balance using linear regression analysis. We used a cluster-adjusted mixed effects model to further examine the effectiveness of the training program in improving both ECS and ECD balance, controlling for other baseline covariates.[24] To determine our final model, we eliminated covariates through a step-wise process, with the alpha set at 0.05. A Breusch and Pagan Lagrange multiplier test in Stata was used to examine for random cluster effects (i.e., tests for evidence against the null hypothesis, Ho: between school variance = 0).[68] If there is no evidence against this null hypothesis (i.e., $p>0.05$), standard multiple linear regression models are presented.

We present the relative risk (RR) of injury, based on a univariate analysis comparing incidence rate of injury in the two study groups. To compare incidence rates in the two study groups we used Fisher's exact methods. Stratified analysis based on previous injury is also examined using Fisher's exact methods.[1] A cluster-adjusted logistic regression analysis was considered, but proved unnecessary based on evidence against increased similarities in injury rates within schools.[22]

5.2.5 Ethical Considerations:

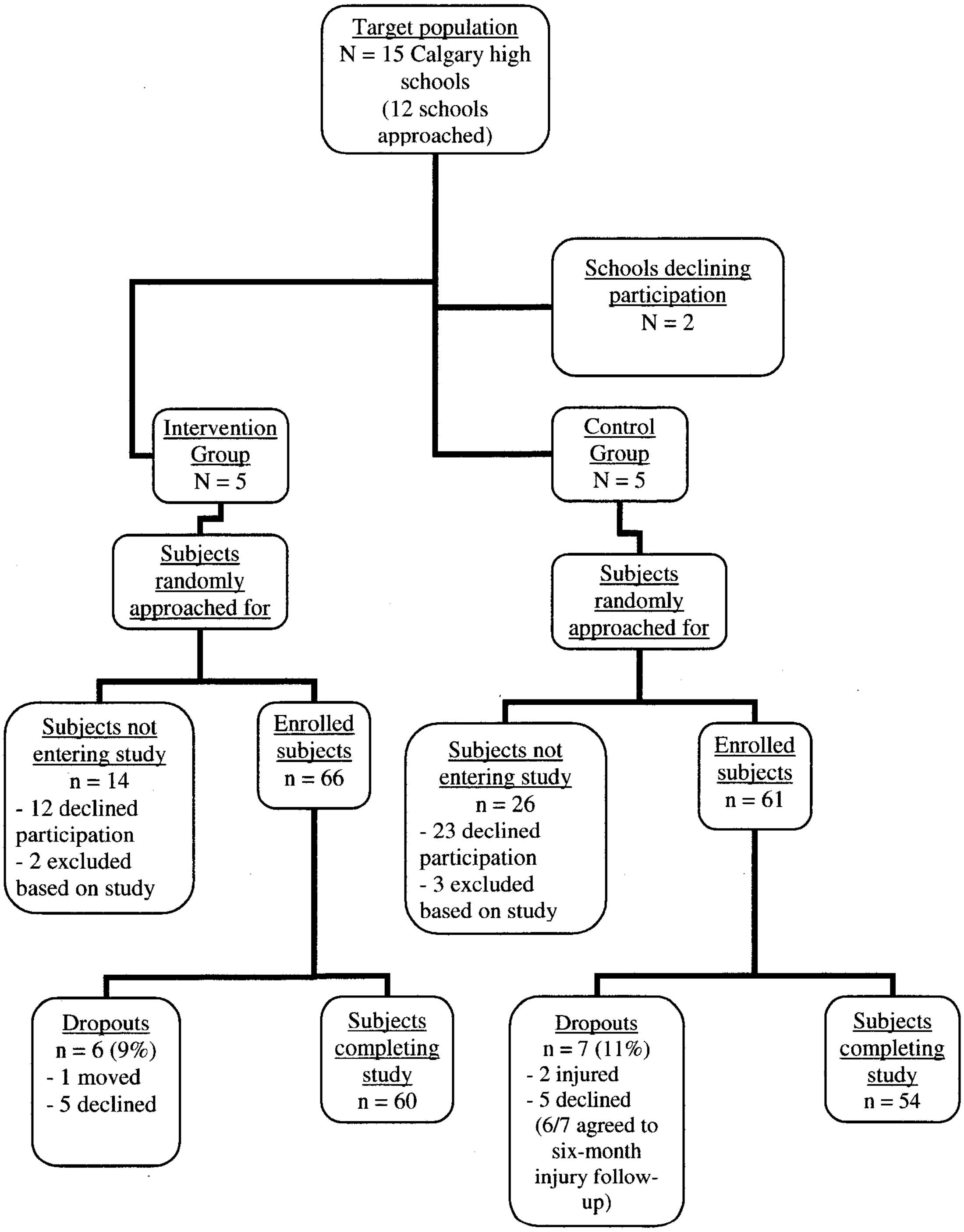
This cluster-RCT was approved by the University of Alberta Health Research Ethics Board, the University of Calgary, Office of Medical Bioethics and the Calgary School Board Ethics Review Committees. Every effort was be made to maintain the privacy of subjects participating in this study. Following completion of the initial study questionnaire all subjects were assigned a study number. All data entered into the computer were identified by that study number alone. Subject names appeared on paper copies of questionnaires and record forms only. All paper copies were kept in a locked filing cabinet located in the Sport Medicine Centre at the University of Calgary. All data obtained in this study by which the subject could be identified remained confidential between the subject and research team.

5.3 Results

5.3.1 Descriptive Statistics

School recruitment, allocation to intervention, and subject recruitment is summarized in Figure 5.6 (Appendix L; Table 5.i). A dropout included any subject who did not participate in all assessments (baseline, two, four and six weeks). Of the 114 subjects completing the study, 97 subjects completed all follow-up assessment components and 114 subjects completed all follow-up session components excluding the shuttle run test at all three follow-up test sessions.

Figure 5.6: Flow Diagram summarizing recruitment and allocation of intervention



In examining differences between baseline covariates in subjects completing all study components (n=114) and drop-out subjects (n=13), we found that study subjects had a greater predicted VO_2 Maximum (two-tailed Student's t-test, $t_{122} = -2.27$, $p = 0.03$)

and did not have as high dynamic balance maximum times (two-tailed Student's t-test, $t_{124} = 2.2$, $p = 0.03$). However, if Bonferroni adjustments are made for multiple tests, these differences are no longer statistically significant (Appendix L [Table 5.ii]).

On the ECS test, four of 120 subjects reached 180 seconds at the baseline assessment, ten of 119 subjects reached it at the two-week follow-up, ten of 114 subjects reached it at the four-week follow-up and 14 of 114 subjects reached it at the six-week follow-up assessment. All of these subjects who reached180 seconds were excluded from the analysis. We logarithmically transformed all balance measurements to meet the assumption of normality (Appendix M [Figures 5.i - 5.iv]).

We found no statistically significant baseline differences between the study groups (Table 5.1). However, if we examine the point estimates there may be clinically important imbalances for previous injury and sports participation which may bias the study results. Adolescents in the training group appear to participate more in sport and have higher injury rates. We found no difference between males and females on static or dynamic balance measurement (Appendix L; Table 5.iii) in this study or a pilot study.[28] Consequently, we did not adjust these results based on gender sub-grouping. Other differences on baseline characteristics between male and female subjects are summarized in Appendix L (Table 5.iv and 5.v).

Table 5.1: Comparison of baseline characteristics for training and control groups
(Two-tailed Student's t-test based on log transformed balance measurements)

Covariate	**Training Group [n=60] Mean (95% CI) (exact 95% CI for binomials)**	**Control Group [n=60] Mean (95% CI) (exact 95% CI for binomials)**	**Two-tailed Student's t-test or test of proportions**
Age (years)	15.88 (15.64, 16.13)	15.78 (15.52, 16.04)	$t_{118} = -0.56$; $p = 0.58$
Gender	30 male, 30 female	30 male, 30 female	N/A
Previous Injury (Lower Extremity)	15/60=25% (14.7, 37.9)	9/60=15% (7.1, 26.6)	$z = 1.37$; $p = 0.17$
Previous Injury (All)	24/60= 40% (27.6, 53.5)	19/60= 31.7% (20.3, 45)	$z = 0.95$; $p = 0.34$
Height (m)	1.71 (1.7, 1.74)	1.69 (1.67, 1.71)	$t_{118} = -2.22$; $p = 0.03$
Weight (kg)	64.83 (61.41, 68.26)	65.43 (62.14, 68.72)	$t_{118} = 0.25$; $p = 0.8$
Body Mass Index (kg/m^2)	21.95 (20.84, 23.06)	23.07 (21.87, 24.26)	$t_{118} = 1.37$; $p = 0.17$
Sport participation previous 6 weeks (hours/week)	9.45 (7.56, 11.34)	7.81 (6.16, 9.47)	$t_{118} = -1.3$; $p = 0.2$
Vertical Jump (cm)	40.35 (37.59, 43.1)	37.2 (34.63, 39.77)	$t_{118} = -1.67$; $p = 0.1$
Predicted VO_2 Max (ml/kg.min)	34.92 (32.59, 37.25)	34.4 (32.4, 36.39)	$t_{117} = -0.34$; $p = 0.73$
Geometric Mean ECS balance (s)	25.89 (21.13, 31.73) 1 subject reached 180 s	33.08 (26.79, 40.85) 3 subjects reached 180 s	$t_{114} = 1.67$; $p = 0.097$
Geometric Mean ECD balance (s)	5.53 (4.88, 6.23)	5.95 (5.3, 6.67)	$t_{118} = 0.86$; $p = 0.39$

5.3.2 Effectiveness of Training Program on Static and Dynamic Balance

Maximums for ECS and ECD balance measurements failed to meet assumptions of normality. The difference between follow-up and baseline assessments for ECS and ECD balance, however, did meet these assumptions (Appendix M [Figures 5.v and 5.vi]). Between test-session differences by study group, based on univariate individual analyses using a two-tailed Student's t-test, show differences for static balance and dynamic balance (Table 5.2, Figures 5.7 and 5.8).

Table 5.2: Between test session differences for static and dynamic balance measurements

Difference examined	Training group (95% CI)	Control group (95% CI)	Two-tailed Student's t-test
Static Balance (Baseline – 2 weeks)	2.31 (-5.56, 10.18)	-0.06 (-7.51, 7.38)	t_{107}=0.44; p = 0.66
Static Balance (2 weeks – 4 weeks)	9.91 (2.68, 17.13)	-5.03 (-10.26, 0.19)	t_{99}=-3.24; p = 0.0016*
Static Balance (4 weeks – 6 weeks)	11.28 (5.37, 17.2)	-0.61 (-4.71, 3.49)	t_{96}=-3.17; p = 0.002*
Static Balance (Baseline – 6 weeks)	20.31 (12.34, 28.29)	-6.12 (-14.09, 1.85)	t_{96}=-4.66; p< 0.00005*
Dynamic Balance (Baseline – 2 weeks)	0.69 (-0.45, 1.84)	2.23 (0.35, 4.10)	t_{117}=1.4; p=0.16
Dynamic Balance (2 weeks – 4 weeks)	1.49 (0.38, 2.59)	-0.39 (-2.51, 1.73)	t_{112}=-1.62; p = 0.11
Dynamic Balance (4 weeks – 6 weeks)	1.30 (0.23, 2.36)	-0.74 (-1.78, 0.31)	t_{112}=-2.72; p = 0.008*
Dynamic Balance (Baseline – 6 weeks)	3.48 (2.21, 4.74)	1.32 (0.11, 2.52)	t_{112}=-2.46,; p = 0.015*

*denotes significance based on $p \leq 0.05$

Figure 5.7: Geometric means for eyes-closed static balance (ECS)

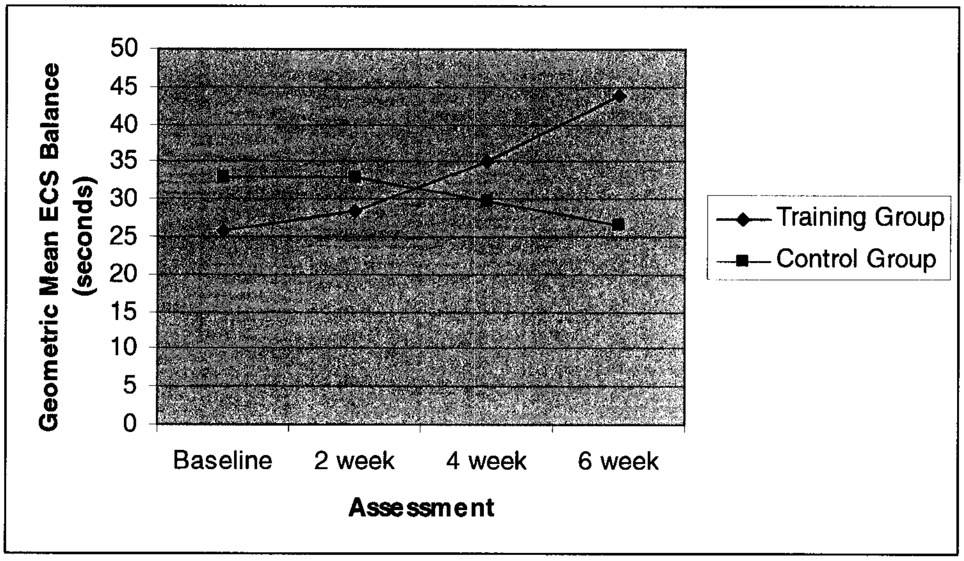
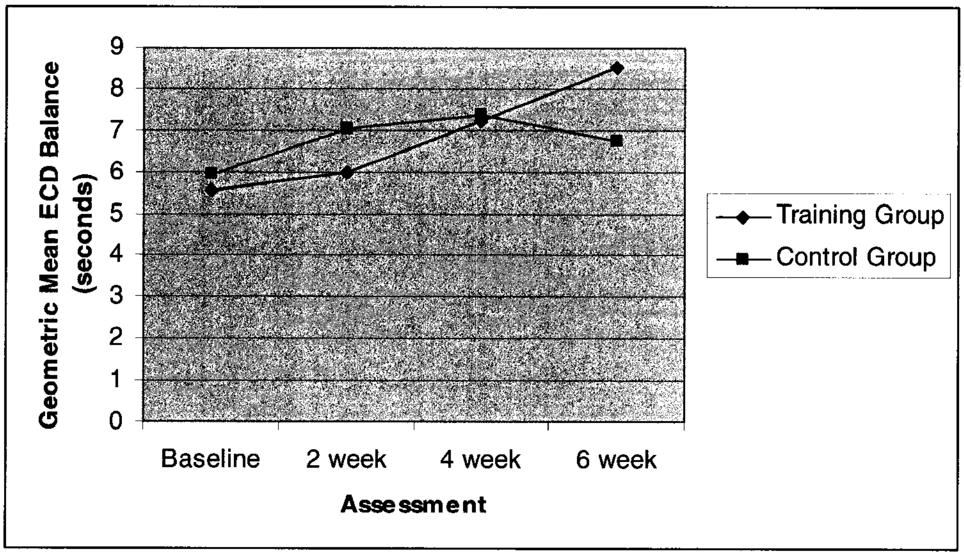


Figure 5.8: Geometric means for eyes closed dynamic balance (ECD)



The results of the individual level and cluster-adjusted analyses examining ECS and ECD balance differences are summarized in table 5.3 (calculations Appendix N [I]).

Table 5.3: Summary of individual and cluster adjusted two-sample t-test analysis

Difference	**Difference between groups (Control group – Training group) (95% CI cluster-adjusted if appropriate)**	**Cluster adjusted t-test (ρ = intracluster correlation coefficient)**	**Individual level analysis t-test**
Static balance (Baseline- 2 weeks)	-2.37 (95% CI; -4.18, 6.53)†	N/A **($\rho = 0$)**††	$t_{107}=0.44$; p = 0.66
Static balance (2 weeks- 4 weeks)	-14.94 (95% CI; -24.07, -5.82)†	N/A **($\rho = 0$)**††	$t_{99}=-3.24$; p = 0.0016*
Static balance (4 weeks- 6 weeks)	-11.89 (95% CI; -19.34, -4.45)†	N/A **($\rho = 0$)**††	$t_{96}=-3.17$; p = 0.002*
Static balance (Baseline- 6 weeks)	-26.43 (95% CI; -41.48, -11.38)	$t_8 = 4.05$; p=0.0037* **($\rho = 0.0358$)**	$t_{96}=-4.66$; p< 0.00005*
Dynamic balance (Baseline- 2 weeks)	1.53 (95% CI; -2.01, 5.08)	$t_8= -0.997$; p=0.35 **($\rho = 0.0873$)**	$t_{117}=1.4$; p=0.16
Dynamic balance (2 weeks- 4 weeks)	-1.88 (95% CI; -5.74, 1.99)	$t_8 = 1.118$; p=0.3 **($\rho = 0.1007$)**	$t_{112}=-1.62$; p = 0.11
Dynamic balance (4 weeks- 6 weeks)	-2.04 (95% CI; -3.85, -0.23)	$t_8 = 2.595$; p=0.03* **($\rho = 0.0095$)**	$t_{112}=-2.72$; p = 0.008*
Dynamic balance (Baseline- 6 weeks)	-2.16 (95% CI; -5.18, 0.86)	$t_8 = 1.647$; p=0.14 **($\rho = 0.1089$)**	$t_{112} = - 2.46$; p=0.015*

*denotes significance based on $p \leq 0.05$

†† negative values of intracluster correlation coefficient set equal to 0

$\dagger$ 95% CI not adjusted for cluster randomization if intracluster correlation coefficient equal to 0

When we adjust p-values for multiple comparisons (i.e., 8 comparisons) we can calculate highly conservative Bonferonni adjusted p-values (p') by multiplying the p-value found by 8.[1] Even when adjustments are made for multiple tests we still find significant differences for all static balance differences which were significant without adjustment (static balance week 2 – week 4: p'=0.013, static balance week 4 – week 6: p'=0.016, static balance baseline – week 6: p'=0.0004). Differences for dynamic balance differences are no longer statistically significant (dynamic balance week 4 – week 6: p'=0.24).

Multiple linear regression (MLR) analyses to further examine effectiveness of the training program in improving static and dynamic balance while controlling for other baseline covariates reproduces the results based on the primary outcome of interest, balance difference between baseline and six-weeks. We found that using mixed effects models (i.e., allowing random effects for cluster) to predict static balance difference and dynamic balance difference was not necessary given that the variance between schools was equal to 0 (Appendix N [II and III].

We developed a final model to predict the difference between static balance (ECS) at baseline and six-weeks, Sdiff6, for adolescents based on training group, Group (Control = 0, Training = 1); ECSbaseline (ECS balance at baseline where <40 seconds = 0 and ≥40 seconds = 1); and VO_2 (predicted VO_2 maximum at baseline measured in ml/kg.min) (Table 5.4):

$$\mathbf{Sdiff6 = -21.13 + 20.67\ Group - 30.23\ ECSbaseline + 0.76\ VO_2}\ (r^2 = 0.38)$$

Table 5.4: Multiple linear regression model to predict static balance difference between baseline and six-weeks

Variable	Coefficient (β)	Standard Error	95% CI	Wald Statistic (t_{93})	p
Intercept	-21.133	10.57	-42.12, -0.14	-2.0	0.049*
Group	20.67	4.97	10.79, 30.55	4.16	<0.0005*
ECSbaseline	-30.23	5.69	-41.53, -18.93	-5.31	<0.0005*
VO_2	0.76	0.31	0.16, 1.37	2.5	0.014*

*denotes significance based on $p \leq 0.05$

The average static balance difference between baseline and six-weeks for training group students is estimated to be 20.67 (95% CI, 10.79, 30.55) seconds greater than among control group students, if baseline static balance and predicted Vo2max are held constant. In addition, the difference in static balance between baseline and six-weeks is estimated to be 30.23 (95% CI; 18.93, 41.53) seconds less, on average, if static balance measured at baseline is at least 40 seconds. The difference in static balance between baseline and six-weeks increases 0.76 (95% CI; 0.16, 1.37) seconds for each additional ml/kg.min predicted $V0_2$max. (Appendix N [II]). There are no apparent confounders in the relationship between training group and change in static balance between baseline and six-weeks.

We developed a final model to predict the difference between dynamic balance (ECD) at baseline and six-weeks, Ddiff6, for adolescents based on training group Group (Control = 0, Training = 1); and ECDbaseline (based on ECD balance at baseline where <8 seconds = 0 and ≥8 seconds = 1) (Table 5.5):

Ddiff6 = 1.93 + 2.34Group – 2.98 ECDbaseline ($r^2 = 0.105$)

Table 5.5: Multiple linear regression model to predict dynamic balance difference between baseline and six-weeks

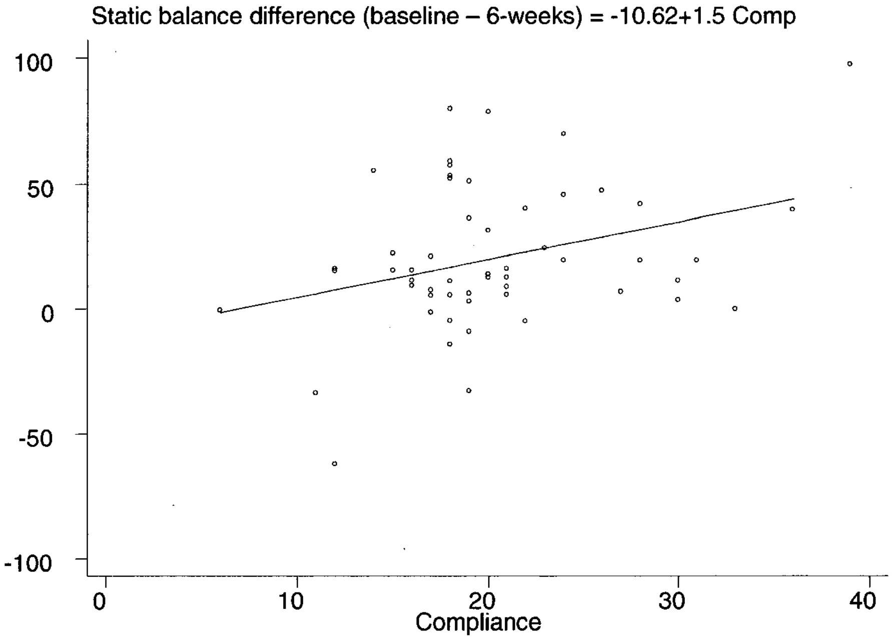
Variable	Coefficient (β)	Standard Error	95% CI	Wald Statistic(t_{111})	p
Intercept	1.93	0.65	0.64, 3.21	2.97	0.004*
Group	2.34	0.85	0.66, 4.02	2.76	0.007*
ECDbaseline	-2.98	0.98	-4.95, -1.0	-2.98	0.004*

*denotes significance based on $p \leq 0.05$

The average dynamic balance difference between baseline and six-weeks for training group students is estimated to be 2.34 (95% CI: 0.66, 4.02) seconds greater than among control group students, if baseline dynamic balance is held constant. In addition, the difference in static balance between baseline and six-weeks is estimated to be 2.98 (95% CI: 1.0, 4.95) seconds less, on average, if dynamic balance measured at baseline is at least 8 seconds (Appendix N [III]).

There is evidence of a dose-response relationship between training program compliance and effectiveness based on change in static balance over the six-week training period. The expected change in static balance in training group subjects reporting less than 18 sessions balance training over six weeks is 6.12 seconds (95% CI: -8.42, 20.67). This is significantly less than in those reporting at least 18 sessions which is 25.77 seconds (95% CI: 16.45, 35.1 two-tailed Student's t-test, $t_{52}= -2.301$; $p = 0.025$). The mean reported compliance to the home training program was 21.3 (95% CI, 19.6, 23.1) sessions over six weeks (Appendix M, Figure 5.vii). A linear regression analysis shows the estimated change in static balance increases with increased reported compliance to training [slope = 1.52; 95% CI: 0.29, 2.75; $t_{52} = 2.47$; $p = 0.017$; sdiff = -10.62 + 1.5Compliance; $r^2 = 0.105$] (Figure 5.8 and Appendix N [IV]). Compliance did not have a significant effect on change in dynamic balance (Appendix N [IV]).

Figure 5.9: Cluster-adjusted simple linear regression analysis examining change in static balance (ECS) by reported compliance to six-week training program



5.3.3 Effectiveness of Training Program on Functional Strength and Endurance

There were no significant between-session or between-group differences found for vertical jump or predicted VO_2Max measurements (Appendix L [Table 5.v and 5.vi]). As such, cluster-adjusted analyses were not warranted.

5.3.4 Effectiveness of Training Program on Prevention of Injury in Adolescent Sport

There were five female and seven male subjects who reported an athletic injury in the six-month follow-up period. Five injuries were reported by grade 12 subjects, three by grade 11 subjects and four by grade ten subjects. The median time loss from injury was 13 (range, 7-28) days. Based on the 26-week follow-up period, the median time of injury occurrence was 13 (range, 2-24) weeks. The injuries reported occurred in basketball (4/12), soccer (3/12), football (2/12), hockey (2/12) and volleyball (1/12). The injuries reported are summarized in Table 5.6. The RR of injury was 0.2 (95% CI; 0.05, 0.88) (Table 5.7). The RR of ankle sprain injury was 0.14 (95% CI; 0.018, 1.13).

Table 5.6: Reported injuries requiring medical attention or time-loss from sport

Training Group (n=60)	Control Group (n=60)
▪ 1 ankle sprain ▪ 1 metatarsal fracture	▪ 7 ankle sprains ▪ 1 metacarpal fracture ▪ 1 shoulder strain ▪ 1 low back strain

Table 5.7: Injury Data

RR = 0.2 (95% CI; 0.05, 0.88)

Group	Injury	No Injury	Total
Training	2	58	60
Control	10	50	60
Total	12	108	120

There was a significant difference in injury incidence rate between study groups (Table 5.8). Given the small number of injuries reported in six months, the intra-cluster correlation coefficient was calculated based on the one-year previous history of injury reported. A cluster-adjusted chi-square analysis was not warranted given that the intra-cluster correlation coefficient estimated was negative and hence given the value 0 (see calculations Appendix O [V]). This indicates that cluster randomization was not expected to affect the outcome related to comparison of injury rates.

Table 5.8: Incidence rate by intervention group

Injury Rate	Training Group (95% CI)	Control Group (95% CI)	Difference	2-sided Fisher's exact test
Incidence Rate (6 month study period) (injuries/100 participants)	3.33 (0.41,11.53)	16.67 (8.29, 28.52)	13.33 (2.87, 23.8)	p = 0.03*

* denotes significance based on p≤ 0.05

There is evidence that the training program was preventative in subjects who reported an injury in the previous year [RR = 0.13; 95% CI: 0.02, 1.0 (2-sided Fisher's exact test, p = 0.03)] and not in those reporting no previous history of injury [RR = 0.28; 95% CI; 0.03, 2.43 (2-sided Fisher's exact test, p = 0.36)].

