Technical models for change of direction: biomechanical principles

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OVERVIEW

It is commonly reported that team sports utilise multi-directional running patterns containing frequent and varied changes of direction (COD).[7,19,27] In order to ensure optimum performance and effective task completion, it is important that strength and conditioning (S&C) coaches understand the key technical parameters associated with the type of COD being executed. Traditionally, the technical model for the execution of an exercise or a movement has been described in detail with step-by-step descriptions of the body's movements and positions during different phases.[8] However, during sports performance, the types of COD performed are task-, environment- and individually-dependent.[4] For example, invasion sports such as football and hockey may contain frequent 180° changes of direction to transition from one end of the pitch to the other (task) in reaction to a change in possession (environment). The specific movement executed will be influenced by these factors, as well as the individual's capabilities, such as strength levels, range of motion, and anthropometrics.[4]

Manoeuvrability and COD ability

Multi-directional performance during sporting tasks has recently been sub-categorised into different skills, including manoeuvrability and COD ability.[23] Manoeuvrability is described as the ability to manoeuvre around obstacles and maintain speed as proficiently as possible;[23] COD ability is described as the ability to effectively change speed and direction.[23] Recent research exploring kinetic and kinematic factors associated with COD execution has described three key step/stance phases: a deceleration step (penultimate foot contact); a plant step (foot contact to re-direct the athlete's centre of mass [COM]); and a propulsion step (re-acceleration).[23] These key steps are incorporated within initiation movements, which include a plyo step (Figure 2 [1a-1d]), a crossover step (Figure 2 [2a – 2d]) a drop step (Figure 2 [3a – 3d]) and a cutting manoeuvre (Figure 2 [4a – 4d]).[15] All of these steps can be seen in Figure 2 on page 19. The main aim of initiation movements is either to decelerate and reaccelerate in a new direction or to begin accelerating in any direction from a static starting position (planned or reactive). Therefore, optimal execution of the propulsion step requires a clear understanding of acceleration technique.[15]

Moreover, due to task and environmental factors, these initiation movement patterns may be completed with a certain level of variation.[15] For example, changes in environment from pre-planned to reactive will likely impact the movement seen when adjusting the base of support (BOS) and lowering the COM (Figure 1). An initiation movement may also be utilised where the task is not to accelerate maximally into

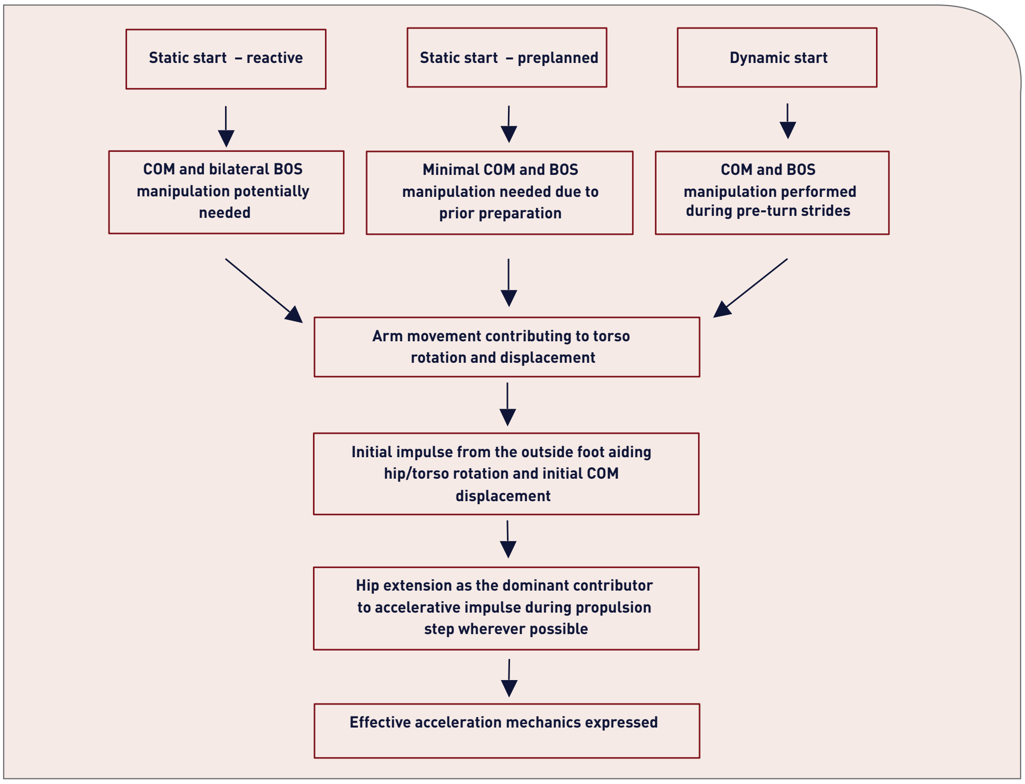

Figure 1. A flow chart showing the stages of biomechanical principle application with different starting conditions

a new direction: for example, an athlete may perform a crossover step but need to continue to scan the field in their initial facing direction, meaning the propulsion step may not represent optimal acceleration mechanics. In this scenario, optimal positioning is sacrificed for perceptual information which may have a greater impact on the situational outcome.

Where a task affords the use of more than one initiation movement, the technique will depend on the athlete's own physical capabilities and the environment.[4] Some scenarios will result in a greater variety of movements than others: for example, a drop step is likely to occur in static, or back pedalling starts when the athlete needs to turn greater than 90°. In contrast, the movement utilised to cut 90° will show a much greater variation due to the complexity of the scenario facing the athlete (movement velocities, BOS and COM positioning etc). These factors create increased complexity and uncertainty of the optimal movement and thus technical models are required for successful completion. Furthermore, when a sudden angular change is not required in order to evade an opponent, a curved run may be utilised if the individual finds it faster from point to point.[25] Nevertheless, when discussing COD tasks that require a sudden COD for success, there are common biomechanical principles that underpin their effectiveness, regardless of which technique is utilised.

An understanding of these principles may improve clarity for the S&C coach, help with error correction in coaching and allow for a broader