Table 5.9: 2 X 2 Injury data stratified by previous history of injury status

NO PREVIOUS INJURY
RR = 0.28 (95% CI; 0.03, 2.43)

Group	Injury	No Injury	Total
Training	1	35	36
Control	4	37	41
Total	5	72	77

PREVIOUS INJURY
RR = 0.13 (95% CI; 0.02, 1.0)

Group	Injury	No Injury	Total
Training	1	23	24
Control	6	13	19
Total	7	36	43

Multiple logistic regression analysis reproduces the main finding that the training program is preventative, when other covariates are controlled for in the analysis (Appendix O). Our results were used to construct a model to predict the occurrence of injury, Injury, based on Group (training = 1, control = 0), and Previous Injury (previous injury = 1, no previous injury = 0):

Probability of Injury = 1 / 1 + $e^{-(-2.12 - 1.93\text{Group} + 1.25\text{Previous Injury})}$

Table 5.10: Multiple logistic regression model to predict injury

Variable	Coef-ficient (β)	Standard Error	95% CI	z	P>lzl	Odds Ratio	95% CI
Intercept	-2.12	0.48	-	-	-	-	-
Group	-1.93	0.82	-3.52, -0.33	-2.364	0.018*	0.15	0.03, 0.72
Previous Injury	1.25	0.65	-0.02, 2.52	1.936	0.053	3.51	0.98, 12.49

*denotes significance based on $p \leq 0.05$

The estimated odds ratio (OR) (i.e., odds of injury in the training group/ odds of injury in the control group) is 0.15 (95% CI, 0.03, 0.72). In addition, the OR associated with previous injury (i.e., the odds of injury in subjects reporting a previous one-year history of injury/ odds of injury in subjects with no history) is 3.51 (95% CI, 0.98, 12.49). Although the 95% CI includes one, this finding is likely to be clinically relevant given the small sample size and small number of injuries. These estimates do not change significantly when other covariates are included in the analysis (Appendix N [VI]).

5.4 Discussion

This is the first RCT study to examine a specific balance training program in adolescents, measure the improvement in static and dynamic balance over time, and adjust the analysis for baseline differences, cluster randomization, compliance with intervention, and effectiveness of the training program. Using a simple, home-based, proprioceptive balance-training program, using a wobble board, we have demonstrated statistically impressive and clinically important improvements in static balance and reduction in overall sport-related injury in adolescents (ages 14-18 years) who are participating in a regular PE program. The effectiveness of this program in improving dynamic balance is evident in an individual and cluster-adjusted analysis, but not when the analysis is adjusted for multiple comparisons.

The improvement of static balance is consistent with other studies demonstrating an improvement in static balance following balance-training using a wobble board.[7,32,35,41,51,62,71] The multivariate analysis suggests that there are no other confounders in this relationship. It is not surprising, however, that adolescents with a higher VO_2 maximum (i.e., those with higher fitness levels) are likely to improve more between baseline and week six, independent of training group. Adolescents with higher fitness levels may have trained more diligently in the training group and those with higher fitness levels in the control group may have been more likely to practice their balance skills, knowing they would be tested biweekly for six weeks. It is also not surprising that adolescents who demonstrate the best static balance ability at baseline (i.e., > 40 seconds) are less likely to demonstrate further improvement between baseline and six weeks compared to those with less static balance ability (i.e., ≤ 40 seconds) at baseline.

There is evidence of improvement in static balance between weeks two and four, as well as weeks four and six in the training group only. This result suggests the need for more than two weeks balance training to elicit an improvement in static balance. There is also evidence of effectiveness of training in improving dynamic balance over a six-week training period, particularly between weeks 4 and 6, based on an individual level analysis. The cluster-adjusted analyses reproduced these results for the improvement between week 4 and week 6, suggesting the need for a longer (>4 weeks) program and more difficult balance training exercises, as were taught at week 4, to improve dynamic balance. The lack of evidence to support an overall improvement in dynamic balance between baseline and six weeks, baseline and 2 weeks, and 2 weeks and 6 weeks, is likely a result of decreased statistical efficiency when accounting for increased variability of individuals between clusters than within clusters.[21,24] The dynamic balance measurement has a very small variability, both within and between clusters.[28] As a result, small changes may not be significant when controlling for cluster randomization in the analysis.

The multivariate analysis examining dynamic balance difference demonstrates a significant improvement in dynamic balance in the training group compared to the control group when baseline dynamic balance is controlled for in the analysis. Similar to the findings examining static balance difference, the improvement in dynamic balance from baseline to six weeks is less for adolescents who already demonstrate the best balance ability (i.e., > 8 seconds) at baseline.

There is some evidence of a dose-response relationship between duration of program and effectiveness based on improvement of static and dynamic balance. Static balance in the training group improves significantly between two and four weeks and again between four and six weeks of training. Dynamic balance improved between week four and six. This is inconsistent with Balogun et al's[7] findings that biweekly follow-up measurements in the balance training group improves ECS balance up to week 4, but not between weeks 4 and 6. In their study, however, the wobble board activity was bipedal, eyes-open, lacked progression in difficulty (though the session length did increase from 10 to 25 minutes), and did not include core stability exercises. Static balance improvement also increases with increased reported compliance. This result validates self-reported compliance to training. This has not been demonstrated in other studies.[7,41]

It is not surprising that the training program had no effect on vertical jump height or predicted VO_2Max. Balogun et al[7] also demonstrated that a six-week wobble-board training program did not improve isometric lower extremity strength. Our balance training program specifically focuses on progressively difficult tasks to challenge dynamic balance. There are no specific components addressing aerobic endurance or lower extremity functional strength. It was essential, however, to demonstrate this in order to focus on balance ability in examining risk factors for injury in sport, or balance training as a prevention strategy for injury in sport. Other studies examining balance training as a prevention strategy to reduce injury in sport use multi-faceted programs, which may also address functional strength and endurance.[6,17,39,56,67,75] In addition to decreased static balance, both decreased strength and endurance have been demonstrated to be significant risk factors for injury in sport.[14,15,18,26,27,42,59,73,79]

Despite the small number of clusters and wide confidence intervals around the estimates for injury incidence rates, there is a significant difference in injury rate in the training and control groups. The RR of injury found in our study (RR = 0.2 [95% CI, 0.05, 0.88]) is consistent with the only other RCT examining a similar prevention program in adolescents (RR = 0.17 [95% CI, 0.089, 0.324]).[75] Other adult RCTs examining a training program that includes a proprioceptive balance training component, are also consistent with these findings (RR = 0.06 - 0.51).[6,17,40,56,72,77] Soderman et al[67] failed to demonstrate a protective effect of balance training on lower extremity injury rates in female elite soccer players. Although teams were randomized to study groups, players were not randomly recruited. In addition, the study groups were not compared on other baseline covariates. As such, other differences between groups may have contributed to their results, which may also be sport-specific.

Based on a stratified contingency table analysis, it is evident that the effectiveness of the training program may depend on previous injury status. The training program is only effective in reducing injury in adolescents reporting a previous history of injury in the previous year. Based on the logistic regression analysis, there is some evidence that previous injury may be associated with injury, independent of training group, (OR = 3.51 [95% CI, 0.98, 12.49]). This is consistent with other studies reporting previous injury as a strong predictor of sports injury (RR's = 2.88 - 9.41).[6,26,27,73]

The reported sports injury incidence rate for Alberta (based on self-reported injuries requiring medical attention) is 26 (95% CI, 21.3, 30.7) injuries/100 adolescents /year.[54] The six-month sports injury incidence rate found in this study in the control group (16.7 [95% CI, 8.3, 28.5] injuries/100 adolescents /six months) can be doubled to estimate a one year rate of 33.4 injuries/100 adolescents /year (95% CI: 16.6, 57). This is consistent with the self-reported previous one-year injury rate of 35.83 (95% CI, 27.29, 46.02) injuries/100 adolescents /year. The slightly higher point estimates in our study may reflect recruitment of PE participants only, rather than recruitment from the general population. Mummery at al[54] also demonstrated that lower extremity injuries accounted for 50% (95% CI, 45.1, 54.9) of all sports injuries reported. This is also consistent with our study where lower extremity injuries account for 57.8% (95% CI, 42.2, 72.3) of all previous injuries reported and 83.3%(95% CI, 51.6, 97.9) of prospective injuries reported.

A significant limitation of this study is in the collection of self-reported injury and sport participation data. Compliance in collecting prospective sport participation data was low (43.3%), which lead to the inability in using incidence density as the injury outcome measurement. Incidence density is preferred over cumulative incidence as an outcome measurement because it more accurately measures time exposure to risk of injury. With respect to the self-reported prospective injury data, biweekly telephone follow up was identical for all study subjects, regardless of group allocation. Low compliance in completion of sport participation journals may be associated with the time and commitment in completing a daily journal. One study coordinator telephoned all of the subjects in this study. A preferred arrangement would be to have an on-site study associate at each school to facilitate regular compliance with sport participation journal completion. In the case of examining a sport-specific injury prevention strategy, an on-site study associate (i.e., team trainer) would collect injury participation data from all games and practices.

There were no significant differences found between study groups with respect to baseline characteristics. Hence, the effectiveness of the training program found in this study is valid and not accounted for by differences in baseline covariates. The moderate reliability and small inter-subject variability associated with the dynamic balance measurement (ECD) in the pilot study could lead to an increased similarity between study groups on this study variable and resultant non-differential measurement bias. This would lead to an underestimation of the association between study group and change in dynamic balance over a six week training period. As such, it is possible that the lack of association found in the cluster-adjusted analysis examining dynamic balance may be related to non-differential measurement bias.

Greater effectiveness in improving balance and decreasing the risk of injury may have resulted if the training program chosen was more dynamic, perhaps more challenging and inclusive of other components such as jump training.[39,56] Hewett et al[39] demonstrated the effectiveness of a neuromuscular jump training program (in conjunction with a strength and flexibility program) in reducing knee injury in varsity athletes. It should be noted that this six-week program was performed with supervision, for 60 to 90 minutes per session, three sessions per week. This session duration and associated supervision may not be realistic from a time or cost perspective in most high-school settings. While other studies have demonstrated proprioceptive balance training as an effective prevention strategy for specific injury in specific sport, most of these studies involve a multifaceted training program, which includes a balance training component. [6,17,40,56,67,75] As such, the effectiveness of the balance training component of these programs on sports injury rates has remained unclear. Because of our experimental design, the improvement in balance and reduction of injury in our intervention group can be attributed to balance

An additional strength of our cluster-RCT is the random recruitment of schools and subjects, which increases the generalizability of the study results. The high rate of consent to participate (≅ 76%) and the low drop-out rate (≅ 10%) limited potential selection bias. This study also confirms the need to consider appropriate cluster-adjusted analyses when the unit of randomization is a cluster.

5.5 Conclusions

A six-week home-based proprioceptive balance training program using a wobble board is effective in improving timed eyes-closed static balance in healthy adolescents. This balance training program specifically focuses on balance and not other components of training such as sport related technique, strengthening, jump training or endurance. There is some evidence, based on an individual analysis, that this training program may also be effective in improving timed eyes-closed dynamic balance on a foam support surface. There is evidence of a dose-response effect over a six-week training period in improving timed eyes closed static and dynamic balance in healthy adolescents. More than two weeks of training (minimum, three sessions per week) is required to improve static balance. More than four weeks of training (minimum, three sessions per week) is required to improve dynamic balance. This improvement may also be attributed to the addition of more challenging balance exercises in this progressive six-week training program. There is no evidence to support a difference between groups for functional strength as measured by the vertical jump test or endurance as measured by predicted V02 max based on a 20- meter shuttle run test.

A six-week balance training program followed by a weekly six-month maintenance program also appears to be effective in preventing sports injury in adolescents. There is some evidence that it also reduces the risk of ankle sprain injury specifically. Future research should include a larger cluster-RCT with greater power to further examine the effectiveness of a home-based proprioceptive balance training program in preventing specific injury in specific adolescent sports. The injuries reported in this study occurred in basketball, volleyball, soccer and hockey. The majority of injuries reported were lower extremity injuries. All of these sports involve a high degree of pivoting or change of direction and rapid acceleration and deceleration maneuvers. As such, it is these sports which may be the future focus for examination of prevention strategies including balance training to improve lower extremity dynamic joint stability and reduce sports related injury in adolescents.

References

1. Altman DG. *Practical statistics for medical research.* Great Britain: Chapman & Hall; 1991.

2. Armstrong N, vanMechelen W. *Paediatric exercise and science in medicine.* Oxford: Oxford University Press;2000.

3. Backx FJG, Erich WBM, Kemper ABA, Verbeek ALM. Sports injuries in school-aged children. An epidemiologic study. *Am J Sports Med* 1989;17:234-240.

4. Backx FJG, Beijer HJM, Bol E, Erich WBM. Injuries in high-risk persons and high-risk sports. A longitudinal study of 1818 school children. *Am J Sports Med* 1991;19:124-130.

5. Bahr R, Bahr IA. Incidence of acute volleyball injuries: a prospective cohort study of injury mechanisms and risk factors. *Scand J Med Sci Sports* 1997;7:166-71.

6. Bahr R, Lian O. A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports* 1997;7:172-177.

7. Baxter-Jones A, Maffulli N, Helms P. Low injury rates in elite athletes. *Arch Dis Child* 1993;68:130-2.

8. Balogun JA, Adesinasi CO, Marzouk DK. The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada* 1992;44:23-30.

9. Bienfeld M, Pickett W, Carr PA. A descriptive study of childhood injuries in Kingston, Ontario, using data from computerized injury surveillance system. *Chronic diseases in Canada* 1996;17:21-27.

10. Bijur PE, Trumble A, Harel Y, Overpeck MD, Jone D, Scheidt PC. Sports and recreation injuries in US children and adolescents. *Arch Pediatr Adolesc Med* 1995;149:1009-16.

11. Blair SN, Kohl HW, Barlow CE et al. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. JAMA 1995;273:1093-1098.

12. Bland JM, Kerry SM. Trials randomized in clusters. *BMJ* 1997;315:600.

13. Brust JD, Leonard BJ, Pheley A, Roberts WO. Children's ice hockey injuries. *AJDC* 1992;146:741-747.

14. Burkett LN. Causative factors in hamstring strains. *Med Sci Sports Exerc* 1970;2(1):39-42.

15. Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of highschool football knee injuries. *Am J Sports Med* 1978;6:180-4.

16. Canadian Fitness and Lifestyle Research Institute website 2001; http:www.cflri.ca/cflri/resources/pub.php#98pamrep.

17. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee surg, Sports Traumatol, Arthroscopy* 1996;4:19-21.

18. Christensen CS, Wiseman DC. Strength, the common variable in hamstring strain. *Athl Train* 1972;7:36-40.

19. Cooley D, McNaughton L. Aerobic fitness of Tasmanian secondary school children using the 20-M shuttle run test. *Perceptual and Motor Skills* 1999;8:188-198.

20. Daniel DM, Stone ML, Dobson BE et al. Fate of the ACL injured patient. A prospective outcome study. Am J Sports Med 1994;22:632-644.

21. Donner A, Brown KS, Brasher P. A methodological review of non-therapeutic intervention trials employing cluster randomization, 1979-1989. *Int J Epidemiol* 1990;19:795-800.

22. Donner A, Klar N. Methods for comparing event rates in intervention studies when the unit of allocation is a cluster. *Am J Epidemiol* 1994;140:279-89.

23. Donner A, Klar N. Statistical considerations in the design and analysis of community intervention trials. *J Clin Epidemiol* 1996;49:435-439.

24. Donner A, Klar N. *Design and Analysis of Cluster Randomization Trials in Health Research.* Oxford University Press, Inc., New York, 2000.

25. Drawer F, Fuller CW. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med* 2001;35:402-408.

26.Emery CA. Does decreased muscle strength cause acute muscle strain injury in sport? A systematic review of the evidence. *Phys Ther Rev* 1999;4:79-85.

27. Emery CA, Meeuwisse WH. Risk factors for groin and abdominal strain injury in the National Hockey League. A Multivariate approach. *Med Sci Sport Exerc* 1999;33:1423-1433.

28. Emery CA, Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH. Development of a clinical static and dynamic standing balance measurement tool appropriate for use in healthy adolescents. Unpublished, 2003.

29. Gallagher SS, Guyer B, Kotelchuck M, Bass J, Lovejoy FH, McLoughlin E, Mehta K. A Strategy for the reduction of childhood injuries in Massachusetts: SCIPP. *New Engl J Med* 1982;307:1015-1019.

30. Gallagher SS, Finison K, Guyer B, Goodenough S. The incidence of injuries among 87,000 Massachusetts children and adolescents: results of the 1980-81 statewide childhood injury prevention program surveillance system. *Am J Public Health* 1984;74:1340-1347.

31. Garrick JG, Requa RK. Injuries in high school sports. *Pediatrics* 1978;61:465-9.

32. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med* 1988;9:141-144.

33. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long term incidence of gonarthrosis. *Sports Med* 1999;27:143-156.

34. Goldberg B, Rosenthal PP, Robertson LS, Nicholas JA. Injuries in youth football. *Pediatrics* 1988;81:255-61.

35. Goldie PA, Evans OM, Bach TM. Postural control following inversion injuries of the ankle. *Arch Phys Med Rehabil* 1994;75:969-75.

36. Grimmer KA, Jones D, Williams J. Prevalence of adolescent injury from recreational exercise: an Australian perspective. J Adolesc Health 2000;27:1-6.

37. Grubbs N, Nelson RT, Bandy WD. Predictive validity of an injury score among high school basketball players. *Med Sci Sports Exerc* 1997;29:1279-85.

38. Hahn T, Foldspang A, Vestergaard E, Ingermann-Hansen T. One-legged standing balance and sports activity. *Scand J Med Sci Sports* 1999;9:15-18.

39. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Am J Sports Med* 1999;27:699-705.

40. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports* 1999;9:104-109.

41. Hoffman M, Payne VG. The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopaedic and Sports Physical Therapy* 1995;21:90-94.

42. Jones BH, Bovee MW, Harris JM, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993;21:705-710.

43. King MA, Pickett W, King AJC. Injury in Canadian youth: A secondary analysis of the 1993-94 health behaviour in school-aged children survey. *Can J Public Health* 1998;89:397-401.

44. Leger L. *The 20m Shuttle Test. Instruction Manual.* Montreal; Sportmed Technology Inc., 1985.

45. Leger L, Gadoury C. Validity of the 20 m shuttle run test with one minute stages to predict VO_2max in adults. *Can J Sports Sci* 1989;14:21-6.

46. Lenaway DD, Ambler AG, Beaudoin DE. The epidemiology of school-related injuries: New perspectives. *Am J Prev Med* 1992;8:193-8.

47. Lephart SM. Pincivero DM, Rozzi SL. Proprioception of the ankle and knee. *Sport Med 1998;25*:149-155.

48. Lysens R, Steverlynck A, van den Auweele Y, Lefevre J, Renson R, Claessens A, Ostyn M. The predictability of sports injury. *Sports Med* 1984;1:6-10.

49. Macnab AJ, Cadman R. Demographics of alpine skiing and snowboarding injury: lessons for prevention programs. *Injury Prevention* 1996;2:286-289.

50. Maffulli N, King JB, Helms P. Training in elite young athletes (the training of young athletes (TOYA) study): injuries, flexibility and isometric strength. *Br J Sports Med* 1994;28:123-136.

51. Mattacola CG, Wills Lloyd J. Effects of a 6-week strength and proprioception training program on mesasures of dynamic balance: A single-case design. *J of Athletic Training* 1997;32:127-135.

52. McLain LG, Reynolds S. Sports injuries in a high school. *Pediatrics* 1989;84(3):446-450.

53. McNaughton L, Cooley D, Kearney V, Smith S. A comparison of two different shuttle run tests for the estimation of VO_2 max. *J Sports Med Phys Fitness* 1996;36:85-9.

54. Mummery WK, Spence JC, Vincenten JA, Voaklander DC. A descriptive epidemiology of sport and recreation injuries in a population-based sample: Results from the Alberta Sport and Recreation Injury Survey (ASRIS). *Can J Public Health* 1998;89:53-6.

55. Murray DM, Rooney BL, Hannan PJ, Peterson AV, Avry DV, Biglan A et al. Intraclass correlation among common measures of adolescent smoking: Estimates, correlates, and applications in smoking prevention studies. *Am J Epidemiol* 1994;140:1038-50.

56. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen O, Bahr R. Prevention of ACL injuries in female handball players: a prospective intervention study over 3 seasons. *Clin J Sports Med* 2003;13:71-78.

57. Nieman DC. *Exercise testing and prescription (4th edition).* Mountain View,CA: Mayfield Publishing Company, 1999.

58. Northern Sydney Area Health Services. *New South Wales Youth Sports Injury Report.* July 1997.

59.Orchard J, Marsden J, Lord S,and Garlick D. Preseason hamstring muscle weakness associated with hamstring muscle injury in Australian footballers. *Am J Sports Med* 25: 81-85, 1997.

60. Paffenbarger RS, Kamput JB, Lee IM et al. Changes in physical fitness and other lifestyle patters influence longevity. *Med Sci Sports Exerc* 1994;26:857-865.

61. Roberts WO, Brust JD, Leonard B. Youth ice hockey tournament injuries:rates and patterns compared to season play. *Med Sci Sports Exerc* 1999;31:46-51.

62. Rozzi S, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *J Orthop and Sport Phys Ther* 1999;29:478-486.

63. Statistics Canada, Culture and Tourism Division. *Canada's culture and heritage and identity: A statistical perspective.* Minister of Industry, Ottawa, 1997.

64. Sheps SB, Evans GD. Epidemiology of school injuries: a 2-year experience in a municipal health department. *Pediatrics* 1987;79:69-75.

65. Shumway-Cook A, Woollacott M. *Motor control: Theory and practical applications.* Baltimore,Md: Williams and Wilkins, 1995.

66. Slymen DJ, Hovell MF. Cluster versus individual randomization in adolescent tobacco and alcohol studies: Illustrations for design decisions. *International Journal of Epidemiology* 1997;26:765-771.

67. Soderman K, Werner S, Pietila T, Engstrom B, Alfredson H. Balance board training: prevention of traumatic injuries of the lower extremities in female soccer players? A prospective randomized intervention study. *Knee Surg Sports Traumatol Arthrosc* 2000;8:356-363.

68. StataCorp. *Stata Statistical Software [computer program].* Release 5.0 College Station (TX): Stata Corporation; 1997.

69. Sullivan JA, Gross RH, Grana WA, Garcia-Moral CA. Evaluation of injuries in youth soccer. *Am J Sports Med* 1980;8:325-7.

70. Tremblay MS, Willims JD. Secular trends in the body mass index of Canadian children. *CMAJ* 2000:163(111);1429-1433.

71. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and it's value in predicting injury. *Med Sci Sports Exerc* 1984;16:64-66.

72. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;13:259-62.

73. Van Mechelen W, Twisk J, Molendijk A, Blom B, Snel J, Kemper HCG. Subject-related risk factors for sports injuries: a one year prospective study in young adults. *Med Sci Sports Exerc* 1996;28:1171-9.

74.Watson AWS. Sports injuries during one academic year in 6799 Irish school children. *Am J Sports Med* 1984;12:65-71.

75. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999;9:41-47.

76. Weir MA, Watson AWS. A twelve month study of sports injuries in one Irish school. *IJMS* 1996;3:165-9.

77. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *Journal of Orthopaedic and Sport Physical Therapy* 1996;23:332-336.

78. Williams GN, Chmielewski T, Rudolph KS et al. Dynamic knee stability: Current theory and implications for clinicians and scientists. *J Orthop Sport Phys Ther 2001;*31:546-566.

79.Yamamoto T. Relationship between hamstring strains and leg muscle strength. *J Sport Med Phys Fit* 6:194-199, 1993.

80. Zaricznyj B, Shattuck LJM, Mast TA, Robertson RV, D'Elia G. Sports-related injuries in school aged children. *Am J Sports Med* 1980;8:318-324.

Chapter 6

Conclusions

6.1 Risk Factors for injury in child and adolescent sport

My initial research goal was to examine known risk factors for injury in adolescent sport by systematically reviewing the literature. The conclusions that I have drawn from this systematic review are:

- The strength of the evidence for modifiable risk factors for injury in adolescents is limited by research design and concerns with internal validity (Chapter 2).[17]
- There is very limited randomized controlled trial (RCT) evidence supporting preventative training programs in adolescents to reduce the risk of injury in specific sports.[45]
- There is more convincing evidence in adult epidemiological studies that decreased endurance, decreased strength, decreased proprioception and decreased pre-season, sport-specific training are associated with sports injury.[4,8,9,15,16,26,27,30,32,33,35,40,45,47]
- The consistency of the findings, in both adolescent and adult RCT's, is encouraging and indicates that some combination of neuromuscular and/or proprioceptive balance training may reduce the risk of specific injuries in specific sports.[4,9,22,28,30,40,45-47]
- Limitations of these RCT's include: 1. These prevention programs are multifaceted and there is no measurement of balance reported in any of these RCT's. 2. The treatment groups have most often been randomized by cluster (ie. team), which has not been accounted for in the analysis.[11,12] As such, the effectiveness of proprioceptive balance training specifically on the improvement of balance and prevention of injury in adolescent sport remains unclear.

- The need for a RCT to examine the effectiveness of proprioceptive balance training alone in reducing the risk of injury in adolescent sport is clear. Prior to embarking on an RCT to examine this, an appropriate clinical standing balance measurement required development.

6.2 Is there a clinical standing balance measurement appropriate for use in sports medicine?

My second research goal was to review the literature to determine if there is an appropriate clinical standing balance measurement for use in healthy adolescents (Chapter 3).[19] The conclusions I have drawn from this review include:

- There may not be only one balance measurement tool appropriate for use in healthy adolescents, given the complexity of dynamic balance and the sport specificity of dynamic forces acting on the joints and soft tissues.
- Development of a clinical balance measurement appropriate for use in adolescents was necessary. This measurement needed to be simple to administer, inexpensive and feasible for use in large populations by multiple examiners.
- There is evidence that both a timed eyes-closed static unipedal balance measurement and an eyes-open and eyes-closed dynamic unipedal balance measurement (using a foam support surface, based on an error scoring system only) are reliable.[1,8,14]
- There is evidence of concurrent validity for both a timed static balance measurement and a dynamic unipedal balance measurement (using a foam support surface, based on an error scoring system only) with stabilometry sway path measurements.[14,42]

- Further development of a timed unipedal static and dynamic balance measurement, specifically for measurement of standing balance in healthy adolescents, was required prior to their use in injury prevention research.

6.3 Development of a clinical static and dynamic standing balance measurement tool appropriate for use in healthy adolescents

We completed a pilot study examining the reliability, concurrent validity between static and dynamic balance, norms and influencing factors of such a timed unipedal clinical balance measurement protocol in healthy adolescents (Chapter 4).[19] The conclusions we have drawn from this pilot study include:

- A timed eyes-closed unipedal static (ECS) balance measurement and timed eyes-closed dynamic (ECD) balance measurement (using an Airex Balance Pad® for base of support), with a 180 second trial maximum, are reliable and appropriate clinical balance measurements for use in healthy adolescents.
- Intra-rater reliability was moderate for the eyes open dynamic (EOD) balance measurement and more than 18% of subjects achieved the maximum of 180 seconds on this test. As such, we considered the EOD test to be inappropriate for use as a clinical balance measurement in healthy adolescents.
- Excellent inter-rater reliability was consistently found across all three tests examined in this study (ECS, EOD and ECD).
- It is critical to consider previous lower extremity injury as a key factor influencing balance in adolescents in future research examining balance in adolescents. ECS and ECD balance in adolescents with a one-year history of previous lower extremity injury were both significantly less than those with no

history of injury.

- There was no evidence found to support the influence of other factors we examined, including leg dominance, age, order of testing, height, weight, BMI, length of foot, width of foot and estimated hours/week of sport participation in the previous six weeks on ECS or ECD balance measurements in healthy adolescents.

6.4 The effectiveness of a proprioceptive balance training program in healthy adolescents

We examined the effectiveness of a six-week, home-based, proprioceptive balance-training program in healthy adolescents using a cluster RCT design (Chapter 5).[20] This balance training program included wobble board exercises with progressive difficulty and specifically focused on balance and not other components of training such as sport-related technique, strengthening, jump training or endurance. The conclusions we have drawn from this cluster-RCT include:

- This balance-training program is effective in improving timed eyes-closed static balance in healthy adolescents. This is consistent with other studies.[5,23,25,31,36,43,44]
- There is evidence that this training program is also effective in improving timed eyes-closed dynamic balance on a foam support surface.
- There is evidence of a dose-response effect over a six-week period in improving timed eyes-closed static and dynamic balance in healthy adolescents.
- Compliance to training sessions was an essential element in improving static balance in this population.
- This balance-training program was not effective in improving functional strength as measured by the vertical jump test or endurance as measured by predicted $V0_2$

max based on a 20- meter shuttle run test.

- This balance-training program was effective in preventing overall sports injury in adolescents. These results were consistent with other studies examining prevention programs, including a proprioceptive balance-training component, for specific injury in specific sports.[4,9,30,40,45-47]
- There is evidence that this training program is most effective in adolescents reporting a one year history of previous injury and that adolescents reporting a previous one year history of injury are at greater risk of injury than those with no history, independent of training group.
- Limitations of this cluster-RCT include the small number of injuries in this study. Though significant relative risks were found, the 95% confidence intervals are wide. The power to examine specific injury and specific sport was also limited by sample size. In addition, the power to examine the influence of other potentially confounding variables was also limited by sample size.
- Strengths of our study include: 1. The improvement in balance and reduction of injury in the intervention group can be attributed to balance training alone. Given the use of multifaceted training programs in previous studies examining proprioceptive balance-training as a prevention strategy for injury in sport, the effectiveness of the balance training component of these programs in the reduction of sports injury has remained unclear. 2. Control for cluster randomization in the analyses, strengthen our conclusions supporting the effectiveness of proprioceptive balance training in both the improvement of balance and reduction of injury in adolescent sport. In other studies, there is a

consistent lack of adjustment for cluster randomization in the analyses, which may have led to an overestimation of the effectiveness of these programs.

3. The high rate of consent to participate and the low dropout rate, also support the validity of our study results. 4. The generalizability of our findings is strengthened by the random recruitment of schools and students for participation.

6.5 Future research recommendations

Future research should include a larger cluster RCT with greater power to further examine the effectiveness of a home-based balance training program in preventing lower extremity injuries in specific adolescent sports. By examining injury prevention in a specific sport, improvement in study logistics working with high-school teams rather than randomized individuals from multiple physical education classes would be possible. Randomizing teams to study groups would make it possible to involve team trainers to facilitate accurate recording of sport participation and compliance with training program for which self-report was relied upon in this study. In addition, a team trainer may record injuries, which may have been missed by self-report of injury in both study groups, more accurately. A proprioceptive balance-training program is likely to be most effective in preventing lower extremity injuries in a sport requiring running, pivoting, and rapid changes of direction. It would be appropriate to examine such an injury prevention strategy in a sport such as basketball where participation rates are clearly high for both male and female adolescents. In addition, basketball is consistently one of the top injury producing sports in both male and female adolescents.[2,3,37,39] A conservative estimate of the incidence rate of injury in high-school basketball is high (30 injuries/100 participants/season).[2,3,29,34,37-39] In addition, in basketball, the majority of injuries (greater than 65%) are lower extremity injuries.[29,38]

6.6 Research contribution

This thesis provides a significant contribution to research in the field of injury prevention in sport. There have been no previous systematic reviews published examining risk factors for injury specifically in child and adolescent sport. In addition, a review examining clinical standing balance measurements appropriate for use in a healthy adolescent population has not been previously reported. Original work includes the development of reliable, timed, unipedal, static and dynamic clinical balance measurements appropriate for use in healthy adolescents. These measurements will contribute to future research examining balance as a risk factor, or balance training as a prevention strategy, for injury in adolescent sport. This work also provides RCT evidence that participation in a home-based proprioceptive balance training program will prevent injury in adolescent sport. This is the first cluster RCT examining proprioceptive balance training as a prevention strategy for injury in adolescent sport, which includes static and dynamic balance measurements in addition to injury as primary outcome measurements of interest. This RCT emphasizes the importance of controlling for cluster randomization in the analysis, which has not been previously reported in other similar injury prevention studies.

Sports is the leading cause of injury in adolescents as well as the leading cause of injury leading to hospitalization.[6,21,22,34] Sports injury in adolescence may lead to reduced participation in physical activity in the future. Decreased physical activity increases the risk of all-cause morbidity and mortality.[7,37] Some sports injuries in adolescents will increase the risk of development of osteoarthritis in the future.[10,13,24] There is a significant public health cost associated with these injuries and future development of osteoarthritis and other disease associated with decreased levels of physical activity. This and future research in injury prevention in adolescent sport is essential in maintaining a healthy lifestyle in adolescence and adulthood.

References

1. Atwater SW, Crowe TK, Deitz JC, Richardson PK. Interrater and test-retest reliability of two pediatric balance tests. *Phys Ther* 1990;70:79-87.

2. Backx FJG, Erich WBM, Kemper ABA, Verbeek ALM. Sports injuries in school-aged children. An epidemiologic study. *Am J Sports Med* 1989;17:234-240.

3. Backx FJG, Beijer HJM, Bol E, Erich WBM. Injuries in high-risk persons and high-risk sports. A longitudinal study of 1818 school children. *Am J Sports Med* 1991;19:124-130.

4. Bahr R, Lian O. A two-fold reduction in the incidence of acute ankle sprains in volleyball. *Scand J Med Sci Sports* 1997;7:172-177.

5. Balogun JA, Adesinasi CO, Marzouk DK. The effects of a wobble board exercise training program on static balance performance and strength of lower extremity muscles. *Physiotherapy Canada* 1992;44:23-30.

6. Bienfeld M, Pickett W, Carr PA. A descriptive study of childhood injuries in Kingston, Ontario, using data from computerized injury surveillance system. *Chronic diseases in Canada* 1996;17:21-27.

7. Blair SN, Kohl HW, Barlow CE et al. Changes in physical fitness and all-cause mortality: a prospective study of healthy and unhealthy men. *JAMA* 1995;273:1093-1098.

8. Cahill BR, Griffith EH. Effect of preseason conditioning on the incidence and severity of highschool football knee injuries. *Am J Sports Med* 1978;6:180-4.

9. Caraffa A, Cerulli G, Projetti M, Aisa G, Rizzo A. Prevention of anterior cruciate ligament injuries in soccer. A prospective controlled study of proprioceptive training. *Knee surg, Sports Traumatol, Arthroscopy* 1996;4:19-21.

10. Daniel DM, Stone ML, Dobson BE et al. Fate of the ACL injured patient. A prospective outcome study. Am J Sports Med 1994;22:632-644.

11. Donner A, Brown KS, Brasher P. A methodological review of non-therapeutic intervention trials employing cluster randomization, 1979-1989. *Int J Epidemiol* 1990;19:795-800.

12. Donner A, Klar N. *Design and Analysis of Cluster Randomization Trials in Health Research.* Oxford University Press, Inc., New York, 2000.

13. Drawer F, Fuller CW. Propensity for osteoarthritis and lower limb joint pain in retired professional soccer players. *Br J Sports Med* 2001;35:402-408.

14. Ekdahl C, Jarnlo G-B, Andersson SI. Standing balance in healthy subjects. Evaluation of a quantitative test battery on a force platform. *Scand J Rehab Med* 1989;21:187-195.

15. Emery CA. Does decreased muscle strength cause acute muscle strain injury in sport? A systematic review of the evidence. *Phys Ther Rev* 1999;4:79-85.

16. Emery CA, Meeuwisse WH. Risk factors for groin and abdominal strain injury in the National Hockey League. A Multivariate approach. *Med Sci Sport Exerc* 1999;33:1423-1433.

17. Emery CA. Risk factors for injury in child and adolescent sport. A systematic review of the literature. *Clin J Sports Med* 2003 (in press).

18. Emery CA. Is there a clinical standing balance measurement appropriate for use in sports medicine? A review of the literature. *J Science Med Sport* 2003 (in press).

19. Emery CA, JD Cassidy, TP Klassen, RJ Rosychuk, BH Rowe. Development of a clinical static and dynamic standing balance measurement tool appropriate for use in healthy adolescents. Unpublished, 2003.

20. Emery CA, Cassidy JD, Klassen TP, Rosychuk RJ, Rowe BH. The effectiveness of a proprioceptive balance training program in healthy adolescents: A cluster randomized controlled trial.Unpublished, 2003.

21. Gallagher SS, Guyer B, Kotelchuck M, Bass J, Lovejoy FH, McLoughlin E, Mehta K. A Strategy for the reduction of childhood injuries in Massachusetts: SCIPP. *New Engl J Med* 1982;307:1015-1019.

22. Gallagher SS, Finison K, Guyer B, Goodenough S. The incidence of injuries among 87,000 Massachusetts children and adolescents: results of the 1980-81 statewide childhood injury prevention program surveillance system. *Am J Public Health* 1984;74:1340-1347.

23. Gauffin H, Tropp H, Odenrick P. Effect of ankle disk training on postural control in patients with functional instability of the ankle joint. *Int J Sports Med* 1988;9:141-144.

24. Gillquist J, Messner K. Anterior cruciate ligament reconstruction and the long term incidence of gonarthrosis. *Sports Med* 1999;27:143-156.

25. Goldie PA, Evans OM, Bach TM. Postural control following inversion injuries of the ankle. *Arch Phys Med Rehabil* 1994;75:969-75.

26. Hahn T, Foldspang A, Vestergaard E, Ingermann-Hansen T. One-legged standing balance and sports activity. *Scand J Med Sci Sports* 1999;9:15-18.

27. Heidt RS, Sweeterman LM, Carlonas RL, Traub JA, Tekulve FX. Avoidance of soccer injuries with preseason conditioning. *Am J Sports Med* 2000;28:659-662.

28. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes. *Am J Sports Med* 1999;27:699-705.

29. Hippe M, Flint A, Lee RK. University basketball injuries: a five-year study of women's and men's varsity teams. Scand J Med Sci Sports 1993;3:117-121.

30. Holme E, Magnusson SP, Becher K, Bieler T, Aagaard P, Kjaer M. The effect of supervised rehabilitation on strength, postural sway, position sense and re-injury risk after acute ankle ligament sprain. *Scand J Med Sci Sports* 1999;9:104-109.

31. Hoffman M, Payne VG. The effects of proprioceptive ankle disk training on healthy subjects. *Journal of Orthopaedic and Sports Physical Therapy* 1995;21:90-94.

32. Jones BH, Bovee MW, Harris JM, Cowan DN. Intrinsic risk factors for exercise-related injuries among male and female army trainees. *Am J Sports Med* 1993;21:705-710.

33. Junge A, Rosch D, Peterson L, Graf-Baumann T, Dvorak J. Prevention of soccer injuries: a prospective intervention study in youth amateur players. *Am J Sports Med* 2002;30:652-659.

34. King MA, Pickett W, King AJC. Injury in Canadian youth: A secondary analysis of the 1993-94 health behaviour in school-aged children survey. *Can J Public Health* 1998;89(6):397-401.

35. Lysens R, Steverlynck A, van den Auweele Y, Lefevre J, Renson R, Claessens A, Ostyn M. The predictability of sports injury. *Sports Med* 1984;1:6-10.

36. Mattacola CG, Wills Lloyd J. Effects of a 6-week strength and proprioception training program on mesasures of dynamic balance: A single-case design. *J of Athletic Training* 1997;32:127-135.

37. McLain LG, Reynolds S. Sports injuries in a high school. *Pediatrics* 1989;84:446-450.

38. Messina DF, Farney WC, DeLee JC. The incidence of injury in Texas high school basketball. A prospective study among male and female athletes. Am J Sports Med 1999;27:294-299.

39. Mummery WK, Spence JC, Vincenten JA, Voaklander DC. A descriptive epidemiology of sport and recreation injuries in a population-based sample: Results from the Alberta Sport and Recreation Injury Survey (ASRIS). *Can J Public Health* 1998;89:53-6.

40. Myklebust G, Engebretsen L, Braekken IH, Skjolberg A, Olsen O, Bahr R. Prevention of ACL injuries in female handball players: a prospective intervention study over 3 seasons. *Clin J Sports Med* 2003;13:71-78.

41. Paffenbarger RS, Kamput JB, Lee IM et al. Changes in physical fitness and other lifestyle patters influence longevity. *Med Sci Sports Exerc* 1994;26:857-865.

42. Rozzi S, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *J Orthop and Sport Phys Ther* 1999;29:478-486.

43. Tropp H, Ekstrand J, Gillquist J. Stabilometry in functional instability of the ankle and it's value in predicting injury. *Med Sci Sports Exerc* 1984;16:64-66.

44. Tropp H, Askling C, Gillquist J. Prevention of ankle sprains. *Am J Sports Med* 1985;13:259-62.

45. Wedderkopp M, Kaltoft M, Lundgaard B, Rosendahl M, Froberg K. Prevention of injuries in young female players in European team handball. A prospective intervention study. *Scand J Med Sci Sports* 1999;9:41-47.

46. Weir MA, Watson AWS. A twelve month study of sports injuries in one Irish school. *IJMS* 1996;3:165-9.

47. Wester JU, Jespersen SM, Nielsen KD, Neumann L. Wobble board training after partial sprains of the lateral ligaments of the ankle: A prospective randomized study. *Journal of Orthopaedic and Sport Physical Therapy* 1996;23:332-336.

Appendix A: Baseline Study Questionnaire

Name: ______________________________

ID#: (to be completed by study team) _____________

Date of Initial Assessment (day/month/year) ___________________

Telephone Number(s): 1. _______________ 2. ___________________

Gender: Male ___ Female ___

School: __________________________________ Grade: ______

Birth Date (day/month/year): _____/____/_____Age (as of September 1, 2000):____

Please answer the following questions as accurately as possible:

1. Have you sustained an injury requiring medical attention and at least one day of time lost from physical activity in the past 6 weeks? Yes___ No___
Describe this injury to the best of your ability:

2. Have you sustained any injury requiring medical attention and at least one day of time lost from physical activity in the past year? Yes____ No___
Describe this injury to the best of your ability:

3. Have you been diagnosed by a physician with a bone fracture, arthritis, systemic disease (ie. cancer, heart disease) or have you required surgery in the past year?
Yes____ No___
Describe this condition to the best of your ability:

4. Do you have any ongoing medical condition or disability (including high blood pressure or fainting/dizziness spells) preventing you from participation in sport beyond an adapted Physical Education class or which may prevent you from participation in a balance test, endurance running test or single leg hop test.
Yes____ No____
Describe this condition to the best of your ability:

5. Based on the past 6 weeks of activity, did you participate in any sport or combination of sports (beyond your Physical Education class) on a weekly basis? Yes___ No

If Yes, estimate the average number of hours per week you participated in each sport:

football ___
basketball ___
soccer ___
volleyball ___
track and field___
rugby ___
field hockey___
swimming ___
rock climbing___

baseball ___
lacrosse___
tennis___
badminton ___
squash___
raquetball___
gymnastics___
waterpolo___
Other (list): ______________________________

marshal arts
skiing: X-country __Alpine___
snowboarding___
hockey ___
figure skating__
speed skating__
dance ___
diving ___

6. Based on the past year of activity, did you participate in any sport or combination of sports (beyond your Physical Education class) on a weekly basis? Yes___ No___

If Yes, estimate the average number of hours per week you participated in each sport:

football ___
basketball ___
soccer ___
volleyball ___
track and field___
rugby ___
field hockey___
swimming ___
rock climbing___

baseball ___
lacrosse___
tennis___
badminton ___
squash___
raquetball___
gymnastics___
waterpolo___
Other (list): ______________________________

marshal arts
skiing: X-country __Alpine___
snowboarding___
hockey ___
figure skating__
speed skating__
dance ___
diving ___

Appendix B: Baseline and Follow-up Assessment Form (Pilot)

1. Name: ______________________________ 2. ID # ________

3. School: ______________________________

4. Completion of Baseline Questionnaire Yes ____ No

5. Leg Dominance Left ____ Right ____

6. Unipedal static balance test: **(seconds)**	**Left 1. ____** **2. ____** **3. ____** **Max ______**	**Right 1. ____** **2. ____** **3. ____** **Max _______**
7. Unipedal foam balance test: **Eyes open (seconds)**	**Left 1. ____** **2. ____** **3. ____** **Max ______**	**Right 1. ____** **2. ____** **3. ____** **Max _______**
8. Unipedal foam balance test: **Eyes closed (seconds)**	**Left 1. ____** **2. ____** **3. ____** **Max ______**	**Right 1. ____** **2. ____** **3. ____** **Max**
9. Vertical Jump test: **(centimetres)**	**1. ____** **2. ____** **3. ____** **Max ______**	

10. 20 meter shuttle run **Level _____**
Estimated VO2 Max ______________

Examiner Name:

Examiner Signature:

Date (day/month/year):

Appendix C: Chapter 4 Technical Appendix : Tables

Table 4.i: Comparison of baseline covariates between study subjects completing and drop-out subjects

(Two-tailed Student's t-test based on log transformed balance measurements)

Covariate	Study Subjects Completing [n=111] Mean (95% CI) (binomial 95% CI exact)	Drop-out Subjects [n=12] Mean (95% CI) (binomial 95% CI exact)	Two tailed Student's t-test or test of proportions
Age (years)	16.59 (16.4, 16.78)	16.5 (16.05, 16.95)	$t_{121} = -0.63$; $p = 0.53$
Gender	56 male, 55 female	5 male, 7 female	N/A
Grade	39 grade 10, 36 grade 11, 36 grade 12	3 grade 10, 5 grade 11, 4 grade 12	N/A
Previous Injury (Lower Extremity)	15/111 =13.51% (7.77, 21.31)	3/12 = 25 % (5.49, 57.19)	$z = -1.069$; $p = 0.28$
Previous Injury (All)	25/111 = 22.52% (15.14, 31.43)	4/12 = 33.33% (9.92, 65.11)	$z = -0.84$; $p = 0.4$
Height (m)	1.70 (1.68, 1.72)	1.69 (1.64, 1.76)	$t_{121} = -0.2$; $p = 0.84$
Weight (kg)	68.05 (65.41, 70.68)	69.17 (55.8, 82.53)	$t_{121} = 0.25$; $p = 0.8$
Body Mass Index (kg/m^2)	23.42 (22.57, 24.28)	23.95 (19.58, 28.33)	$t_{121} = 0.36$; $p = 0.72$
Foot length (cm)	25.24 (24.87, 25.6)	25.47 (24.28, 26.66)	$t_{121} = 0.39$; $p = 0.69$
Foot width (cm)	9.64 (9.51, 9.77)	9.64 (9.22, 10.05)	$t_{121} = -0.002$; $p = 0.999$
Sport participation previous 6 weeks (hours/week)	9.93 (7.98, 11.89)	10.2 (7.53, 12.98)	$t_{121} = 0.08$; $p = 0.94$
Geometric mean ECS balance (s)	25.57 (21.91, 29.85) (2 subjects reached 180)	24.17 (17.5, 33.38)	$t_{119} = -0.23$; $p = 0.82$
Geometric mean EOD balance (seconds)	54.59 (46.92, 63.54) (20 subjects reached 180)	52.7 (34.93, 79.52) (2 subjects reached 180)	$t_{99} = -0.15$; $p = 0.88$
Geometric mean ECD balance (seconds)	5.38 (5.02, 5.77)	4.75 (3.83, 5.91)	$t_{121} = -1.11$; $p = 0.27$

Table 4.ii: Baseline covariates by gender for all subjects at baseline
(Two-tailed Student's t-test based on log transformed balance measurements)

Baseline Covariate	Male (n=61) mean (95% CI) (binomial 95% CI exact)	Female (n=62) mean (95% CI) (binomial 95% CI exact)	Two tailed Student's t-test or test of proportions
Age	16.65 (16.39, 16.91)	16.53 (16.28, 16.79)	$t_{121} = -0.63$; $p = 0.53$
Previous Injury (lower extremity)	9/61 = 14.75% (6.98, 26.17)	9/62 = 14.52% (6.86, 25.78)	$z = -0.037$; $p = 0.97$
Previous Injury (all)	15/61 = 24.59% (14.46, 37.29)	14/62 = 22.58% (12.93, 34.97)	$z = -0.26$; $p = 0.79$
Sports Participation (hours/week) based	14.22 (11.2, 17.24)	6.69 (4.65, 8.63)	$t_{121} = -4.21$; $p < 0.00005$*
Leg dominance (right)	57/61 = 93.44% (84.05, 98.18)	61/62 = 98.39% (91.34, 99.96)	$z = 1.39$; $p = 0.17$
Height (m)	1.76 (1.74, 1.78)	1.65 (1.62, 1.67)	$t_{121} = -7.19$; $p < 0.00005$*
Weight (kg)	73.43 (69.44, 77.42)	62.97 (59.97, 65.97)	$t_{121} = -4.19$; $p = 0.0001$
Body Mass Index (kg/m2)	23.65 (22.42, 24.88)	23.31 (22.09, 24.53)	$t_{121} = -0.39$; $p = 0.7$
Foot length (cm)	26.52 (26.12, 26.92)	24.02 (23.67, 24.36)	$t_{121} = -9.52$; $p < 0.00005$*
Foot width (cm)	10.1 (9.98, 10.23)	9.18 (9.04, 9.32)	$t_{121} = -10.1$; $p < 0.00005$*
Geometric mean ECS balance (seconds)	22.47 (18.5, 27.29) (1 subject reached 180)	28.72 (23.33, 35.35) (1 subject reached 180)	$t_{119} = 1.72$; $p = 0.09$
Geometric mean EOD balance (seconds)	54.6 (46.06, 64.07) (10 subjects reached 180)	54.18 (42.72, 68.71) (12 subjects reached 180)	$t_{99} = -0.06$; $p = 0.96$
Geometric mean ECD balance (seconds)	5.37 (4.85, 5.93)	5.27 (4.85, 5.94)	$t_{121} = -0.28$; $p = 0.78$

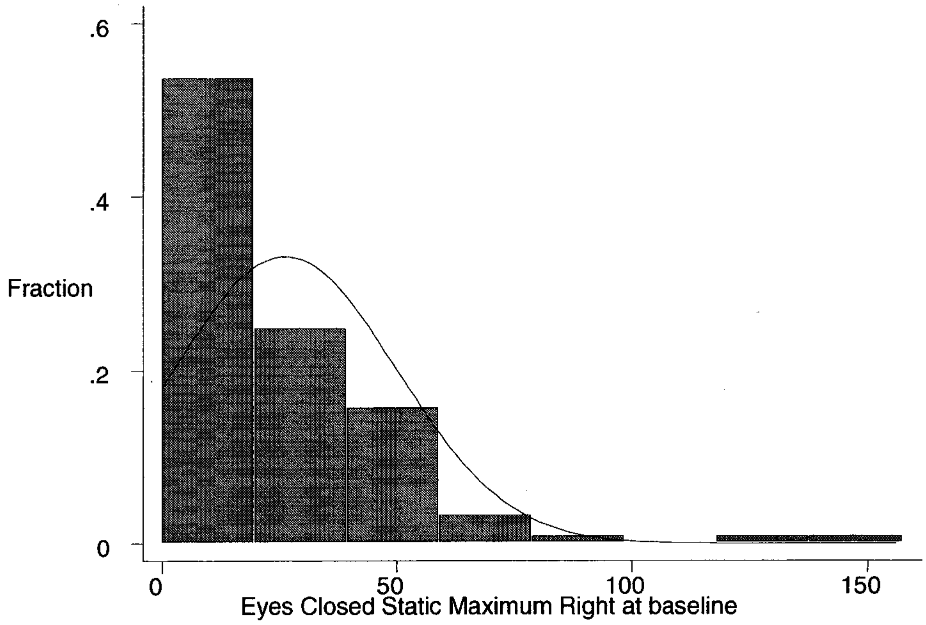
* denotes significance based on $p \leq 0.05$

Table 4.iii: Sport specific participation (based on self report from previous one year)

Male (n=61) % sport participation (binomial exact 95% CI)	Female (n=62) % sport participation (binomial exact 95% CI)
1. Basketball 25/61 = 41%(28.6, 54.3)	1. Soccer 15/62 = 24.2 %(14.2, 36.7)
2. Football 16/61 = 26.2%(15.8, 39.1)	2. Volleyball 14/62 = 22.6%(12.9, 35)
3. Hockey 15/61 = 24.6%(14.5, 37.3)	3. Basketball 12/62 =19.4%(10.4, 31.4)
4. Volleyball 10/61 = 16.4%(8.2, 28.1)	4. Track and Field 11/62=17.7%(9.2,29.5)
5. Ski/Snowboard 10/61 = 16.4%(8.2, 28.1)	5. Dance 10/62 = 16.1%(8, 27.7)

Appendix D: Chapter 4 Technical Appendix: Figures

Figure 4.i: Comparison of distribution for Eyes Closed Static Balance Maximum (ECS) on right leg at baseline and Log transformation of Eyes Closed Static Balance Maximum (ECS)



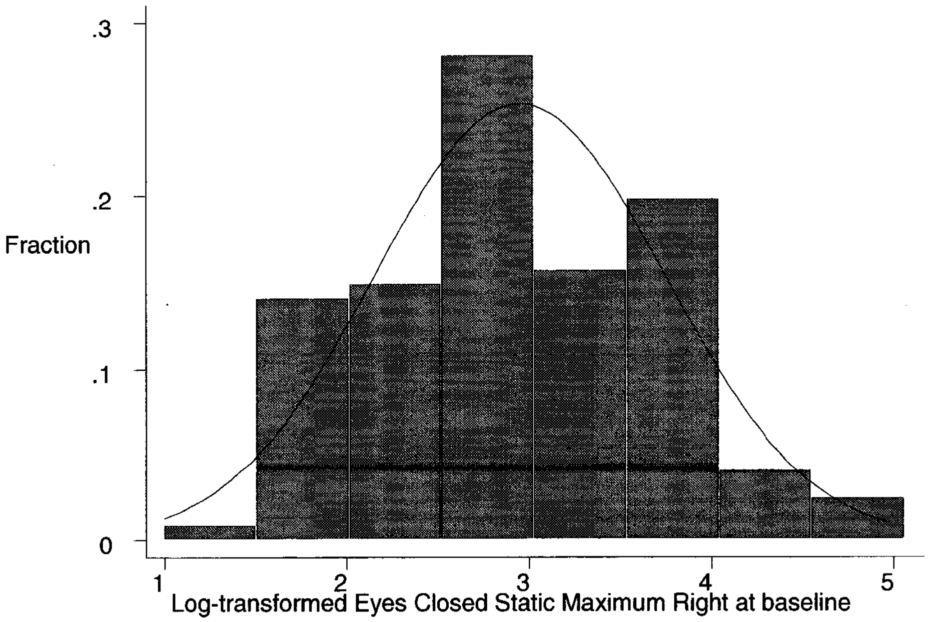
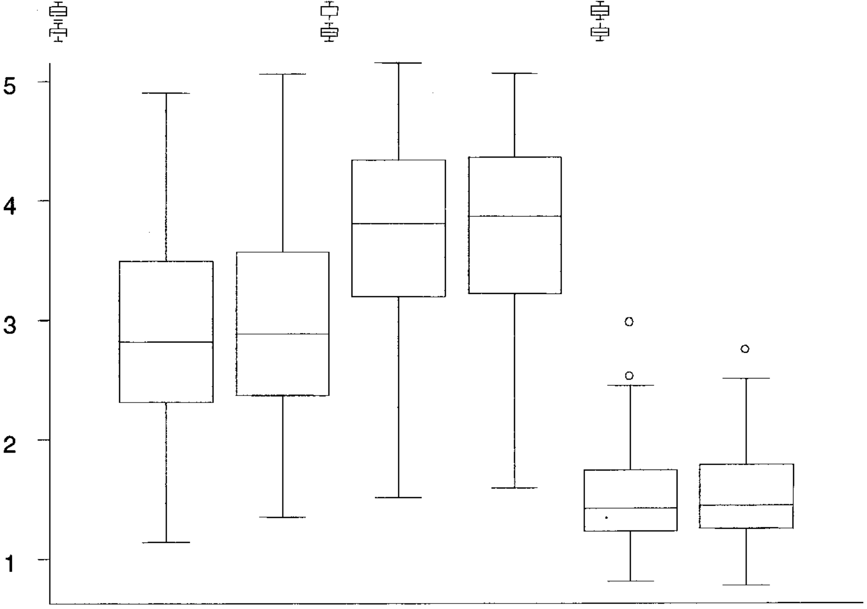


Figure 4.ii: Box plot comparison of log transformed maximum for left and right on all three balance tests in log-seconds (ECS, EOD, ECD)



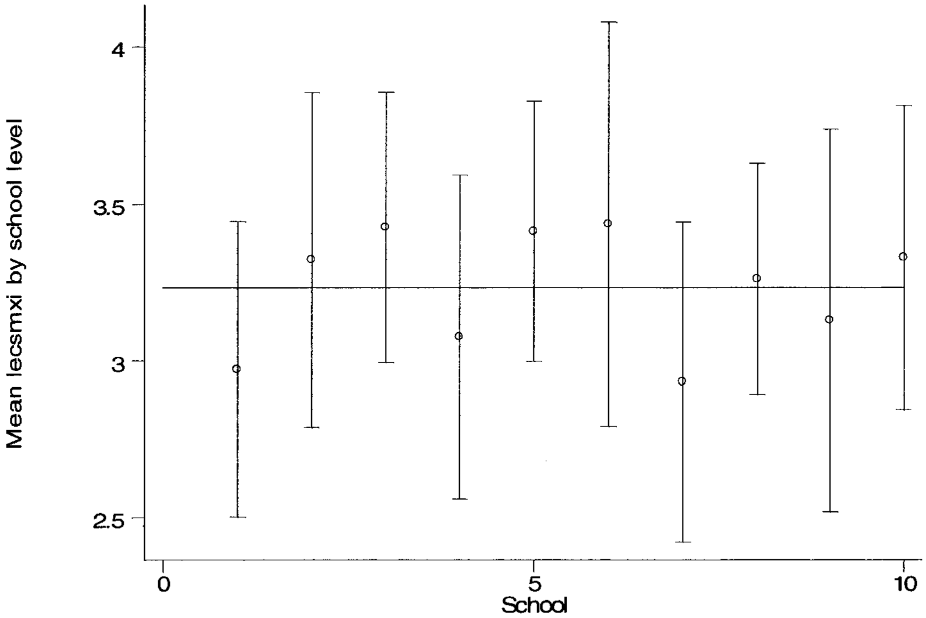
ECSL ECSR EODL EODR ECDL ECDR

ECSL = log ECS maximum left, ECSR = log ECS maximum left,

EODL = log EOD maximum left, EODR = log EOD maximum right,

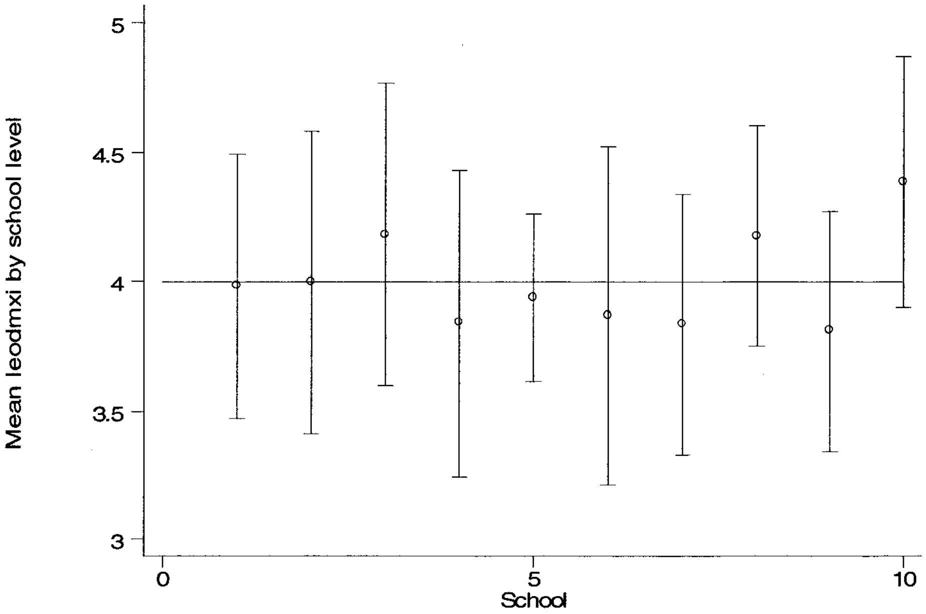
ECDL = log ECD maximum left, ECDR = log ECD maximum right

Figure 4.iii: Log-transformed ECS balance maximum by school (95% CI's)



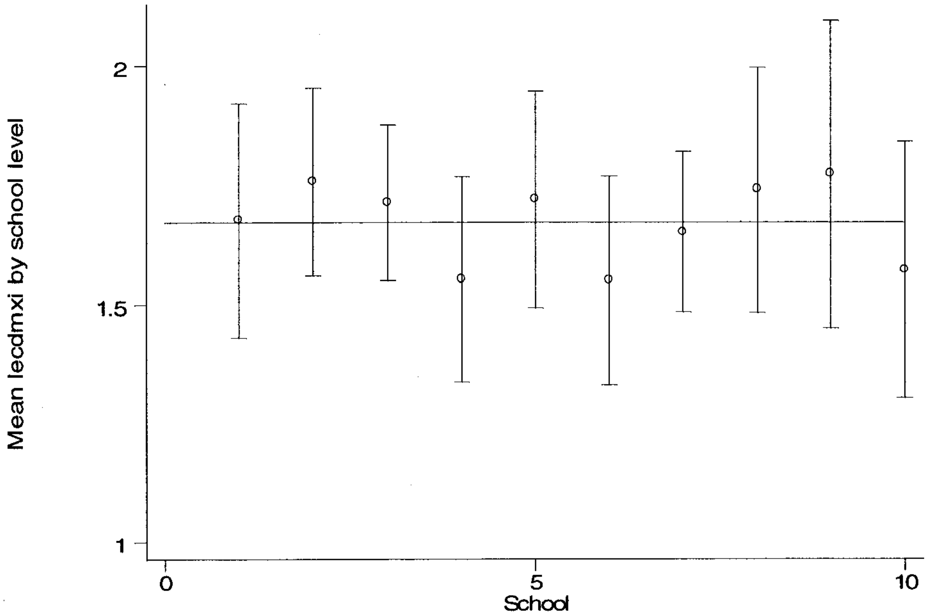
*lecsmxi = log transformed ECS maximum balance at baseline

Figure 4.iv: Log-transformed EOD balance maximum by school (95% CI's)



*leodmxi = log transformed EOD maximum balance at baseline

Figure 4.v: Log-transformed ECD balance maximum by school (95% CI's)



*lecdmxi = log transformed ECD maximum balance at baseline

Figure 4.vi: Eyes-closed static maximum difference (n=107) (ECS follow-up – ECS baseline)

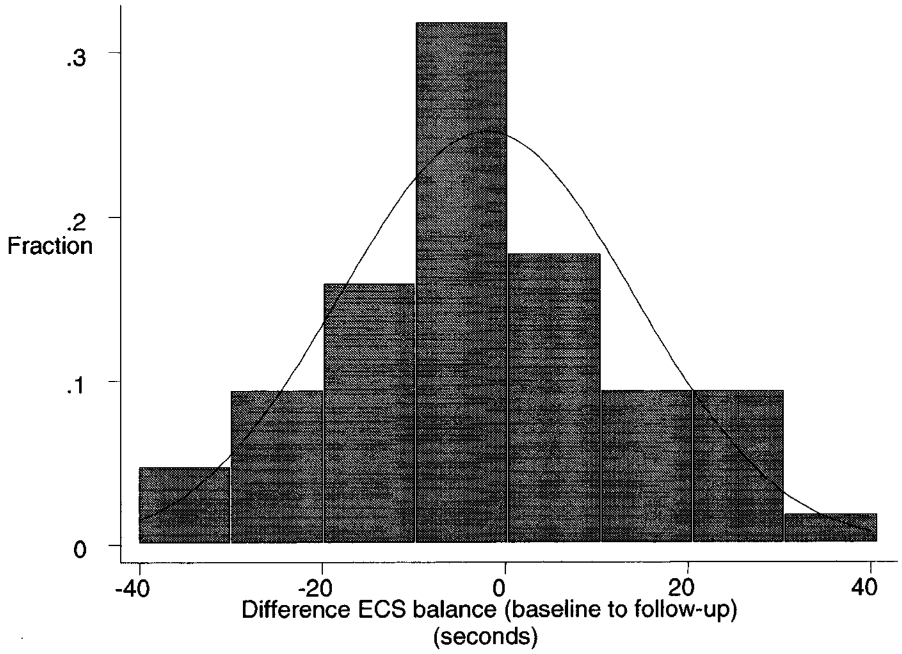
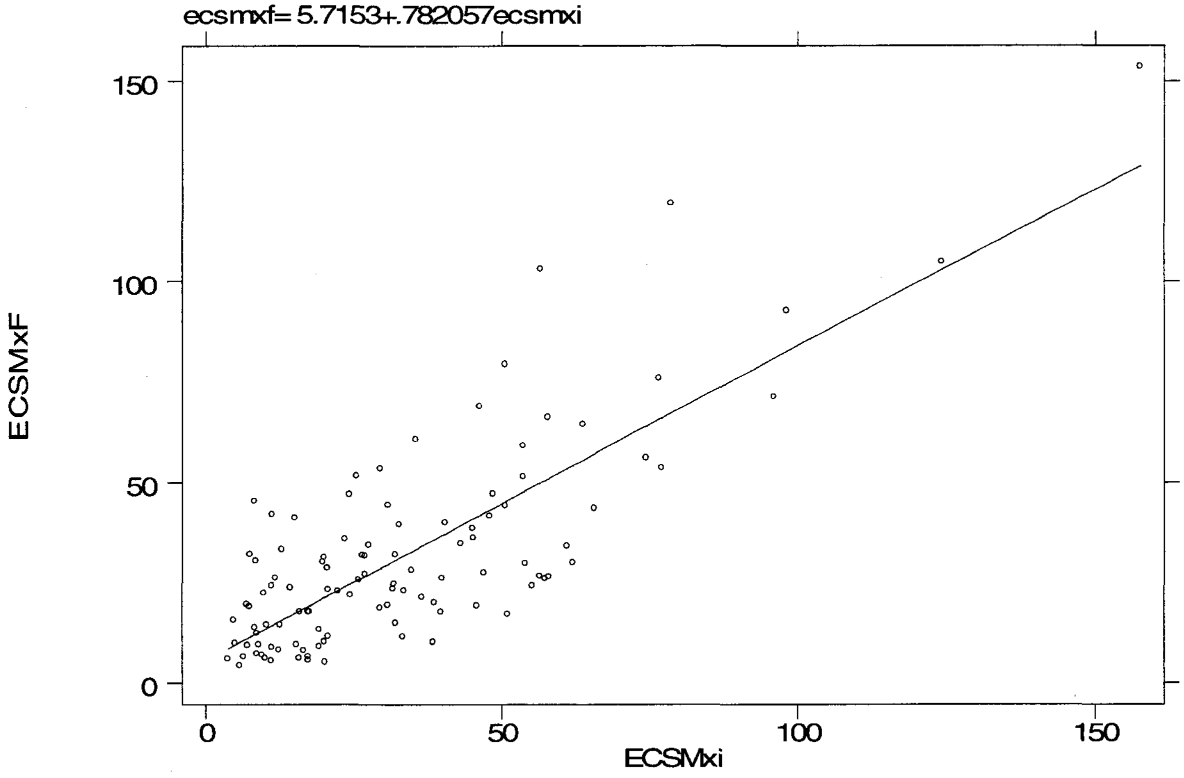


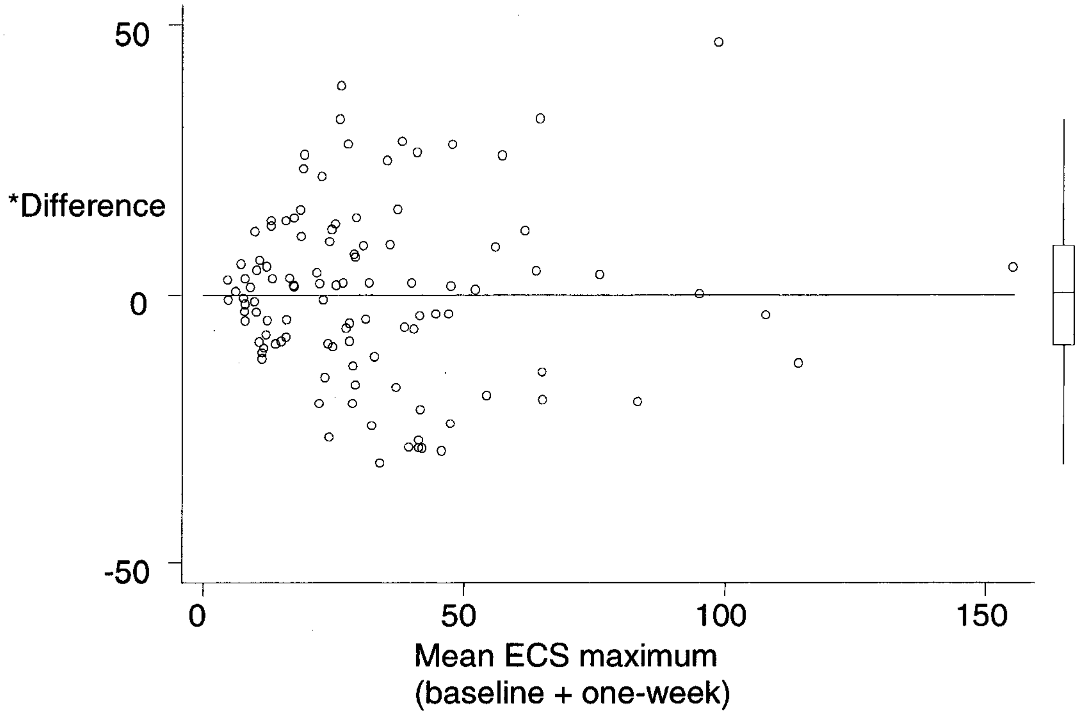
Figure 4.vii: Measurements of maximum balance (ECS) at baseline and one-week follow-up (n=107)



*ECSMxi = ECS Maximum balance at baseline

*ECSMxF = ECS Maximum balance at one-week follow-up

Figure 4.viii: Plot of differences between follow-up and baseline (ECS) versus average with 95% limits of agreement (n=107)

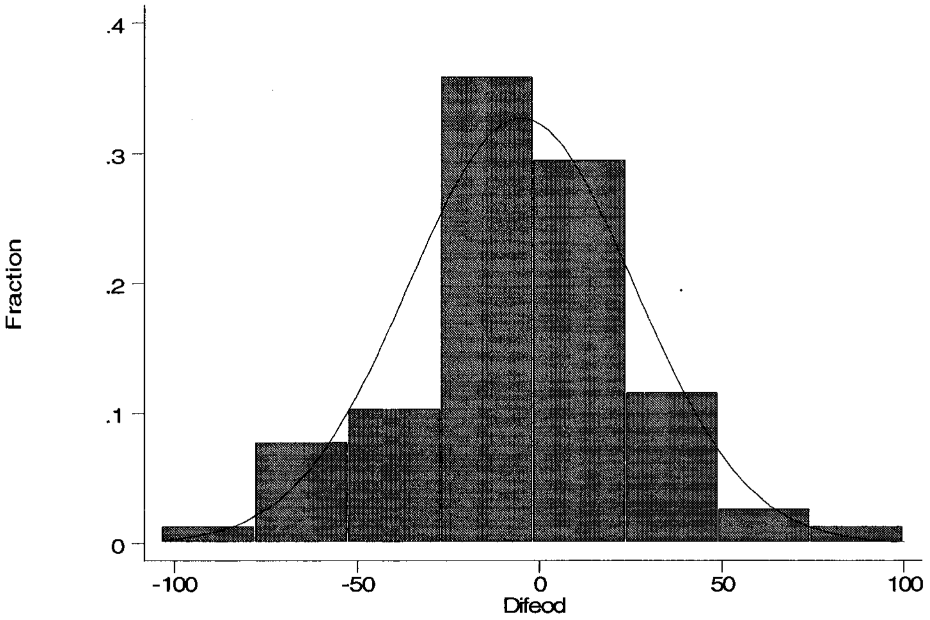


* Difference = difference between follow-up and baseline assessments for ECS Maximum Balance

The mean difference is -2.02 seconds (95% limits of agreement superimposed).

Figure 4.ix: Eyes-open dynamic maximum difference (n=78)

(EOD follow-up – EOD baseline)



*Difeod = difference between EOD maximum balance at 1 week follow-up and baseline

Figure 4.x: Measurements of maximum balance (EOD) at baseline and one-week follow-up (n=78)

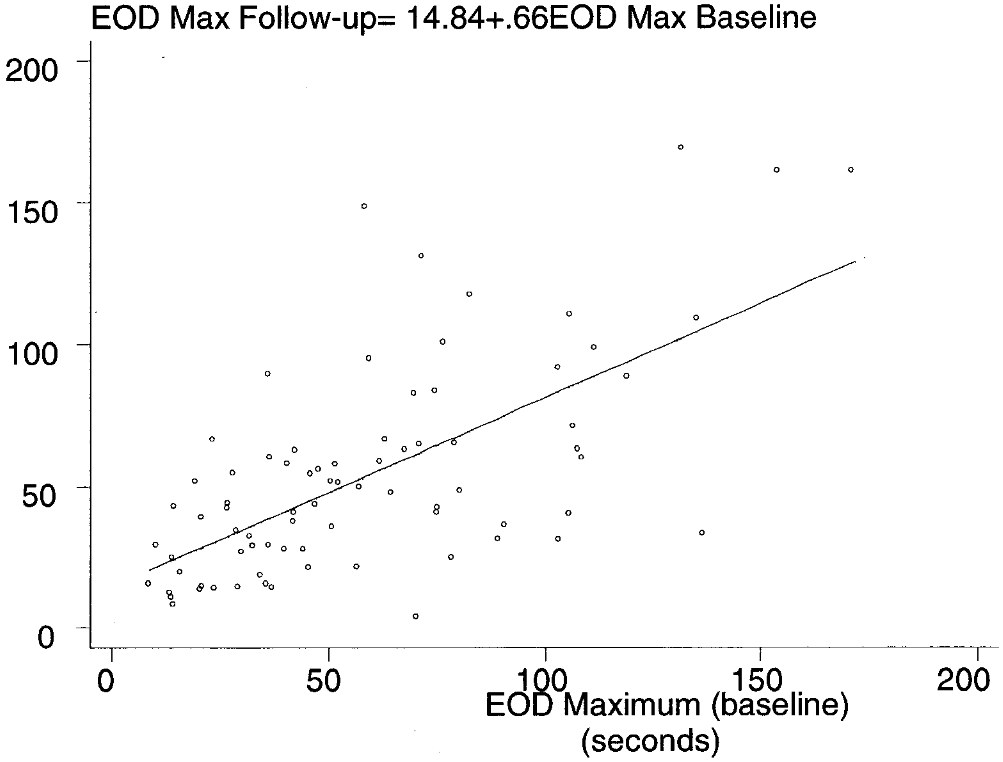
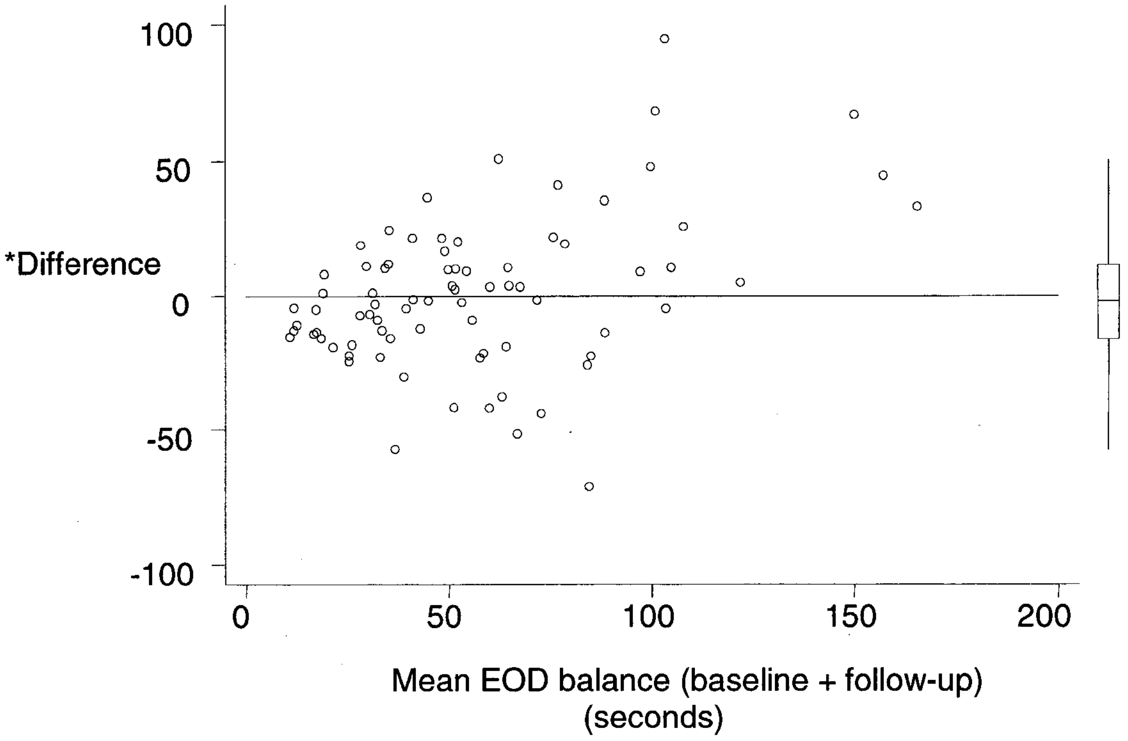


Figure 4.xi: Plot of differences between follow-up and baseline (EOD) versus average with 95% limits of agreement (n=78)



* Difference = difference between follow-up and baseline assessments for EOD Maximum Balance

The mean difference is -5.1 seconds (95% limits of agreement superimposed).

Figure 4.xii: Eyes-closed dynamic maximum difference (n=111)

(ECD follow-up – ECD baseline)

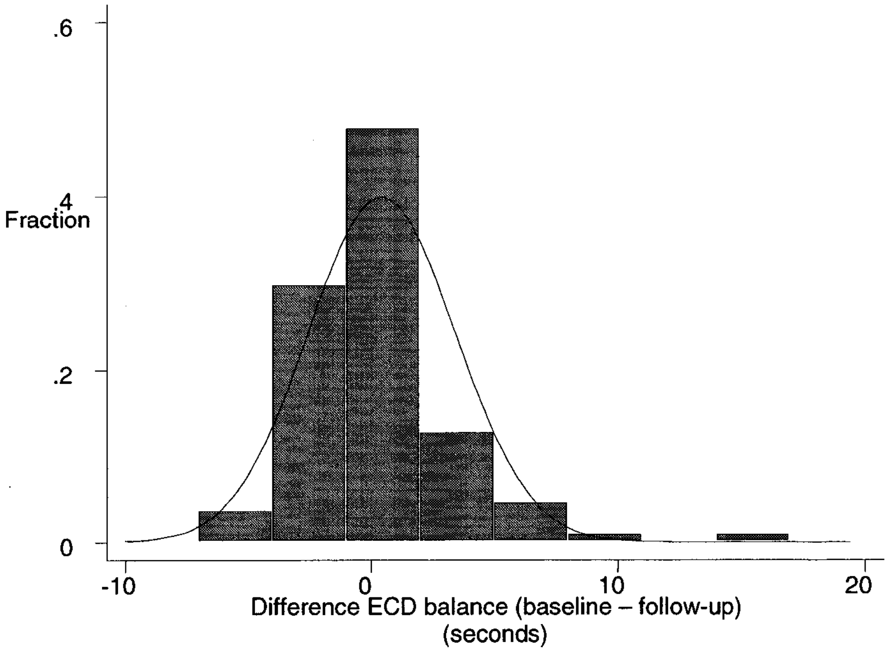
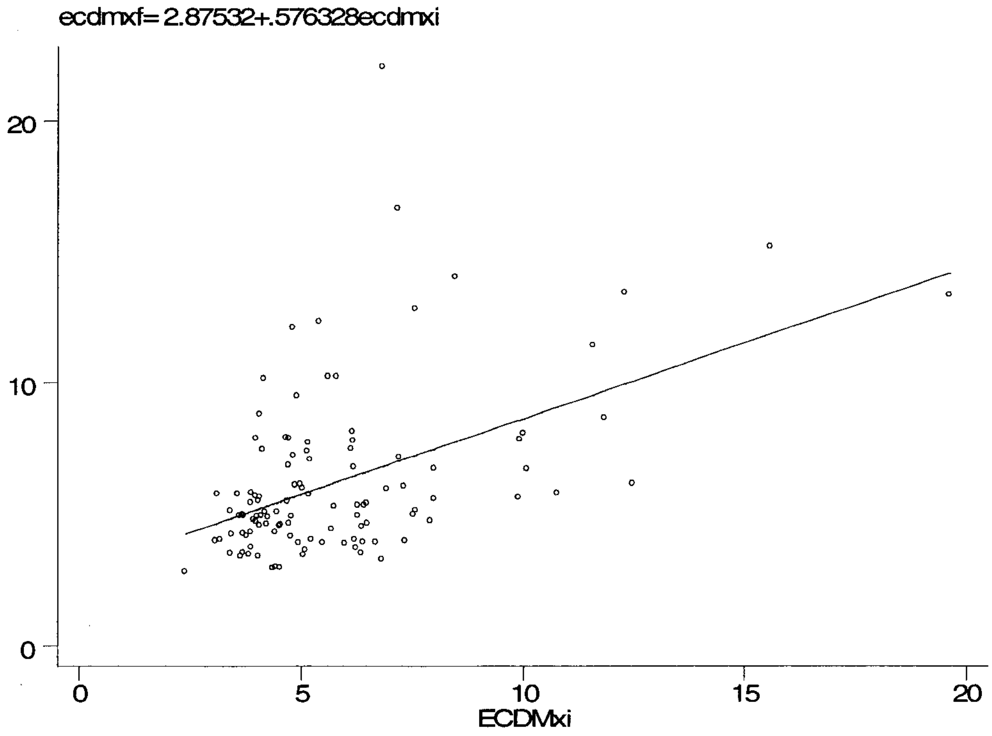


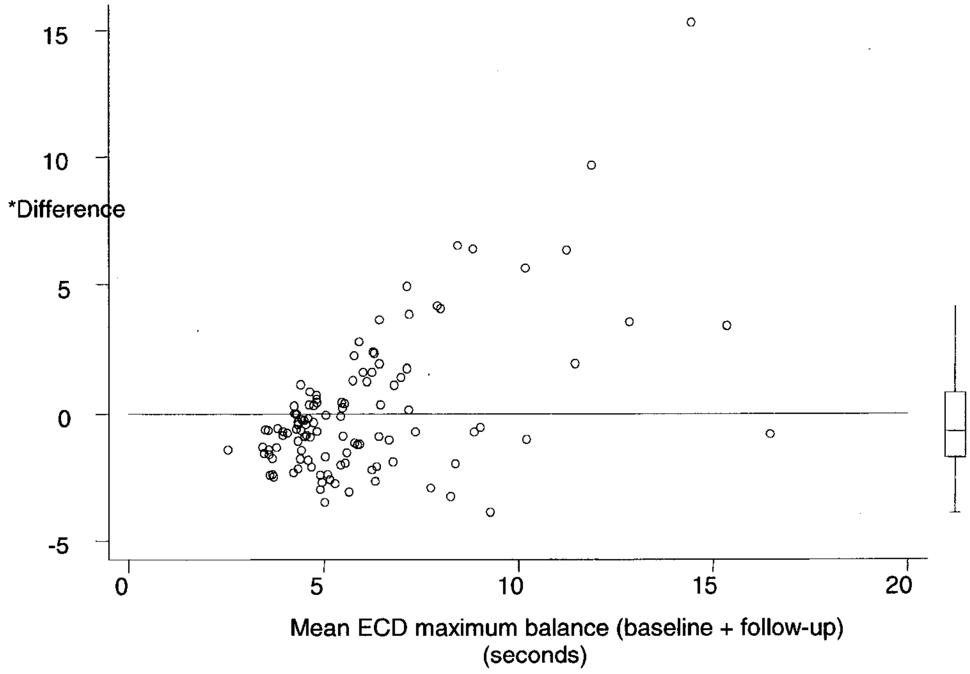
Figure 4.xiii: Measurements of maximum balance (ECD) at baseline and one-week follow-up (n=111)



*ECDMxi = ECD Maximum balance at baseline

*ecdmxf = ECD Maximum balance at 1 week follow-up

Figure 4.xiv: Plot of differences between follow-up and baseline (ECD) versus average with 95% limits of agreement (n=111)



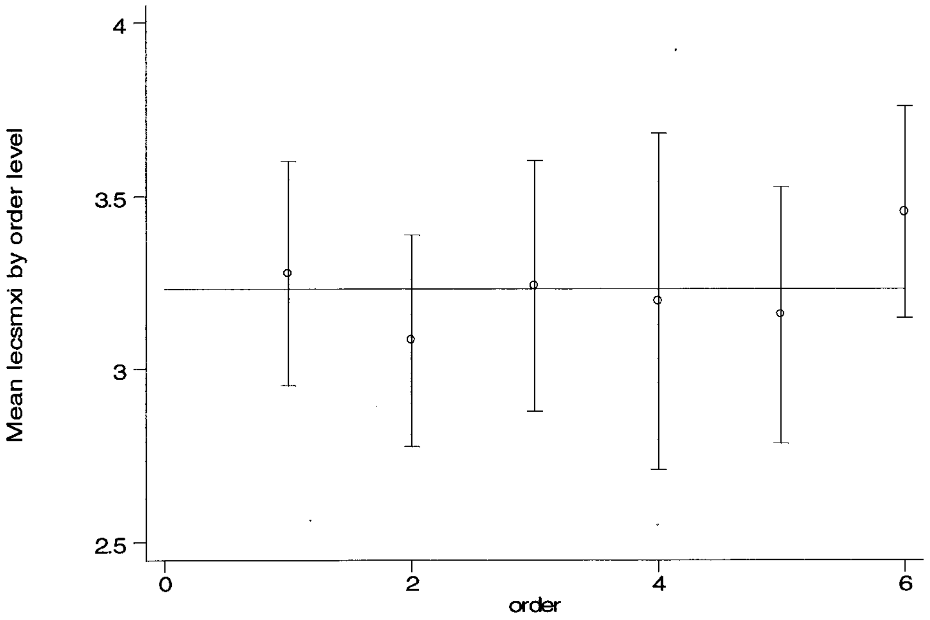
* Difference = difference between follow-up and baseline assessments for ECD maximum balance

The mean difference is 0.42 seconds (95% limits of agreement are superimposed).

Figure 4.xv: Log transformed ECS balance across testing orders 1-6

[One-way ANOVA F(5,115) = 0.52 (p=0.76)]

```
                        Analysis of Variance
    Source              SS         df       MS            F     Prob > F
------------------------------------------------------------------------
Between groups      1.59537912      5   .319075823      0.52     0.7644
 Within groups      71.2362063    115   .619445272
------------------------------------------------------------------------
    Total           72.8315854    120   .606929878
```

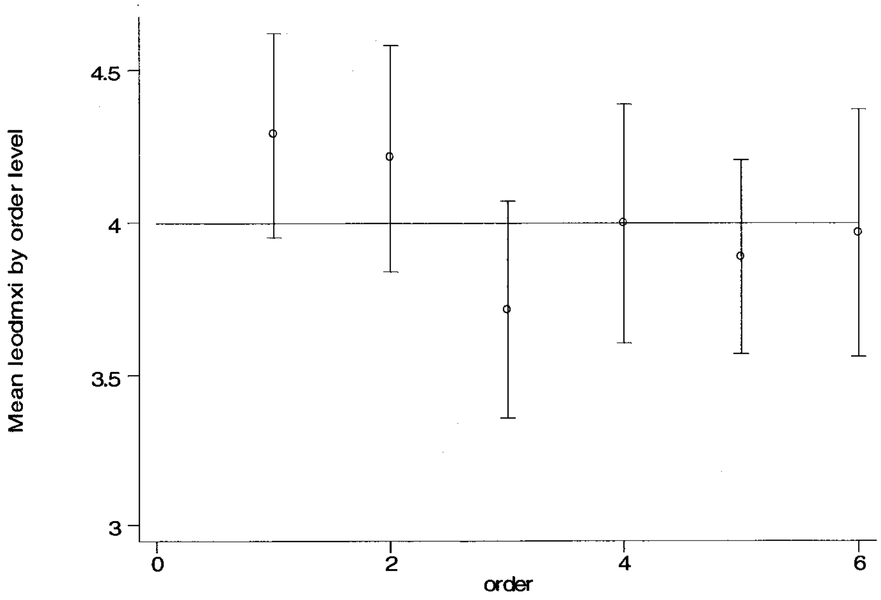


*lecsmxi = log transformed ECS maximum balance at baseline

Figure 4.xvi: Log transformed EOD Balance across testing orders 1-6

[One-way ANOVA F(5,95) = 1.6 (p=0.17)]

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      3.93037443      5   .786074885      1.60     0.1677
 Within groups      46.6832907     95    .49140306
------------------------------------------------------------------------
    Total           50.6136652    100   .506136652
```

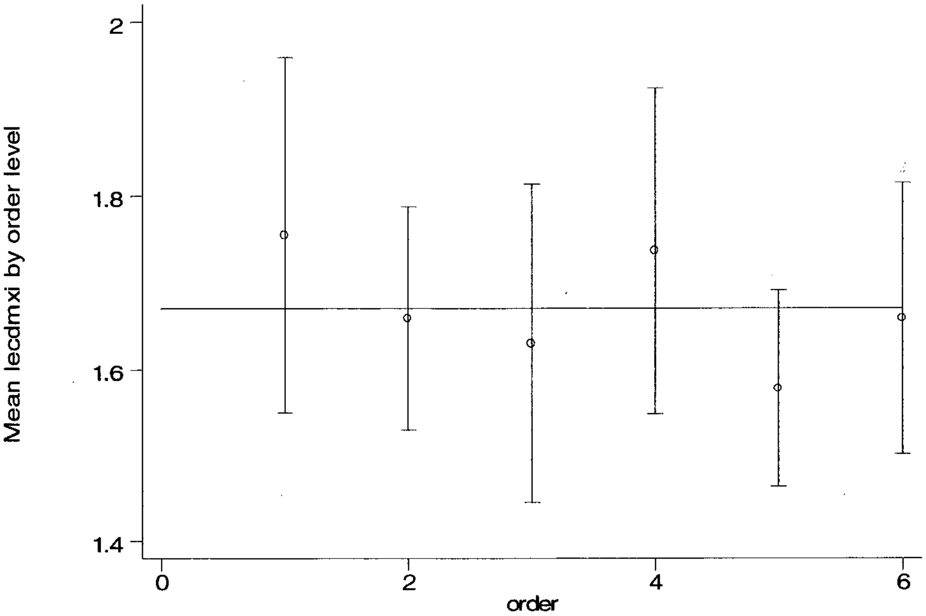


*leodmxi = log transformed EOD maximum balance at baseline

Figure 4.xvii: Log transformed ECD Balance across testing orders 1-6

[One-way ANOVA F(5,117) = 0.65 (p=0.66)]

```
                        Analysis of Variance
    Source              SS         df      MS            F     Prob > F
------------------------------------------------------------------------
Between groups      .444518318      5   .088903664      0.65     0.6619
 Within groups      15.9984368    117   .136738776
------------------------------------------------------------------------
    Total           16.4429551    122   .134778321
```



lecdmxi = log transformed EOD maximum balance at baseline

Figure 4.xviii: Log transformed ECS Balance (right) across trials 1,2 and 3

[Repeated-measures ANOVA $F_{(2,242)} = 0.18$ (p=0.83)]

```
                           Number of obs =     367     R-squared     =  0.6148
                           Root MSE      = .709766     Adj R-squared =  0.4175

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  194.609284   124  1.56942971       3.12     0.0000
                         |
                      id |  194.340819   122  1.59295753       3.16     0.0000
                  assess |   .1863879      2   .09319395       0.18     0.8312
                         |
                Residual |  121.911752   242  .503767572
              -----------+----------------------------------------------------
                   Total |  316.521036   366  .864811574
```

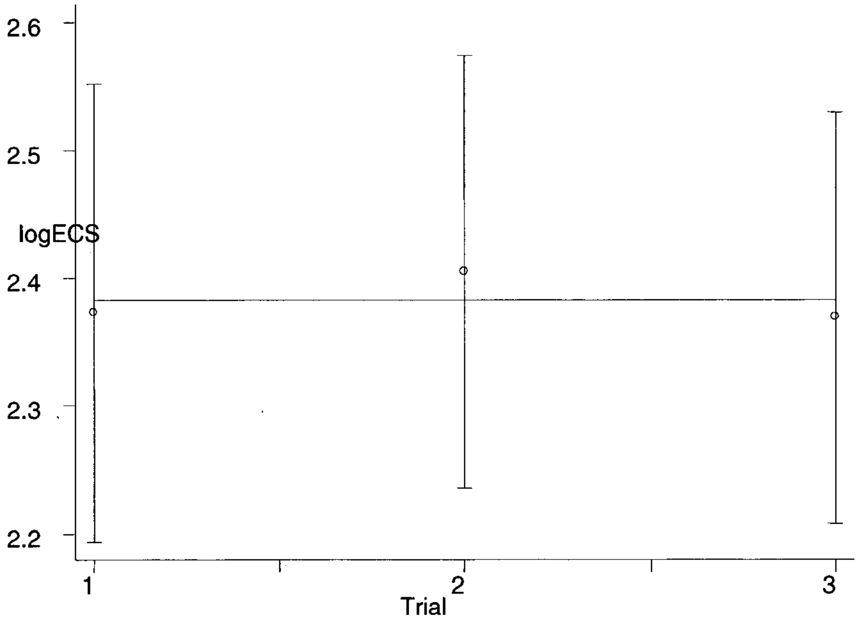


Figure 4.xix: Log transformed EOD Balance (right) across trials 1,2 and 3

[Repeated-Measures ANOVA $F_{(2,217)} = 0.01$ (p=0.99)]

```
                  Number of obs =     336     R-squared     =  0.6468
                  Root MSE      = .749674     Adj R-squared =  0.4547

         Source |  Partial SS    df       MS           F     Prob > F
     -----------+----------------------------------------------------
          Model |  223.307396   118  1.89243556       3.37     0.0000
                |
             id |  223.238591   116  1.92447062       3.42     0.0000
         assess |  .012303013     2  .006151506       0.01     0.9891
                |
       Residual |  121.956457   217  .562011323
     -----------+----------------------------------------------------
          Total |  345.263853   335  1.03063837
```

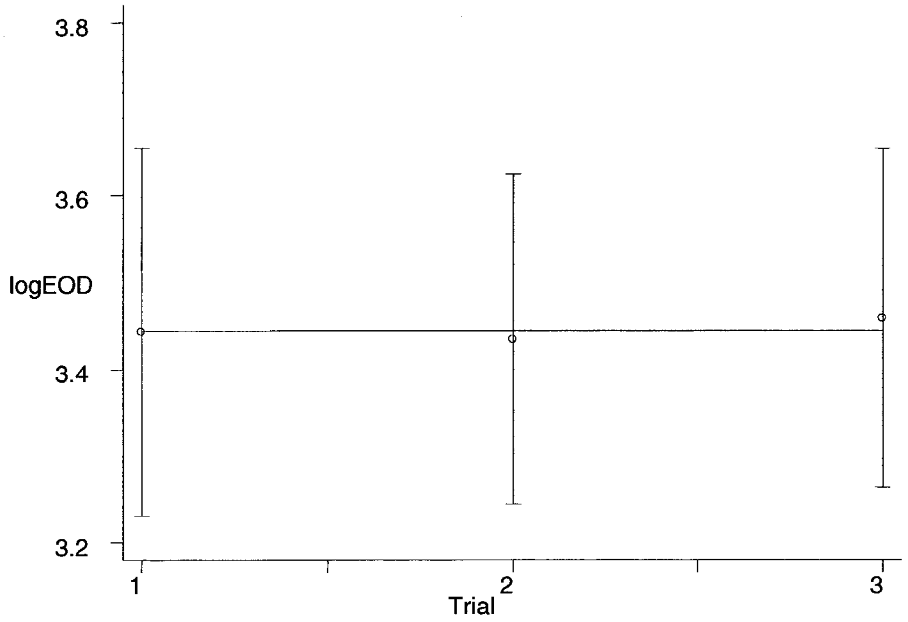
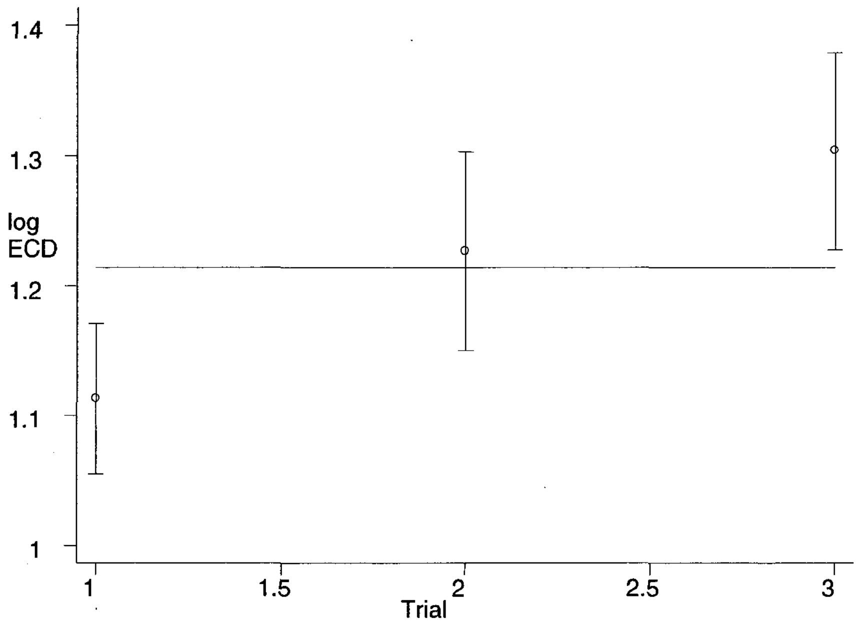


Figure 4.xx: Log transformed ECD Balance (right) across trials 1,2 and 3

[Repeated-Measures ANOVA $F_{(2,244)} = 4.69$ (p=0.01)]

```
                          Number of obs =     369     R-squared     =  0.4451
                          Root MSE      = .344045     Adj R-squared =  0.1631

                  Source |  Partial SS    df       MS           F     Prob > F
              -----------+----------------------------------------------------
                   Model |  23.1654789   124  .186818378       1.58     0.0013
                         |
                      id |   22.054567   122  .180775139       1.53     0.0028
                  assess |  1.11091192     2  .555455959       4.69     0.0100
                         |
                Residual |  28.8815724   244    .1183671
              -----------+----------------------------------------------------
                   Total |  52.0470513   368  .141432205
```



Appendix E: Chapter 4 Technical Appendix: Multivariable Models

1. Multivariate regression analysis examining other potential influencing factors on eyes-closed static balance

Full model:

```
regress lecsmxi leg order age gender height weight bmi length width injury
sport6wk

  Source |       SS       df       MS                  Number of obs =     121
---------+------------------------------               F( 11,   109) =    1.13
   Model |  7.44769454    11  .67706314                Prob > F      =  0.3463
Residual |  65.3838909   109  .59985221                R-squared     =  0.1023
---------+------------------------------               Adj R-squared =  0.0117
   Total |  72.8315854   120  .606929878               Root MSE      =   .7745

------------------------------------------------------------------------------
 lecsmxi |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     leg |  -.0473059   .3750702     -0.126   0.900      -.7906828    .6960709
   order |   .0387989   .0501066      0.774   0.440      -.0605106    .1381085
     age |    .041392   .0878398      0.471   0.638      -.1327036    .2154876
  gender |  -.3192609   .2145173     -1.488   0.140      -.7444272    .1059054
  height |   1.983174   4.336824      0.457   0.648      -6.612269    10.57862
  weight |  -.0353907   .0518279     -0.683   0.496       -.138112    .0673305
     bmi |   .0870494   .1557138      0.559   0.577      -.2215703     .395669
  length |   .0173922   .0893941      0.195   0.846       -.159784    .1945683
   width |   .1688094   .2056925      0.821   0.414      -.2388665    .5764853
  injury |     -.5065   .2024465     -2.502   0.014*     -.9077423   -.1052577
sport6wk |  -.0003886   .0073041     -0.053   0.958      -.0148651    .0140879
   _cons |  -2.004329   7.229948     -0.277   0.782      -16.33385    12.32519
```

* denotes significance based on $p \leq 0.05$

Where,
lecsmxi (log transformed eyes closed static balance at baseline)
leg (leg dominance = 1 if right, leg dominance = 0 if left)
order (order 1 - 6 based on order of testing ECS, EOD, and ECD)
age (years)
height (metres)
weight (kilograms)
bmi (body mass index (kg/m^2)
length (foot length in centimetres)
width (foot width in centimetres)
injury (history of lower extremity injury in the previous year = 1, no injury = 0)
sport6wk (estimated number of hours/week sport participation beyond PE class)

Final Model:

```
regress lecsmxi injury

  Source |       SS       df       MS                  Number of obs =     121
---------+------------------------------               F(  1,   119) =    7.01
   Model |  4.04949405     1  4.04949405               Prob > F      =  0.0092
Residual |  68.7820914   119  .578000768               R-squared     =  0.0556
---------+------------------------------               Adj R-squared =  0.0477
   Total |  72.8315854   120  .606929878               Root MSE      =  .76026

------------------------------------------------------------------------------
 lecsmxi |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
  injury |  -.5140889   .1942236     -2.647   0.009*       -.898671   -.1295067
   _cons |   3.308841    .074911     44.170   0.000         3.16051    3.457172
```

* denotes significance based on p≤0.05

Where,

lecsmxi (log transformed eyes closed static balance at baseline)

injury (history of lower extremity injury in the previous year = 1, no injury = 0)

Antilog such that if history of injury in previous year (injury = 1)

ECS =$e^{(3.309-0.514\text{injury})} = e^{(3.309)}*e^{(-0.514\text{injury})}$ =(27.36)(0.598)=16.36(95% CI; 10.52,25.43)

and if no history of previous injury (injury = 0)

ECS = $e^{(3.309)}$ = 27.35 (95% CI; 23.58, 31.73)

2. Multivariate regression analysis examining other potential influencing factors on eyes-closed dynamic balance

Full Model:

```
regress lecdmxi leg order age gender height weight bmi length width injury  s
> port6wk

  Source |       SS       df       MS              Number of obs =     123
---------+------------------------------           F( 11,    111) =    1.10
   Model |  1.6144636    11  .146769418            Prob > F      =  0.3691
Residual |  14.8284915   111  .133590014           R-squared     =  0.0982
---------+------------------------------           Adj R-squared =  0.0088
   Total |  16.4429551   122  .134778321           Root MSE      =   .3655

------------------------------------------------------------------------------
 lecdmxi |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
     leg |  -.1629988   .1769589     -0.921   0.359      -.5136547    .1876571
   order |  -.0169256   .0235858     -0.718   0.475      -.0636624    .0298113
     age |    .002953   .0412794      0.072   0.943      -.0788449    .0847508
  gender |  -.0153227   .1010958     -0.152   0.880      -.2156508    .1850053
  height |   1.232018   1.421201      0.867   0.388      -1.584186    4.048223
  weight |  -.0137563   .0122042     -1.127   0.262      -.0379397     .010427
     bmi |    .026544    .035643      0.745   0.458       -.044085    .0971729
  length |   -.034076   .0412447     -0.826   0.410      -.1158052    .0476531
   width |   .0863131   .0961503      0.898   0.371      -.1042152    .2768414
  injury |  -.1631199   .0954261     -1.709   0.090      -.3522131    .0259733
sport6wk |   .0032985   .0034359      0.960   0.339      -.0035099    .0101069
   _cons |   .2550006   2.068404      0.123   0.902      -3.843679    4.353681
------------------------------------------------------------------------------
```

Where,
lecdmxi (log transformed eyes closed dynamic balance at baseline)
leg (leg dominance = 1 if right, leg dominance = 0 if left)
order (order 1 - 6 based on order of testing ECS, EOD, and ECD)
age (years)
height (metres)
weight (kilograms)
bmi (body mass index (kg/m^2)
length (foot length in centimetres)
width (foot width in centimetres)
injury (history of lower extremity injury in the previous year = 1, no injury = 0)
sport6wk (estimated number of hours/week sport participation beyond PE class)

Final Model:

```
regress lecdmxi injury

  Source |       SS       df       MS                  Number of obs =     123
---------+------------------------------               F(  1,    121) =    4.37
   Model |  .573674233     1  .573674233               Prob > F      =  0.0386
Residual |  15.8692809   121  .131151082               R-squared     =  0.0349
---------+------------------------------               Adj R-squared =  0.0269
   Total |  16.4429551   122  .134778321               Root MSE      =  .36215

------------------------------------------------------------------------------
 lecdmxi |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
  injury |   -.193221   .0923863     -2.091   0.039      -.3761241   -.0103179
   _cons |   1.699152    .035342     48.077   0.000       1.629183     1.76912
------------------------------------------------------------------------------
* denotes significance based on p≤0.05
Where,
lecsmxi (log transformed eyes closed static balance at baseline)
injury (history of lower extremity injury in the previous year = 1, no injury = 0)
```

Antilog such that if history of injury in previous year (injury = 1)
ECD = $e^{(1.699-0.193\text{injury})} = e^{(1.699)} * e^{(-0.193\text{injury})}$ = (5.468)(0.824)= 4.51 (95% CI; 3.66,5.56)
and if no history of previous injury (injury = 0)
ECD = $e^{(1.699)}$ = 5.47 (95% CI; 5.1, 5.87)

Appendix F

Baseline and Follow-up Assessment Form (RCT)

1. Name: ________________________________ **2. ID #**

3. School:__________________________**4. Baseline**___ **2**___ **4**___ **6**___

5. Completion of Baseline Questionnaire **Yes** ____ **No**

6. Leg Dominance **Left** ____ **Right** ____

7. Height ________ **(m) 8. Weight** ___________ **kg 9. BMI**____________**(kg/m^2)**

10. Unipedal static balance test: (seconds)

Left 1. ____ **2.** ____ **3.** ____ **Max**______

Right 1. ____ **2.** ____ **3.** ____ **Max** _______

11. Unipedal foam balance test: Eyes closed (seconds)

Left 1. ____ **2.** ____ **3.** ____ **Max**______

Right 1. ____ **2.** ____ **3.** ____ **Max** _____

12. Vertical Jump test: (centimetres)

1. ____ **2.** ____ **3.** ____ **Max** ______

13. 20 meter shuttle run

Level _____

Estimated VO2 Max _______________

Examiner Name:

Examiner Signature:

Date (day/month/year):

Appendix G

Sports Participation Data Journal

Please record your daily sporting activity regardless of level of competition (ie. practice, game, training session). Be as specific as possible as to sport identification (ie. ice hockey, running, tai kwon do). If a training activity is completed, be as specific as possible in recording it (ie. Nautilus weights, free weights, running, sprints, skipping, balance exercises, plyometrics). Estimate time spent doing sporting activity to the nearest ½ hour.

Example:
SEPTEMBER 2000

Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday
					1 run (1/2 hour)	2 basketball (11/2 hours)
3 PE soccer (1 hour)	4 Judo (1 hour)	5 PE soccer (1 hour)	6	7 PE soccer (1 hour)	8 run (1/2 hour)	9
10 PE soccer (1 hour)	11 Judo (1 hour)	12 PE soccer (1 hour)	13	14 PE soccer (1 hour)	15 Skating (2 hours)	16 basketball (11/2 hours)
17 PE soccer (1 hour)	18 Judo (1 hour)	19 PE soccer (1 hour)	20	21 PE soccer (1 hour)	22 run (1/2 hour)	23
24 PE soccer (1 hour)	25 Judo (1 hour)	26 PE soccer (1 hour)	27 run (1/2 hour)	28 PE soccer (1 hour)	29	30 basketball (11/2 hours)

Appendix H

<u>Injury Report Form</u> (2000/2001 School Year)

Please report any injury (new or recurrent) occurring during any type of sporting activity (recreational, competitive or training activity) which requires medical attention and/or results in the inability to complete the session of activity in which the injury occurred and/or requires the you to miss one day of sporting activity on this form. Feel free to get the assistance of a parent or coach. Have any attending medical practitioner (physician, nurse, physiotherapist, athletic therapist) complete the appropriate section on page 2 of this form.

Please return upon completion to your school designate in the supplied envelope.

1. Name: ______________________________ 2. Alberta Health Care #:
3. Study ID # _________________ 4. School:
5. Date of Injury (Day/Month/Year)
6. Sport Played (or training activity) at Time of Injury

7. This injury involved:	**Contact**	___	(with another player or equipment)
	No Contact	___	(with another player or equipment)
	Overuse	___	
	Unknown		
8. Injury Status:	**New Injury**		
	Recurrence of Injury from this year		
	Recurrence of Injury from previous year		

9. Was bracing or taping used on the injured area or limb at the time of injury?
No ___ Yes ___ If so what type?

10. Injury occurred during: Warm-up
Practice
Game
Weight training
Other Conditioning

11. Were you able to return to the same game or practice in which you were hurt?
Yes ___ No

12. Describe to the best of your ability the events surrounding the injury
13. Injury Location: (Describe to the best of your ability)
Side: Right ___ Left ___ Both ___

Body Region:	**Head**	___	**Shoulder**	___	**Groin**	___
	Neck	___	**Upper arm**	___	**Hip**	___
	Upper Back	___	**Elbow**	___	**Thigh**	___
	Lower Back	___	**Lower arm**	___	**Knee**	___
	Ribs	___	**Wrist**	___	**Shin**	___
	Abdomen	___	**Hand**	___	**Ankle**	___
	Pelvis	___	**Thumb**	___	**Foot**	___
	Fingers	___	**Toes**	___		

14. Type of Injury (ie. sprain, fracture):___________________________________

____

15. Total number of days you were unable to participate in any sport due to this injury: _____
16. Total number of days you were unable to participate in the sport in which you were injured: ____
17. Did you see any health care professional for assessment or treatment of this injury?
Physician (Family) ___ (Total # visits __)
Physician (Specialist)___ (Total # visits __)
Physiotherapist ___ (Total # visits __)
Athletic Therapist ___ (Total # visits __)
Massage therapist ___ (Total # visits __)
Dentist ___ (Total # visits __)
Other (be specific) ________________ (Total # visits __)
18. Did you receive any other treatment for this injury (be as specific as possible, including location of service provided)?
First Aid
Xrays
Cast
Brace
Crutches
Taping
Surgery
Medications
Other
If you were seen by a physician, physiotherapist, athletic therapist or school health nurse for this injury please have them complete one of the following sections:

I. Date (Day/Month/Year) ________
Attending Medical Practitioner's Name
Occupation (ie. Family Physician/Specialist/Therapist/Nurse)
Diagnosis
Treatment Plan
II. Date (Day/Month/Year) ________
Attending Medical Practitioner's Name
Occupation (ie. Family Physician/Specialist/Therapist/Nurse)
Diagnosis
Treatment Plan
III. Date (Day/Month/Year) ________
Attending Medical Practitioner's Name
Occupation (ie. Family Physician/Specialist/Therapist/Nurse)
Diagnosis
Treatment Plan

Appendix I

Six-Week Wobble Board Training Program

Warning: Wobble board should be used for prescribed training program only, by study participants only!

Expect each session to take 20 minutes. Complete training at least 5 times per week. Wobble board should be used close to a wall or desk/counter top in order to steady yourself if necessary. However, minimal use of your arms is recommended to maximize the effects of the balance training program. You will be taught how to "stabilize" your trunk to maximize the benefit of the balance training program. Contact study coordinator in the event of pain, discomfort or injury.

WEEKS 1 and 2:

1. Stand with feet parallel on the wobble board, knees slightly bent, and hands on hips as able. Move the front edge towards the floor, followed by the back edge. The edge should not actually touch the floor. Continue this movement repeatedly for 30 seconds. Rest for 5 seconds. Repeat this exercise 5 times.

2. Stand with feet parallel on the wobble board, knees slightly bent, and hands on hips as able. Move the left edge towards the floor, followed by the right edge. The edge should not actually touch the floor. Continue this movement repeatedly for 30 seconds. Rest for 5 seconds. Repeat this exercise 5 times.

3. Stand with feet parallel on the wobble board, knees slightly bent, and hands on hips as able. Move the front edge towards the floor, followed by the right edge, followed by the back edge, followed by the left edge. Continue this circulating movement for 30 seconds. Rest 5 seconds. Repeat this exercise 5 times in this clockwise direction followed by 5 times counterclockwise.

4. Stand with one foot centered on the wobble board, knees slightly bent, and hands on hips as able. Try to keep the wobble board level for 10 seconds. Rest 5 seconds. Repeat this exercise 10 times with each leg.

5. Stand with one foot centered on the wobble board as in 4, keeping the wobble board level for 10 seconds, but close eyes for the last 5 seconds. Rest 5 seconds. Repeat this exercise 10 times with each leg.

WEEKS 3 and 4:

1. As in 1 above but with one foot centered on wobble board. Continue this movement repeatedly for 15 seconds. Rest for 5 seconds. Repeat this exercise 5 times on each leg.

2. As in 2 above but with one foot centered on wobble board. Continue this movement repeatedly for 15 seconds. Rest for 5 seconds. Repeat this exercise 5 times on each leg.

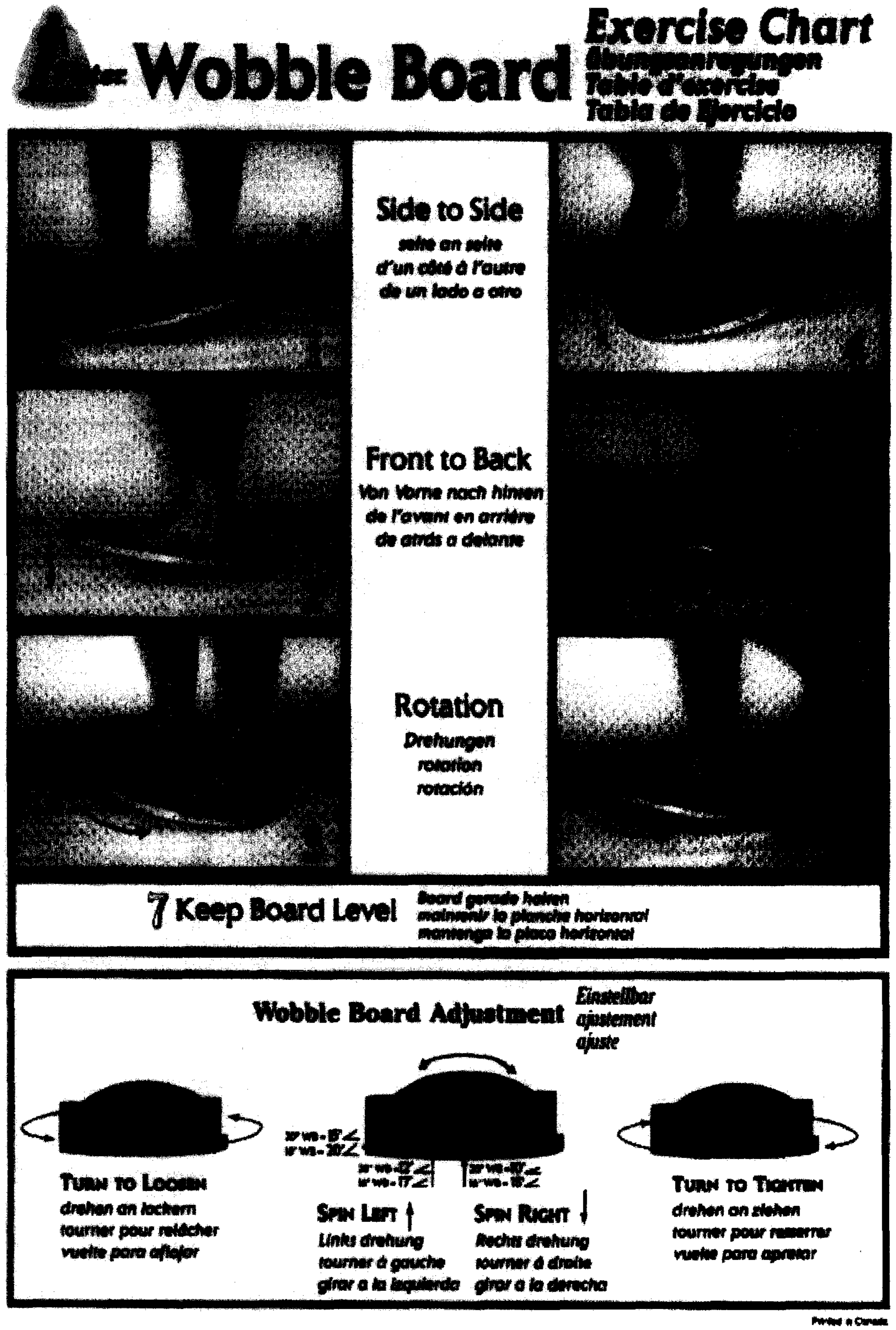
3. As in 3 above but with one foot centered on wobble board. Continue this movement repeatedly for 15 seconds. Rest for 5 seconds. Repeat this exercise 5 times on each leg.

4. As in 4 above but try to keep the wobble board level for 20 seconds. Repeat this exercise 10 times with each leg.

5. As in 5 above but try to keep the wobble board level for 10 seconds with eyes closed throughout each repetition. Repeat this exercise 10 times with each leg.

WEEKS 5 and 6:

Same exercises as 1-5 in WEEKS 3 and 4 but change wobble board adjustment to level 2



Wobble Board

Exercise Chart
Übungsanregungen
Table d'exercise
Tabla de Ejercicio

Side to Side
seite an seite
d'un côté à l'autre
de un lado a otro

Front to Back
Von Vorne nach hinten
de l'avant en arrière
de atrás a delante

Rotation
Drehungen
rotation
rotación

Keep Board Level
Board gerade halten
maintenir la planche horizontal
mantenga la placa horizontal

Wobble Board Adjustment
Einstellbar
ajustement
ajuste

TURN TO LOOSEN
drehen an lockern
tourner pour relâcher
vuelta para aflojar

SPIN LEFT ↑
Links drehung
tourner à gauche
girar a la izquierda

SPIN RIGHT ↓
Rechts drehung
tourner à droite
girar a la derecha

TURN TO TIGHTEN
drehen an ziehen
tourner pour resserrer
vuelta para apretar

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Appendix J

Wobble Board Training Program Completion Sheet

1. Name: _____________________________________
2. ID #
3. School:

Mark with a ✔ in the appropriate box when you have completed your 20 minute daily balance training session using your wobble board. Circle the ✔ on your first training day.

Week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
1							
2							
3							
4							
5							
6							
7							

Appendix K: Sample Size Calculations (Chapter 5 RCT)

Sample size calculations based on Donner and Klar[24]

$$\mathbf{n = (z_{\alpha/2} + z_{\beta})^2(2\sigma^2)[1 + (m - 1)\rho] / (\mu_1 - \mu_2)^2}$$

$\alpha = 0.05$ = acceptable type I error (using 2-tailed test)
$\beta = 0.10$ = acceptable type II error
$\delta = \mu_1 - \mu_2$ = mean (intervention group) – mean (control group) = 9 seconds, the minimum significant difference between control and training group in timed static balance change between baseline and six week follow-up
σ = the estimated common standard deviation of the timed balance test measurement in the control and training group = 11 seconds (based on Hahn et al[38])
d= effect size = δ/σ = 0.8
$\rho = 0.01$= estimated intra-cluster correlation coefficient
k = 3-7 = number of Calgary schools (clusters) to be randomized in each group (varied for initial power curve calculations)

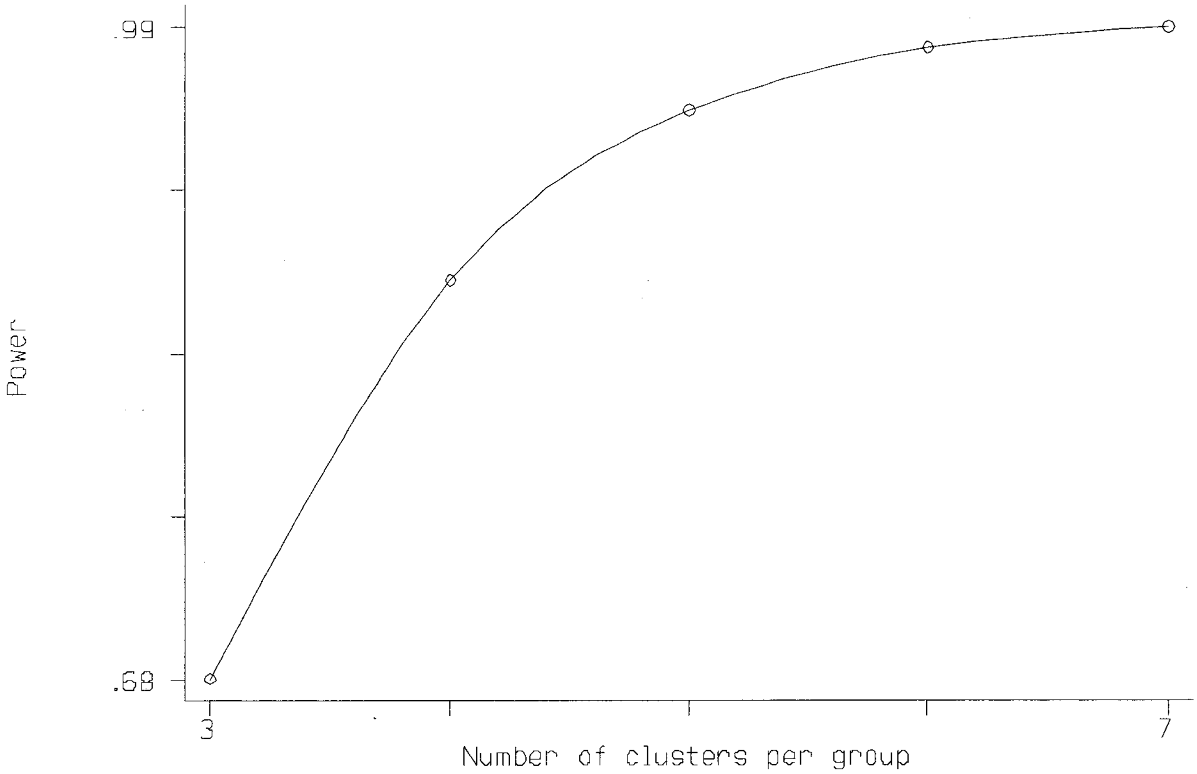
m=10=number of subjects per school

*We must consider a potential drop out/non-compliance rate in the intervention group and a contamination rate in the control group. We will estimate this to be $R_o = 0.10$

Our original sample size per school (n) will have to be adjusted by the following formula:
$m = m/ (1-R_o)^2 = 10/0.9^2 = 12.3$
A cluster size of 12 students per school will be recruited in consideration of drop-out, non-compliance and contamination.

*There has been very little published regarding the estimation of plausible values for intra-cluster correlation.[21,23] There was no information found regarding the degree to which adolescents participating in sport behave similarly with respect to their training behavior and risk of sports injury. An approximation of the intra-cluster correlation used to estimate sample size was based on Murray et al's[55] findings, based on original data from a number of studies examining smoking behaviors in adolescents. The mean values obtained for ρ for weekly smoking incidence was 0.006. The similarities in adolescents with respect to training behavior and risk of sports injury would likely be fewer than their similarities with respect to smoking behavior. As such, an intra-cluster correlation coefficient of 0.01, based on the mean ρ found by Murray et al[55] was conservatively chosen as the largest value likely to be observed in this study.

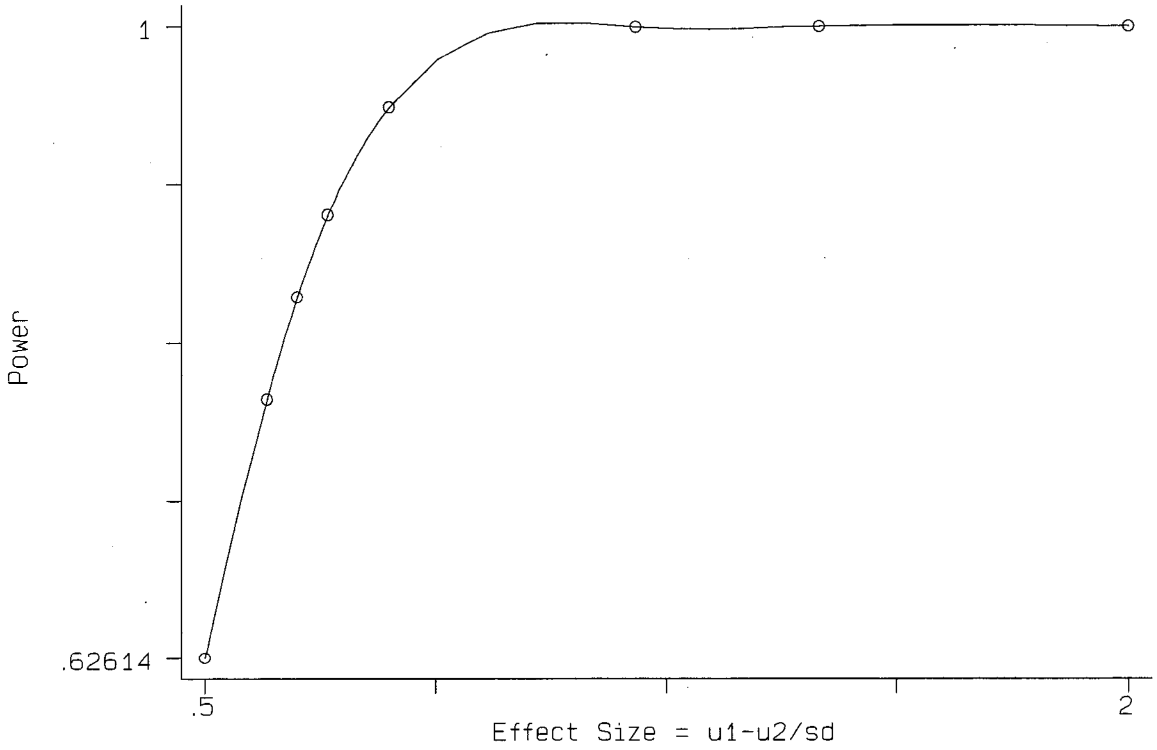
Increasing Power with increased number of clusters in each intervention group



Now we examined power calculations based on variable effect size. Power calculations based on Donner and Klar[143]

$\alpha = 0.05$ = acceptable type I error (using 2-tailed test)
$\beta = 0.10$ = acceptable type II error
$\delta = u1-u2$ = the minimum significant difference between control and training group in timed balance change between baseline and six week follow-up (varied between 5.5 and 22 seconds in power curve analysis of effect size)
σ = the estimated common standard deviation of the timed balance test measurement in the control and training group = 11 seconds
d= effect size = δ/σ= 0.8 (varied from 0.5-2 in power curve analysis of effect size)
$\rho = 0.01$= estimated intra-cluster correlation coefficient
k = 5 = number of Calgary schools (clusters) to be randomized in each group based on the ability to detect an effect size of 0.8 with the power of 0.95 (from above power curve for sample size calculation)
m=10=number of subjects per school

Increased power with increased minimum effect size



Appendix L: Technical Appendix Chapter 5: Tables

Table 5.i: Subject recruitment summary:

School	Group (T = training, C= control)	# students approached	# students declining participation	# initiating study	Drop-outs	# completing study
1	T	18	4	14	2	12
2	T	17	3	14	2	12
3	T	17	3	14	2	12
4	T	14	2	12	0	12
5	T	14	2	12	0	12
6	C	14	2	12	3	9
7	C	16	4	12	1	11
8	C	24	12	12	1	11
9	C	16	3	13	2	11
10	C	17	5	12	0	12
Total		**167**	**40**	**127**	**13**	**114**

Table 5.ii: Comparison of study group completing all three follow-up assessments (n=114) to drop-outs (n=13) (Two-tailed Student's t-test based on log transformed balance measurements)

Co-variable	Study Subjects Completing [n=114] Mean (95% CI) (exact 95% CI for binomials)	Drop-out Subjects [n=13] Mean (95% CI) (exact 95% CI for binomials)	Two tailed Student's t-test or test of proportions
Age (years)	15.82 (15.64, 16.01)	15.69 (15.24, 16.15)	$t_{125} = -0.47$; $p = 0.64$
Gender	57 male, 57 female	6 male, 7 female	N/A
Previous Injury (Lower Extremity)	23/114=20.18% (13.24, 28.72)	4/13=30.77% (9.09, 61.43)	$z = 0.88$; $p = 0.38$
Previous Injury (All)	42/114 = 36.84% (28.0, 46.39)	5/13= 38.46% (13.86, 68.42)	$z = 0.12$; $p = 0.91$
Height (m)	1.70 (1.69, 1.72)	1.68 (1.63, 1.72)	$t_{125} = -1.09$; $p = 0.28$
Weight (kg)	65.07 (62.63, 67.51)	61.27 (55.6, 66.94)	$t_{125} = -1.01$; $p = 0.31$
Body Mass Index (kg/m^2)	22.48 (21.63, 23.33)	21.8 (19.86, 23.75)	$t_{125} = -0.48$; $p = 0.63$
Sport participation previous 6 weeks (hours/week)	8.72 (7.43, 10)	6.77 (3.55, 9.99)	$t_{125} = -0.99$; $p = 0.33$
Vertical Jump (cm)	38.78 (36.9, 40.65)	33.17 (28.66, 37.67)	$t_{124} = -1.82$; $p = 0.07$
Predicted VO_2 Max (ml/kg.min)	34.66 (33.15, 36.16)	28.81 (25.52, 32.1)	$t_{122} = -2.27$; $p = 0.03$*
Geometric mean ECS balance (seconds)	29.25 (25.15, 34.02) 4 subjects reached 180 s max	34.17 (18.91, 61.71) 0 subjects reached 180 s max	$t_{120} = 0.63$; $p = 0.53$
Geometric mean ECD balance (seconds)	5.65 (5.2, 6.15)	7.7 (5.38, 11.02)	$t_{124} = 2.2$; $p = 0.03$*

*denotes significant difference based on $p \leq 0.05$

Table 5.iii: Gender differences for static and dynamic balance tests
(Two-tailed Student's t-tests based on log transformed balance measurements)

Balance Test	Geometric Mean (Male) (95% CI)	Geometric Mean (Female) (95% CI)	Geometric Mean (all subjects) (95% CI)	Two-tailed Student's t-test
Eyes Closed Static Balance (seconds)	32.49 (26.5, 39.83) 3 males reached 180 seconds	26.35 (21.33, 32.55) 1 female reached 180 seconds	29.2 (25.24, 39.83)	$t_{114} = -1.43$; p = 0.16
Eyes Closed Dynamic Balance (seconds)	6.07 (5.32, 6.92)	5.42 (4.87, 6.02)	5.73 (5.27, 6.23)	$t_{118} = -1.35$; p = 0.18

Table 5.iv: Gender differences for other baseline covariates (binomial 95% CI exact)

Covariate	Male (95 % CI)	Female (95% CI)	Two tailed Student's t-test or test of proportions
Age (years)	15.9 (15.64, 16.16)	15.77 (15.52, 16.01)	$t_{118} = -0.75$; $p = 0.46$
Height (m)	1.74 (1.72, 1.76)	1.66 (1.65, 1.68)	$t_{118} = -5.87$; $p < 0.00005$*
Weight (kg)	67.03 (63.69, 70.38)	63.23 (59.93, 66.54)	$t_{118} = -1.62$; $p = 0.11$
Body Mass Index (kg/m^2)	22.18 (21.0, 23.36)	22.83 (21.69, 23.98)	$t_{118} = 0.79$; $p = 0.43$
Sport participation previous 6 weeks (hours/week)	10.87 (9.23, 12.5)	6.4 (9.23, 12.5)	$t_{118} = -3.74$; $p = 0.0003$*
Previous Injury (Lower Extremity)	14/60=23.33% (13.38, 36.04)	10/60=16.67% (8.29, 28.52)	$z = 0.91$ $p = 0.36$
Previous Injury (All)	22/60= 36.67% (24.59, 50.1)	21/60= 35% (23.13, 48.4)	$z = 0.91$ $p = 0.36$
Vertical Jump (cm)	44.67 (42.15, 47.18)	32.88 (31.02, 34.74)	$t_{118} = -7.53$; $p < 0.00005$*
Predicted VO_2 Max (ml/kg.min)	39.07 (36.89, 41.25)	30.32 (28.88, 31.75)	$t_{117} = -6.73$; $p < 0.00005$*

*denotes significant difference based on $p \leq 0.05$

Table 5.v: Sport specific participation (based on self-report from previous one year)

Male (% sport participation) (binomial exact 95% CI)	Female (% sport participation) (binomial exact 95% CI)
1. Basketball 31/60 = 51.7% (38.4, 64.8)	1. Soccer 17/60 = 28.3% (17.5, 41.4)
2. Football 20/60 = 33.3% (21.7, 46.7)	2. Volleyball 16/60 = 26.7% (16.1, 39.7)
3. Hockey 14/60 = 23.3% (13.4, 36)	3. Basketball 14/60 = 23.3% (13.4, 36)
4. Soccer 13/60 = 21.7%(12.1, 34.2)	4. Dance 10/60 = 16.7% (8.3, 28.5)
5. Volleyball 10/60 = 16.7% (8.3, 28.5)	5. Track and field 8/60 = 13.3% (5.9, 24.6)

Table 5.vi: Comparison of functional strength between training groups (vertical jump measurement in centimeters)

Difference examined	Training group (95% CI)	Control group (95% CI)	Student's t-test
Vertical Jump (cm) (Baseline – 2 weeks)	0.93 (0.17, 1.69)	0.64 (-0.21, 1.49)	$t_{117} = -0.51$; $p = 0.61$
Vertical Jump (cm) (2 weeks – 4 weeks)	0.3 (-0.37, 0.98)	0.63 (-0.47, 1.72)	$t_{111} = 0.51$; $p=0.61$
Vertical Jump (cm) (4 weeks – 6 weeks)	0.27 (-0.36, 0.9)	-0.22 (-1.37, 0.92)	$t_{111} = -0.77$; $p=0.44$
Vertical Jump (cm) (Baseline – 6 weeks)	1.5 (0.57, 2.43)	1.11 (-0.1, 2.33)	$t_{112} = -0.51$; $p=0.61$

Table 5.vii: Comparison of endurance between training groups (predicted VO_2Max in ml/kg.min)

Difference examined	Training group (95% CI)	Control group (95% CI)	Student's t-test p-value
Predicted VO_2 Max (ml/kg.min) (Baseline – 2 weeks)	0.6 (-0.88, 2.07)	1.09 (0.18, 2.01)	$t_{111} = 0.58$; p=0.56
Predicted VO_2 Max (ml/kg.min) (2 weeks – 4 weeks)	-0.74 (-1.89, 0.41)	-0.98 (-2.12, 0.15)	$t_{96} = -0.31$; p=0.76
Predicted VO_2 Max (ml/kg.min) (4 weeks – 6 weeks)	-0.25 (-1.56, 1.06)	-0.05 (-1.22, 1.13)	$t_{87} = 0.24$; p=0.81
Predicted VO_2 Max (ml/kg.min) (Baseline – 6 weeks)	-0.14 (-1.7, 1.41)	0.63 (-0.7, 1.96)	$t_{97} = 0.75$; p=0.45

Appendix M: Technical Appendix Chapter 5: Figures

Figure 5.i: Static maximum (ECS) balance at baseline

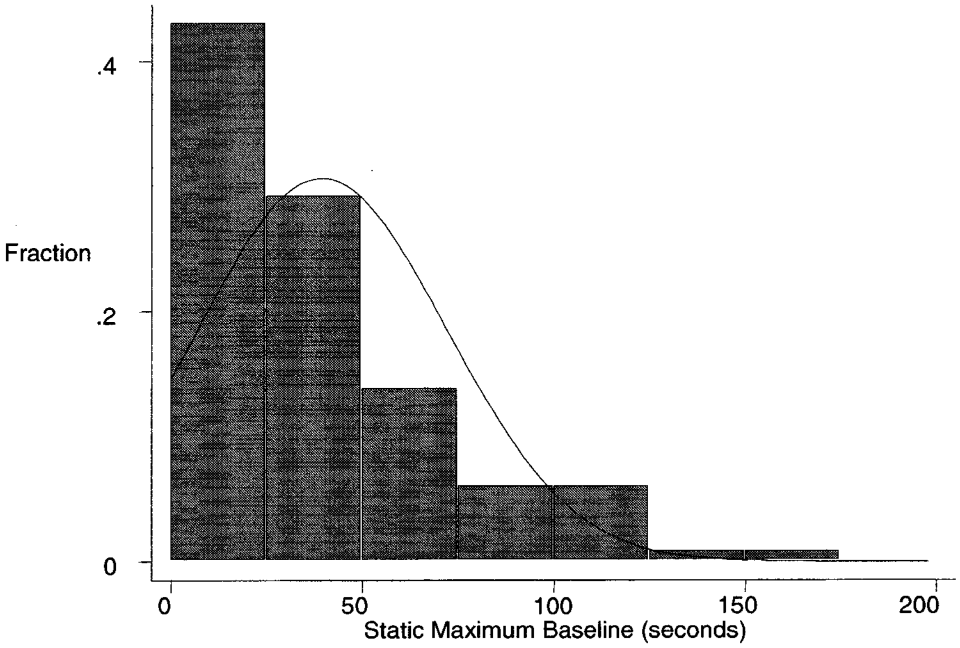


Figure 5.ii: Log-transformed static maximum (ECS) balance at baseline

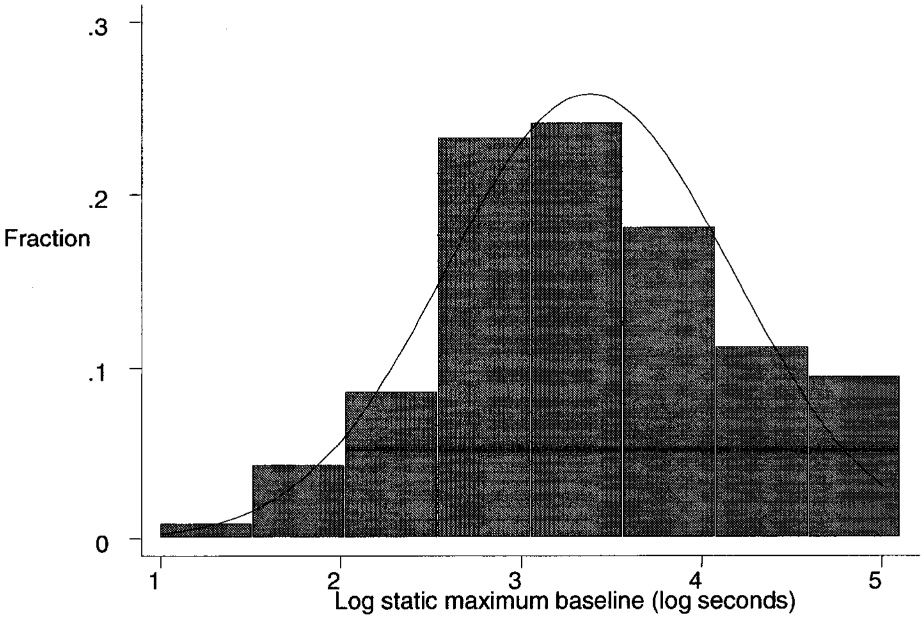


Figure 5.iii : Dynamic maximum (ECD) balance at baseline

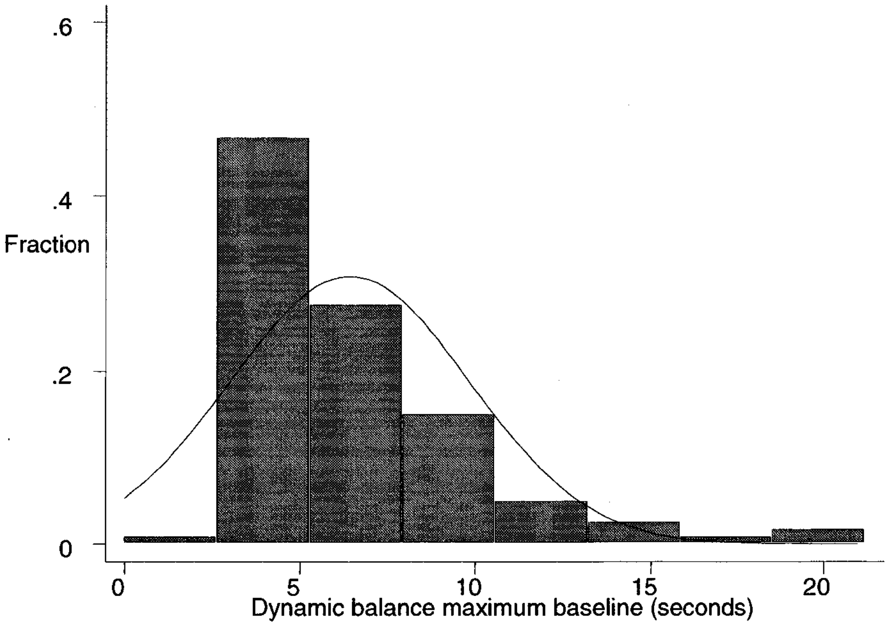


Figure 5.iv: Log-transformed dynamic maximum (ECD) balance at baseline

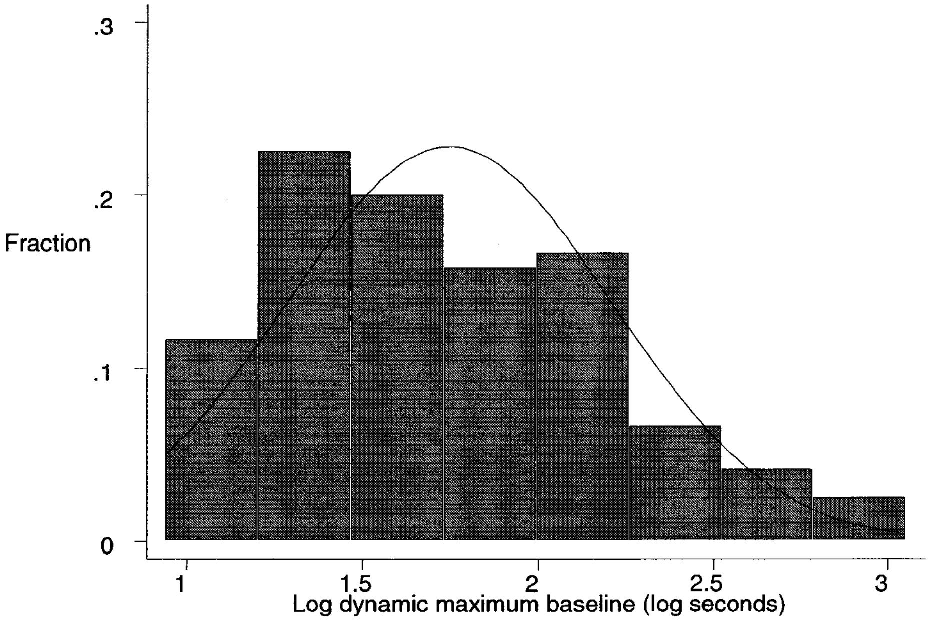


Figure 5.v: Static maximum (ECS) balance difference between baseline and six-weeks

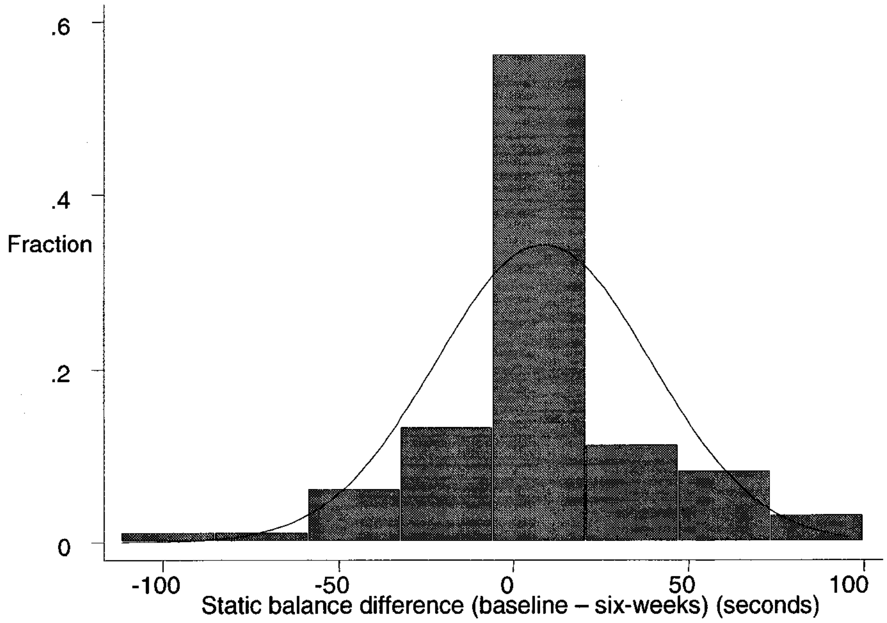


Figure 5.vi: Dynamic maximum (ECD) balance difference between baseline and six-weeks

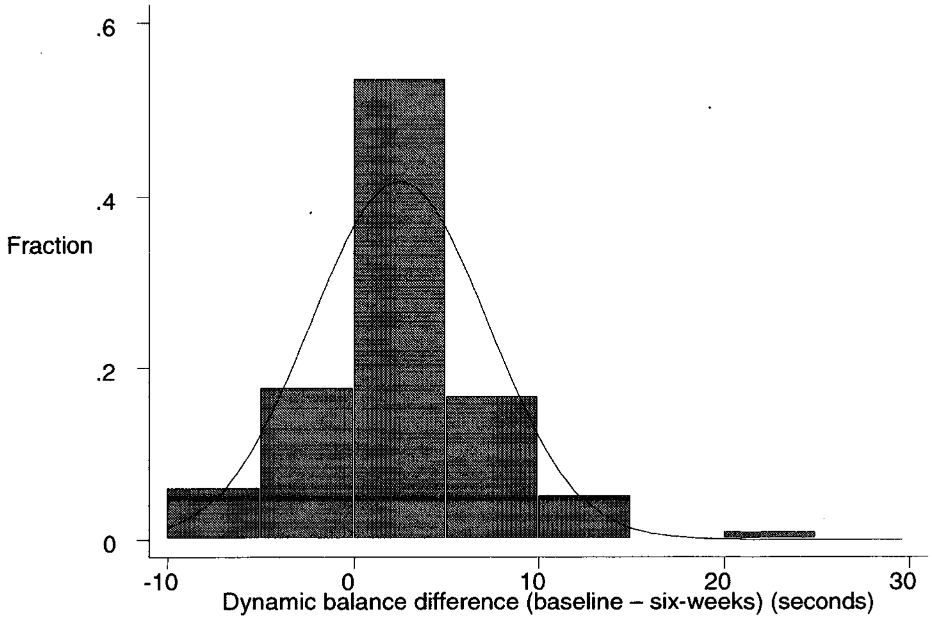
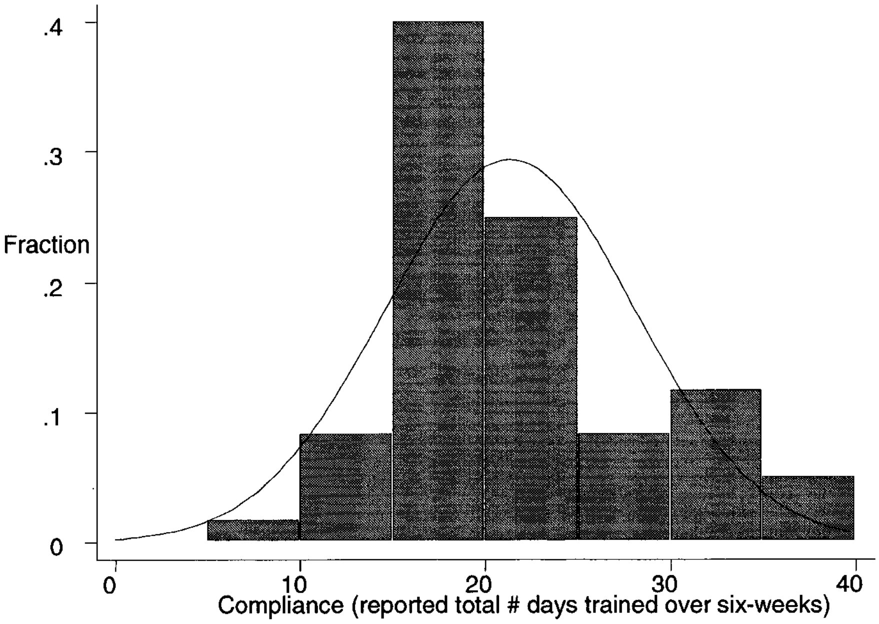


Figure 5.vii: Reported compliance in training group (n=60) over six-week training period



Appendix N: Technical Appendix Chapter 5: Calculations and Statistical Models

I. Cluster-adjusted independent t-test analysis to compare static and dynamic balance difference (baseline – six-weeks) in training and control group (Donner & Klar pp 111-116)[24]

Static Balance Maximum Difference (Baseline – 6 weeks)

Subjects reaching 180 second maximum excluded from data (M=98).

Intra-cluster correlation coefficient (ρ):

$\rho = MSC - MSW / MSC + (m_0 - 1) MSW$

$MSC = {}_{i=1}^{2}\sum {}_{j=1}^{k}\sum m_{ij}(Y_{ij} - Y_i)^2 / K-2$

$=9(22.821112-20.31482)^2 / 8 + 12(34.215834-20.31482)^2 / 8 + 10(10.887001-20.31482)^2 /$
$8 + 12(25.654166-20.31482)^2 / 8$
$+ 11(5.854545-20.31482)^2 / 8 + 7(-5.6928577+6.12182)^2 / 8 +$
$9(-4.254445+6.12182)^2 / 8 + 9(-1.5077776+6.12182)^2 / 8$
$+9(-19.952222+6.12182)^2 / 8 + 10(0.19200058+6.12182)^2 / 8$
MSC=1031.594

$MSW = {}_{i=1}^{2}\sum {}_{j=1}^{ki}\sum {}_{l=1}^{mij}\sum (Y_{ijl} - Y_{ij})^2 / M-K$
= 756.7057
$m0 = [M - {}_{i=1}^{2}\sum m_{Ai}] / (K-2)$ = 9.770623
where M = total number of subjects in the study = 98
i = intervention group
M_i = total number of subjects in group i
j = cluster
m = cluster size
$m_{Ai} = {}_{j=1}^{ki}\sum m^2_{ij} / M_i$
K = total number of clusters

$\rho = MSC - MSW / MSC + (m_0 - 1) MSW$
$\rho = 1031.594 - 756.7057 / 1031.594 + 8.770623(756.7057)$
$= 274.8883 / 7668.374417$
$= 0.035847011$

$SE(Y1-Y2) = Sp(C1/M1 + C2/M2)^{1/2}$
$Sp = \sqrt{S_A^2 + S_w^2}$

$S^2_A = (MSC - MSW)/m_0$
$= 1031.594 - 756.7057 / 9.770623$
$= 28.13416299$
$S_w^2 = MSW = 756.7057$
$Sp = \sqrt{28.13416299 + 756.7057} = 28.01499354$

Calculate inflation factor
$C1 = 1 + (m_{Ai} - 1)\rho = 1 + (10.92593 - 1)(.035847) = 1.355814813$
$C2 = 1 + (8.909091-1).035847 = 1.283517185$

SE(Y1-Y2)= $Sp(C1/M1 + C2/M2)^{1/2} = 28.01499354(1.355814813/54+1.283517185/44)^{1/2}$
=6.526863855

Cluster adjusted t-test
t=Y1-Y2/SE(Y1-Y2)=20.31482- (-6.12182)/6.526863855=4.0504
P=0.0037 8df
Significant ($p<0.05$), evidence to reject the null of **Y1-Y2=0**

95% CI for the difference is (Y1 – Y2) +- $t_{\alpha/2}$SE(Y1 –Y2)
(-6.12 -20.31) +- 2.306(6.526863855)
-26.43 +- 15.051
(95% CI; -41.48, -11.38)

Static Balance Maximum Difference (Baseline – two-weeks)

Subjects reaching 180 second maximum exclude from data (M=109).

Intra-cluster correlation coefficient (ρ)
ρ=MSC-MSW/MSC+(m0 -1)MSW

MSC = $_{i=1}{}^{2}\Sigma\, _{j=1}{}^{k}\Sigma m_{ij}(Y_{ij} - Y_i)^2 / K-2$
MSC=681.2443

MSW = $_{i=1}{}^{2}\Sigma\, _{j=1}{}^{ki}\Sigma\, _{l=1}{}^{mij}\Sigma(Y_{ijl} - Y_{ij})^2 / M-K$
= 811.3033
m0= $[M - {}_{i=1}{}^{2}\Sigma m_{Ai}] / (K-2)$ = 10.89448

ρ=MSC-MSW/MSC+(m0 -1)MSW
ρ= -0.01493, negative so ρ set to 0

Static Balance Maximum Difference (Two-weeks – four-weeks)

Subjects reaching 180 second maximum excluded from data (M=101).

Intra-cluster correlation coefficient (ρ)
ρ=MSC-MSW/MSC+(m0 -1)MSW
MSC = $_{i=1}{}^{2}\Sigma\, _{j=1}{}^{k}\Sigma m_{ij}(Y_{ij} - Y_i)^2 / K-2$
=392.7249
MSW = $_{i=1}{}^{2}\Sigma\, _{j=1}{}^{ki}\Sigma\, _{l=1}{}^{mij}\Sigma(Y_{ijl} - Y_{ij})^2 / M-K$
= 542.18
m0= $[M - {}_{i=1}{}^{2}\Sigma m_{Ai}] / (K-2)$ = 9.770623

ρ=MSC-MSW/MSC+(m_0 -1)MSW
ρ= **- 0.029**, negative so ρ set to 0

Static Balance Maximum Difference (Four-weeks – six-weeks)

Subjects reaching 180 second maximum excluded from data (M=98).

Intra-cluster correlation coefficient (ρ)
ρ=MSC-MSW/MSC+(m_0 -1)MSW

MSC = $_{i=1}{}^{2}\Sigma_{j=1}{}^{k}\Sigma m_{ij}(Y_{ij} - Y_i)^2/K-2$
=167.9626
MSW = $_{i=1}{}^{2}\Sigma_{j=1}{}^{ki}\Sigma_{l=1}{}^{mij}\Sigma(Y_{ijl} - Y_{ij})^2/M-K$
= 356.7359
m0= [M - $_{i=1}{}^{2}\Sigma m_{Ai}$] / (K-2) = 9.770623
ρ=MSC-MSW/MSC+(m_0 -1)MSW
= **-0.05726**, negative so ρ set to 0

Dynamic Balance Maximum Difference (Baseline – six-weeks)

Intra-cluster correlation coefficient (ρ):
ρ=MSC-MSW/MSC+(m_0 -1)MSW
= 47.52091-19.86848/47.5246 + (11.38889 -1)(19.868) =0.108897

m_0 = M-$\Sigma^2{}_{i=1}$ mean(m_{ai})/K-2
= 11.38889
M = 114

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$

Inflation factor
C1= 1 + (m_{Ai} -1)ρ = 1 + 11(.108897)= 2.197867
C2= 1+(10.88889-1)0.108897=2.076870454

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$
Sp= $\sqrt{}S_A{}^2 + S_w{}^2$
$S_A{}^2$= (MSC-MSW)/m_0
= 47.52091-19.86848/11.38889
=2.428018007
$S_w{}^2$=MSW=19.86848
Sp = $\sqrt{}$2.428018007+19.86848= 4.721916773

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$=4.721916773(2.197867/60+2.076870454/54)$^{1/2}$
= 1.309605787

Cluster adjusted t-test
t=Y1-Y2/SE(Y1-Y2)=3.476167-1.31926/1.309605787=1.64701
P=0.1382 8df

Not significant, no evidence to reject the null of **Y1-Y2=0** for dynamic balance difference.

95% CI for the difference is (Y1 – Y2) +- $t_{\alpha/2}$SE(Y1 –Y2)
-2.156907 +- 2.306(1.309605787)
-2.156907 +- 3.019951
(-5.18, 0.86)

Dynamic Balance Maximum Difference (Baseline – two-weeks)

Intra-cluster correlation coefficient (ρ)

$$\mathrm{MSC} = {}_{i=1}{}^{2}\Sigma\,{}_{j=1}{}^{k}\Sigma m_{ij}(Y_{ij} - Y_i)^2/K-2$$
= 70.39774

$$\mathrm{MSW} = {}_{i=1}{}^{2}\Sigma\,{}_{j=1}{}^{ki}\Sigma_{l=1}{}^{mij}\Sigma(Y_{ijl} - Y_{ij})^2/M-K$$
= 32.92673
M = 119
m_0 = M-${}^{2}{}_{i=1}\Sigma$mean(m_{ai})/K-2
= 11.89831

ρ=MSC-MSW/MSC+(m0 -1)MSW
= 0.087296

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$

Inflation factor
C1= 1 + (m_{Ai} -1)ρ = 1 + 11(0.087296)= 1.960256
C2= 1+(11.81356-1)0.087296=1.943980534

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$
Sp= $\sqrt{S_A^2 + S_w^2}$
S_A^2= (MSC-MSW)/m_0
= 3.149273
S_w^2=MSW=32.92673
Sp = √3.149273+32.92673= 6.0063

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$=6.0063(1.960256/60+1.943980534/59)$^{1/2}$
= 1.538595

Cluster adjusted t-test
t=Y1-Y2/SE(Y1-Y2)=0.691-2.225085/1.538595=-0.997069
P=0.3479 8df

Not significant, no evidence to reject the null of **Y1-Y2=0** for dynamic balance difference.
95% CI for the difference is (Y1 – Y2) +- $t_{\alpha/2}$SE(Y1 –Y2)
1.534085 +- 2.306(1.538595)
1.534085 +- 3.548
(-2.01, 5.08)

Dynamic Balance Maximum Difference (Two-weeks – four-weeks)

Intra-cluster correlation coefficient (ρ)

MSC = $_{i=1}{}^{2}\sum_{j=1}{}^{k}\sum m_{ij}(Y_{ij} - Y_i)^2/K-2$
=79.82317
MSW = $_{i=1}{}^{2}\sum_{j=1}{}^{ki}\sum_{l=1}{}^{mij}\sum(Y_{ijl} - Y_{ij})^2/M-K$
= 35.08513
M = 114
$m_0 = M-\sum^{2}_{i=1}$ mean(m_{ai})/K-2
= 11.38889

ρ=MSC-MSW/MSC+(m0 -1)MSW
= 0.100689

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$

Inflation factor
C1= 1 + (m_{Ai} -1)ρ = 1 + 11(0.100689)= 2.107579
C2= 1+(10.88889-1) 0.100689=1.995702445

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$
Sp= $\sqrt{S_A^2 + S_w^2}$
$S_A{}^2$= (MSC-MSW)/m_0
= 3.92819
$S_w{}^2$=MSW=35.08513
Sp = $\sqrt{3.92819+35.08513}$= 6.246066

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$=6.246066(2.107579/60+1.995702445/54)$^{1/2}$
= 1.67697
Cluster adjusted t-test
t=Y1-Y2/SE(Y1-Y2)=1.4855—0.38963/1.67697= 1.1181655
P=0.2959 8df
Not significant, no evidence to reject the null of **Y1-Y2=0** for dynamic balance difference.

95% CI for the difference is (Y1 – Y2) +- $t_{\alpha/2}$SE(Y1 –Y2)
-1.87513 +- 2.306 (1.67697)
-1.87513 +- 3.86709
(-5.74, 1.99)

<u>Dynamic Balance Maximum Difference (Four-weeks – six-weeks)</u>

Intra-cluster correlation coefficient (ρ)

MSC = $_{i=1}{}^{2}\sum {}_{j=1}{}^{k}\sum m_{ij}(Y_{ij} - Y_i)^2 / K-2$
= 17.49265

MSW = $_{i=1}{}^{2}\sum {}_{j=1}{}^{ki}\sum {}_{l=1}{}^{mij}\sum (Y_{ijl} - Y_{ij})^2 / M-K$
= 15.77613

ρ=MSC-MSW/MSC+(m0 -1)MSW
= 0.009463
M = 114
m_0 = M- $^{2}{}_{i=1}\sum$ **mean(m_{ai})/K-2**
= 11.38889
SE(Y1-Y2)= Sp(C1/M1 + C2/M2)$^{1/2}$

Inflation factor
C1= 1 + (m_{Ai} -1)ρ = 1 + 11(0.009463)= 1.104093
C2= 1+(10.88889-1) 0.009463=1.093578566

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)^{½}
Sp= $\sqrt{S_A{}^2 + S_w{}^2}$
$S_A{}^2$= (MSC-MSW)/m_0
= 0.150718
$S_w{}^2$=MSW=15.77613
Sp = √0.150718+15.77613= 3.990846

SE(Y1-Y2)= Sp(C1/M1 + C2/M2)^{½}=3.990846(1.104093/60+1.093578566/54)^{½}
= 0.78461499

Cluster adjusted t-test
t=Y1-Y2/SE(Y1-Y2)=1.299667- - 0.73611/0.78461499= 2.59462
P=0.0319 8df
Not significant, no evidence to reject the null of **Y1-Y2=0** for dynamic balance difference.

95% CI for the difference is (Y1 – Y2) +- $t_{\alpha/2}$SE(Y1 –Y2)
-2.035777 +- 2.306 (0.78461499)
-2.035777 +- 1.8093222
(-3.85, -0.23)

II. Mixed effects linear regression analysis to examine the effectiveness of training program on static (ECS) balance (Donner & Klar pp 120-122)[24]

Mixed Effects Linear Regression Model

$$Y_{ijl} = \beta_0 + \beta_1 X_{ijl} + \beta_2 LEinjury_{ijl} + \beta 3Age_{ijl} + \beta 4Gender_{ijl} + \beta 5Sport_{ijl} + \beta 6BMI_{ijl} + \beta 7Jump_{ijl} + \beta 8VO_2Max_{ijl} + \beta 9smxQ_{ijl} + V_{ij} + e_{ijl}$$

Y_{ijl} denotes static balance difference between baseline and 6 weeks for the lth student, $l = 1,\ldots,m_{ij}$ from the jth cluster, $j = 1,\ldots..,k_i$ of the ith intervention group, i=0(control), i=1(intervention)

X_{ijl} = 1 (intervention), 0 (control)

LEinjury =1 (if previous lower extremity injury in one year), 0 (no previous injury)

Age$_{ijl}$ (years)

Gender$_{ijl}$ (0 if male, 1 if female)

Sport$_{ijl}$ (hours/week based on previous 6 weeks)

BMI$_{ijl}$ (kg/m^2)

Jump$_{ijl}$ (vertical jump test maximum in cm)

VO$_2$Max$_{ijl}$ (ml/kg/min predicted based on shuttle run test)

smxQ (based on static balance test maximum at baseline, 0 if <40 seconds, 1 if >=40 seconds)

V_{ij} denotes random cluster effects or cluster specific error which differs between schools and is constant within schools, it is assumed to be normally distributed with mean 0 and variance σ_A^2 (between cluster component of variance), i.e. $V_{ij} \approx N(0,\sigma_A^2)$

e_{ijl} denotes the usual residual which is assumed to be normally distributed with mean 0 and variance σ_w^2 (within cluster component of variance), i.e. $e_{ijl} \approx N(0,\sigma_w^2)$

Full mixed effects model:

```
Random-effects GLS regression                   Number of obs      =        97
Group variable (i) : school                     Number of groups   =        10

R-sq:  within  = 0.2402                         Obs per group: min =         7
       between = 0.7923                                        avg =       9.7
       overall = 0.4042                                        max =        12

Random effects u_i ~ Gaussian                   Wald chi2(9)       =     59.03
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
  sdiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   23.34084   5.325406     4.383    0.000*      12.90324    33.77845
leinjury |  -8.929408   6.755282    -1.322    0.186      -22.16952    4.310701
     age |   .5213476   2.751842     0.189    0.850      -4.872164    5.914859
  gender |   6.370174   6.354097     1.003    0.316      -6.083627    18.82398
sport6we |  -.2122493   .4139209    -0.513    0.608      -1.023519    .5990207
     bmi |  -.0961885   .6248821    -0.154    0.878      -1.320935    1.128558
    jump|  -.3923669    .376477    -1.042    0.297      -1.130248    .3455145
    smxQ |   -30.8873   6.065786    -5.092    0.000*     -42.77602   -18.99858
  vo2max |   .9359272   .4716694     1.984    0.047*      .0114722    1.860382
   _cons |  -25.24826   43.64369    -0.579    0.563      -110.7883     60.2918
---------+--------------------------------------------------------------------
 sigma_u |          0
 sigma_e |  24.207707
     rho |          0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Final mixed effects model:

```
Random-effects GLS regression                   Number of obs      =        97
Group variable (i) : school                     Number of groups   =        10

R-sq:  within  = 0.1992                         Obs per group: min =         7
       between = 0.8155                                        avg =       9.7
       overall = 0.3800                                        max =        12

Random effects u_i ~ Gaussian                   Wald chi2(3)       =     57.00
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0000

------------------------------------------------------------------------------
  sdiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   20.67189   4.973898     4.156   0.000*      10.92323    30.42056
    smxQ |  -30.23223   5.690449    -5.313   0.000*      -41.3853   -19.07915
 vo2max  |    .763179   .3057129     2.496   0.013*      .1639927    1.362365
   _cons |  -21.13037   10.57137    -1.999   0.046*     -41.84987   -.4108763
---------+--------------------------------------------------------------------
 sigma_u |          0
 sigma_e |  24.033614
     rho |          0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

*denotes significance based on p≤0.05

However, if we do a Breusch and Pagan Lagrange multiplier test in Stata for random effects we find that there is no evidence against the between school variance being equal to 0 (sigma_u = 0).

```
Breusch and Pagan Lagrangian multiplier test for random effects:

        sdiff6[school,t] = Xb + u[school] + e[school,t]

        Estimated results:
                                 Var     sd = sqrt(Var)
                ---------+-----------------------------
                  sdiff6 |   902.6118       30.0435
                       e |   577.6146      24.033614
                       u |          0      0

        Test:   Var(u) = 0
                              chi2(1) =      0.21
                            Prob>chi2 =     0.6476
```

As such the final model without adjustment for cluster effects is the preferred final model:

```
regress sdiff6 group smxQ vo2max

  Source |       SS       df       MS                  Number of obs =      97
---------+------------------------------               F(  3,    93) =   19.00
   Model |  32927.131      3  10975.7103               Prob > F      =  0.0000
Residual |  53723.6054    93  577.673176               R-squared     =  0.3800
---------+------------------------------               Adj R-squared =  0.3600
   Total |  86650.7364    96  902.611838               Root MSE      =  24.035

------------------------------------------------------------------------------
  sdiff6 |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   20.67189   4.973898     4.156   0.000*       10.79472    30.54907
    smxQ |  -30.23223   5.690449    -5.313   0.000*      -41.53233   -18.93212
 vo2max  |    .763179   .3057129     2.496   0.014*       .1560938    1.370264
   _cons |  -21.13037   10.57137    -1.999   0.049*      -42.12301    -.137736
------------------------------------------------------------------------------
```

*denotes significance based on p≤0.05

The assumptions of multiple linear regression (ie. residual plots for normality and constant variance) have been examined for this model graphically

III. Mixed-effects linear regression analysis to examine the effectiveness of training program on dynamic (ECD) balance (Donner & Klar pp 120-122)[24]

Mixed Effects Linear Regression Model

$$\mathbf{Y_{ijl} = \beta_0 + \beta_1 X_{ijl} + \beta_2 LEinjury_{ijl} + \beta 3Age_{ijl} + \beta 4Gender_{ijl} + \beta 5Sport_{ijl} + \beta 6BMI_{ijl} + \beta 7Jump_{ijl} + \beta 8VO_2Max_{ijl} + \beta 9dmxQ_{ijl} + V_{ij} + e_{ijl}}$$

Y_{ijl} denotes dynamic balance difference between baseline and 6 weeks for the lth student, $l = 1,\ldots,m_{ij}$ from the jth cluster, $j = 1,\ldots\ldots,k_i$ of the ith intervention group, i=0(control), i=1(intervention)

$\mathbf{X_{ijl}}$ = 1 (intervention), 0 (control)

LEinjury =1 (if previous lower extremity injury in one year), 0 (no previous injury)

$\mathbf{Age_{ijl}}$ (years)

$\mathbf{Gender_{ijl}}$ (0 if male, 1 if female)

$\mathbf{Sport_{ijl}}$ (hours/week based on previous 6 weeks)

$\mathbf{BMI_{ijl}}$ (kg/m^2)

$\mathbf{Jump_{ijl}}$ (vertical jump test maximum in cm)

$\mathbf{VO_2Max_{ijl}}$ (ml/kg/min predicted based on shuttle run test)

$\mathbf{dmxQ_{ijl}}$ (based on dynamic balance test maximum at baseline, 0 if <8 seconds, 1 if >=8 seconds)

$\mathbf{V_{ij}}$ denotes random cluster effects or cluster specific error which differs between schools and is constant within schools, it is assumed to be normally distributed with mean 0 and variance σ_A^2 (between cluster component of variance), i.e. $V_{ij} \approx N(0,\sigma_A^2)$

$\mathbf{e_{ijl}}$ denotes the usual residual which is assumed to be normally distributed with mean 0 and variance σ_w^2 (within cluster component of variance), i.e. $e_{ijl} \approx N(0,\sigma_w^2)$

Full mixed effects model:

```
Random-effects GLS regression                   Number of obs      =       113
Group variable (i) : school                     Number of groups   =        10

R-sq:  within  = 0.2080                         Obs per group: min =         9
       between = 0.4595                                        avg =      11.3
       overall = 0.2537                                        max =        12

Random effects u_i ~ Gaussian                   Wald chi2(9)       =     35.02
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0001

------------------------------------------------------------------------------
  ddiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   2.233095   .8433839      2.648   0.008*      .5800932    3.886097
leinjury |  -2.113203   1.047698     -2.017   0.044*     -4.166653   -.0597519
     age |   .3055297   .4445621      0.687   0.492       -.565796    1.176855
  gender |    .330693   1.054496      0.314   0.754      -1.736081    2.397467
sport6we |   .0798339     .06542      1.220   0.222       -.048387    .2080548
     bmi |  -.0287418   .1031338     -0.279   0.780      -.2308804    .1733968
    jump|   .0204489   .0615983      0.332   0.740      -.1002815    .1411793
  vo2max |   .1069959   .0733139      1.459   0.144      -.0366967    .2506885
    dmxQ |  -3.305086   .9607108     -3.440   0.001*     -5.188044   -1.422127
   _cons |  -7.417345   7.064379     -1.050   0.294      -21.26327    6.428583
---------+--------------------------------------------------------------------
 sigma_u |          0
 sigma_e |  4.1182838
     rho |          0   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

Final mixed effects model:

```
Random-effects GLS regression                   Number of obs      =       114
Group variable (i) : school                     Number of groups   =        10

R-sq:  within  = 0.0415                         Obs per group: min =         9
       between = 0.4918                                        avg =      11.4
       overall = 0.1216                                        max =        12

Random effects u_i ~ Gaussian                   Wald chi2(2)       =     13.90
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0010

------------------------------------------------------------------------------
  ddiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   2.336713   .9119398     2.562   0.010*       .5493442    4.124083
    dmxQ |  -2.861633   .9957169    -2.874   0.004*      -4.813203   -.9100642
   _cons |   1.902556   .6887866     2.762   0.006*       .5525585    3.252553
---------+--------------------------------------------------------------------
 sigma_u |   .5420815
 sigma_e |  4.3851619
     rho |  .01505121   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

However, if we do a Breusch and Pagan Lagrange multiplier test for random effects we find that there is no evidence against the random cluster effects being equal to 0.

```
Breusch and Pagan Lagrangian multiplier test for random effects:

        ddiff6[school,t] = Xb + u[school] + e[school,t]

        Estimated results:
                                 Var     sd = sqrt(Var)
                ---------+-----------------------------
                  ddiff6 |   22.82112       4.777145
                       e |   19.22964      4.3851619
                       u |   .2938523       .5420815

        Test:   Var(u) = 0
                              chi2(1) =       0.80
                            Prob>chi2 =     0.3711
```

As such the final model without adjustment for cluster effects is the preferred final model:

```
  Source |       SS       df       MS                  Number of obs =     114
---------+------------------------------               F(  2,   111) =    7.69
   Model |  313.823881     2  156.91194                Prob > F      =  0.0007
Residual |  2264.96255   111  20.405068                R-squared     =  0.1217
---------+------------------------------               Adj R-squared =  0.1059
   Total |  2578.78643   113  22.8211189               Root MSE      =  4.5172

------------------------------------------------------------------------------
  ddiff6 |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   2.344688    .849649     2.760   0.007*       .6610516    4.028324
    dmxQ |  -2.976512   .9978622    -2.983   0.004*      -4.953842   -.9991813
   _cons |   1.925215   .6474485     2.974   0.004*       .6422529    3.208178
------------------------------------------------------------------------------
```

***denotes significance based on p≤0.05**
The assumptions of multiple linear regression (ie. residual plots for normality and constant variance) have been examined for this model graphically.

IV. Mixed effects linear regression model examining dose-response between total number of training sessions and balance change

STATIC BALANCE

$$\mathbf{Y_{ijl} = \beta_0 + \beta_1 Comp_{jl} + V_j + e_{jl}}$$

$\mathbf{Y_{jl}}$ denotes static balance difference between baseline and 6 weeks for the lth student, $l = 1,\ldots,m_{ij}$ from the jth cluster, $j = 1,\ldots..,k_i$ of the intervention group
$\mathbf{Comp_{jl}}$ (compliance based on # reported training sessions over 6 week training period)
$\mathbf{V_{ij}}$ denotes random cluster effects or cluster specific error which differs between schools and is constant within schools, it is assumed to be normally distributed with mean 0 and variance σ_A^2 (between cluster component of variance), i.e. $V_{ij} \approx N(0,\sigma_A^2)$
$\mathbf{e_{ijl}}$ denotes the usual residual which is assumed to be normally distributed with mean 0 and variance σ_w^2 (within cluster component of variance), i.e. $e_{ijl} \approx N(0,\sigma_w^2)$

```
Random-effects GLS regression                   Number of obs      =        54
Group variable (i) : school                     Number of groups   =         5

R-sq:  within  = 0.1141                         Obs per group: min =         9
       between = 0.0314                                        avg =      10.8
       overall = 0.1050                                        max =        12

Random effects u_i ~ Gaussian                   Wald chi2(1)       =      6.41
corr(u_i, X)       = 0 (assumed)                Prob > chi2        =    0.0113

------------------------------------------------------------------------------
  sdiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    Comp |   1.501901   .5929902     2.533   0.011       .3396611     2.66414
   _cons |  -10.49169   13.36333    -0.785   0.432      -36.68333    15.69995
---------+--------------------------------------------------------------------
 sigma_u |  10.072352
 sigma_e |  26.960429
     rho |  .12248001   (fraction of variance due to u_i)
------------------------------------------------------------------------------
```

*denotes significance based on $p \leq 0.05$

However, if we do a Breusch and Pagan Lagrange multiplier test for random effects we find that there is no evidence against the random cluster effects being equal to 0.

```
Breusch and Pagan Lagrangian multiplier test for random effects:

       sdiff6[school,t] = Xb + u[school] + e[school,t]
       Estimated results:
                                 Var     sd = sqrt(Var)
                ---------+-----------------------------
                  sdiff6 |   854.5264       29.23228
                       e |   726.8647       26.960429
                       u |   101.4523       10.072352

        Test:   Var(u) = 0
                              chi2(1) =      0.83
                            Prob>chi2 =      0.3631
```

As such the final model without adjustment for cluster effects is the preferred final model:

```
Source |       SS       df       MS                  Number of obs =      54
---------+------------------------------               F(  1,    52) =    6.10
   Model |  4757.3696     1  4757.3696               Prob > F      =  0.0168
Residual | 40532.5309    52  779.471748              R-squared     =  0.1050
---------+------------------------------               Adj R-squared =  0.0878
   Total | 45289.9005    53  854.526424              Root MSE      =  27.919

------------------------------------------------------------------------------
  sdiff6 |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    Comp |   1.518717   .6147428      2.470   0.017*       .2851448    2.752288
   _cons |    -10.622   13.0862      -0.812   0.421       -36.88138    15.63738
------------------------------------------------------------------------------
```

*denotes significance based on $p \leq 0.05$

The assumptions of linear regression (ie. residual plots for normality and constant variance) have been examined for this model graphically.

DYNAMIC BALANCE

$$\mathbf{Y_{ijl} = \beta_0 + \beta_1 Comp_{jl} + V_j + e_{jl}}$$

$\mathbf{Y_{jl}}$ denotes dynamic balance difference between baseline and 6 weeks for the lth student, $l = 1,\ldots,m_{ij}$ from the jth cluster, $j = 1,\ldots..,k_i$ of the intervention group
$\mathbf{Comp_{jl}}$ (compliance based on # reported training sessions over 6 week training period)
$\mathbf{V_{ij}}$ denotes random cluster effects or cluster specific error which differs between schools and is constant within schools, it is assumed to be normally distributed with mean 0 and variance σ_A^2 (between cluster component of variance), i.e. $V_{ij} \approx N(0,\sigma_A^2)$
$\mathbf{e_{ijl}}$ denotes the usual residual which is assumed to be normally distributed with mean 0 and variance σ_w^2 (within cluster component of variance), i.e. $e_{ijl} \approx N(0,\sigma_w^2)$

```
Random-effects GLS regression                    Number of obs      =        60
Group variable (i) : school                      Number of groups   =         5

R-sq:  within  = 0.0001                          Obs per group: min =        12
       between = 0.0681                                         avg =      12.0
       overall = 0.0001                                         max =        12

Random effects u_i ~ Gaussian                    Wald chi2(1)       =      0.00
corr(u_i, X)       = 0 (assumed)                 Prob > chi2        =    0.9769

------------------------------------------------------------------------------
  ddiff6 |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    Comp |  -.0026162   .0902953    -0.029   0.977      -.1795918    .1743595
   _cons |   3.531934   2.197422     1.607   0.108       -.774933    7.838802
---------+--------------------------------------------------------------------
 sigma_u |    1.96362
 sigma_e |  4.6983457
     rho |  .14869902   (fraction of variance due to u_i)
------------------------------------------------------------------
```

However, if we do a Breusch and Pagan Lagrange multiplier test for random effects we find that there is no evidence against the random cluster effects being equal to 0.

```
Breusch and Pagan Lagrangian multiplier test for random effects:

        ddiff6[school,t] = Xb + u[school] + e[school,t]

        Estimated results:
                                Var     sd = sqrt(Var)
                ---------+-----------------------------
                  ddiff6 |   23.93494       4.892334
                       e |   22.07445      4.6983457
                       u |   3.855804      1.96362

        Test:   Var(u) = 0
                                 chi2(1) =     2.05
                               Prob>chi2 =     0.1523
```

As such the final model without adjustment for cluster effects is the preferred final model:

```
Source |       SS       df       MS                  Number of obs =      60
---------+------------------------------                F(  1,    58) =    0.00
   Model |  .083114022      1  .083114022               Prob > F      =  0.9536
Residual |  1412.07816     58  24.3461751               R-squared     =  0.0001
---------+------------------------------                Adj R-squared = -0.0172
   Total |  1412.16127     59  23.9349368               Root MSE      =  4.9342

------------------------------------------------------------------------------
  ddiff6 |      Coef.   Std. Err.       t     P>|t|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    Comp |   .0055288   .0946264      0.058   0.954      -.1838864    .1949441
   _cons |    3.35831    2.11531      1.588   0.118      -.8759426    7.592563
------------------------------------------------------------------------------
```

V. Cluster-adjusted chi-square analysis to compare injury rates in training and control group (Donner & Klar pp 84-90)[148]

Previous Injury by school:

TRAINING

1. 7/12 = 0.583 (0.277-0.848)
2. 4/12=0.333(0.099-0.651)
3. 4/12=0.333(0.099-0.651)
4. 5/12=0.417(0.152-0.723)
5. 4/12=0.333(0.099-0.651)

Pi = 24/60=.4(0.276 - 0 .535)

CONTROL

6. 6/12=0.5(0.211-0.789)
7. 3/12=0.25(0.055-0.572)
8. 5/12=0.417(0.152-0.723)
9. 2/12 =0.167(0.021-0.484)
10. 3/12=0.25 (0.055-0.572)

Pi = 19/60=0.317(0.203 - 0 .4496)

Intracluster correlation coefficient (ρ) (based on previous one year history of injury)

ρ = MSC - MSW/MSC + (m_0-1)MSW

MSC= ${}_{i=1}{}^{2}\Sigma_{j=1}{}^{ki}\Sigma m_{ij}(Pi_j - Pi)^2/(K-2)$

MSC = $[12(0.583-0.4)^2 + 12(0.333-0.4)^2 + 12(0.333-0.4)^2 + 12(0.417-0.4)^2 + 12(0.333-0.4)^2 + 12(0.5-0.317)^2 + 12(0.25-0.317)^2 + 12(0.417-0.317)^2 + 12(0.167-0.317)^2 + 12(0.25-0.317)^2]/10-2$

=0.401868 + 0.053868 + 0.053868 + 0.003468 + 0.053868 + 0.401868 + 0.053868 + 0.12 + 0.27 + 0.053868

= 1.466544/8

MSC=0.1833

MSW = ${}_{i=1}{}^{2}\Sigma_{j=1}{}^{ki}\Sigma m_{ij}Pi_j\ (1- Pij)/\ (M-K)$

MSW = [12(0.583)(1-0.583) + 12(0.333)(1-0.333) + 12(0.333)(1-0.333) + 12(0.417)(1-0.417)+ 12(0.333)(1-0.333) + 12(0.5)(1-0.5) + 12(0.25)(1-0.25) + 12(0.417)(1-0.417) + 12(0.167)(1-0.167) + 12(0.25)(1-0.25)/120-10

= 2.917332 + 2.665332 + 2.665332 + 2.917332 + 2.665332 + 3 + 2.25 + 2.917332 + 1.669332 + 2.25/110

= 25.917324/110

MSW=0.2356

$m_0 = [M - {}_{i=1}{}^{2}\Sigma m_{Ai}\,]/(K-2)$

= [120-(12+12)]/8

=12

Where $m_{Ai} = {}_{j=1}{}^{ki}\Sigma m^2_{ij}/M_i$ =720/60=12

where M = total number of subjects in the study
i = intervention group
M_i = total number of subjects in group i
j = cluster
m = cluster size
$m_{Ai} = {}_{j=1}{}^{ki}\sum m^{2}{}_{ij} / M_i$
K= total # clusters
Pi_j = cluster specific event rate
Pi = event rate as computed over all clusters in group i
$\rho = MSC - MSW/MSC + (m_0-1)MSW$
$\rho=0.1833-0.2356/0.1833+(11)0.2356$
$= - 0.0523/2.7749$
$\rho= - 0.0188$

Negative values of are usually taken to indicate sampling error, and thus set equal to zero. As a result the design effect is also equal to 1 (ie. cluster randomization does not affect the outcome related to comparison of injury rates.)
To calculate the design effect
$C_i =1 + (\text{mean } [m_i] - 1)\rho$
$C_i = 1 + (12-1)(0)$
$= 1$
This estimated design effect indicates that the variance of the observed event rates in each group have not changed as a result of the clustering of responses within schools.

VI. Logistic regression analysis examining effectiveness of the training program in injury prevention

Model

$$\ln(P/[1-P]) = \beta_0 + \beta_1 X + \beta_2 Previnj + \beta 3 Age + \beta 4 Gender + \beta 5 Sport + \beta 6 BMI + \beta 7 Jump + \beta 8 VO_2Max + \beta 9 smx + \beta 10 dmx + e$$

P denotes event rate
X = 1 (intervention), 0 (control)
Previnj =1 (if previous injury in one year), 0 (no previous injury)
Age (years)
Gender (0 if male, 1 if female)
Sport (hours/week based on previous 6 weeks)
BMI (kg/m^2)
Jump (vertical jump test maximum in cm)
VO$_2$Max (ml/kg/min predicted based on shuttle run test)
Smx (static maximum balance at baseline)
Dmx (dynamic maximum balance at baseline)
e denotes the residuals which have a mean of 0 and variance of approximately 1

```
Logit estimates                                   Number of obs   =        119
                                                  LR chi2(9)      =      20.69
                                                  Prob > chi2     =     0.0141
Log likelihood = -28.556757                       Pseudo R2       =     0.2660

------------------------------------------------------------------------------
   injury | Odds Ratio   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    group |   .1690242      .14637    -2.053   0.040*       .0309623   .9227086
  previnj |    4.33103    3.222006     1.970   0.049*       1.007749   18.61359
      age |   2.131194    .9272169     1.739   0.082       .9084301   4.999822
   gender |   4.568864    4.286758     1.619   0.105       .7263812    28.7377
 sport6we |   .9899152    .0560616    -0.179   0.858       .8859152   1.106124
 jump     |   .8700066    .0564948    -2.144   0.032*       .7660353   .9880894
   vo2max |   1.025108    .0759038     0.335   0.738       .8866308   1.185214
      smx |   .9991554    .0092354    -0.091   0.927       .9812174   1.017421
      dmx |   1.038668    .1081787     0.364   0.716        .846882   1.273886
```

*denotes significance based on $p \leq 0.05$

Final Model (coefficients)

```
logit injury group previnj

Logit estimates                                   Number of obs   =        120
                                                  LR chi2(2)      =      10.25
                                                  Prob > chi2     =     0.0059
Log likelihood = -33.884631                       Pseudo R2       =     0.1314

------------------------------------------------------------------------------
   injury | Coefficient   Std. Err.       z      P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
    group |   -1.926287   .8150099    -2.364   0.018*       -3.523677   -.3288969
  previnj |   1.254605    .6479939    1.936    0.053        -.0154393   2.52465
    _cons     -2.122786   .4828546    -4.396   0.000        -3.069164   -1.176409
```

Final Model (odds ratios)

```
logistic injury group previnj

Logit estimates                                   Number of obs   =        120
                                                  LR chi2(2)      =      10.25
                                                  Prob > chi2     =     0.0059
Log likelihood = -33.884631                       Pseudo R2       =     0.1314

------------------------------------------------------------------------------
  injury | Odds Ratio   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |   .1456881    .1187373    -2.364   0.018*       .0294908    .7197172
 previnj |   3.506455    2.272161     1.936   0.053        .9846793    12.48653
```

*denotes significance based on $p \leq 0.05$

Previous injury remains in the model as sample size and proportions are small and tests of significance are approximations based on a standard normal distribution.

It should be noted that attempting to fit a model that accounts for cluster randomization and potential similarities within clusters, gives virtually identical results.

```
Fitting full model:

rho =  0.0      log likelihood = -33.884631
rho =  0.1      log likelihood = -34.067167
Iteration 0:    log likelihood = -33.884632

Random-effects logit                            Number of obs      =       120
Group variable (i) : school                     Number of groups   =        10

Random effects u_i ~ Gaussian                   Obs per group: min =        12
                                                               avg =      12.0
                                                               max =        12

                                                Wald chi2(2)       =      8.19
Log likelihood  = -33.884632                    Prob > chi2        =    0.0166

------------------------------------------------------------------------------
  injury |      Coef.   Std. Err.       z     P>|z|       [95% Conf. Interval]
---------+--------------------------------------------------------------------
   group |  -1.926287    .8150183    -2.363   0.018*     -3.523693   -.3288804
 previnj |   1.254605    .6479955     1.936   0.053      -.0154424    2.524653
   _cons |  -2.122786    .4828554    -4.396   0.000      -3.069165   -1.176407
---------+--------------------------------------------------------------------
/lnsig2u |        -14    893.4012    -0.016   0.987      -1765.034    1737.034
---------+--------------------------------------------------------------------
 sigma_u |   .0009119    .4073382                               0           .
     rho |   8.32e-07    .0007429                               0           .
------------------------------------------------------------------------------
Likelihood ratio test of rho=0:      chi2(1) =     0.00   Prob > chi2 = 0.9987
```

*denotes significance based on $p \leq 0.05$

Based on the likelihood ratio test there is no evidence against rho = 0, indicating the between cluster variance is also unimportant (i.e., sigma_u = 0)

Group coefficient -1.926287 translates to an odds ratio of $e^{-1.926287} = 0.1456881$ as found in standard logistic regression model above.

Previous Injury coefficient 1.254605 translates to an odds ratio of $e^{1.254605} = 3.506453$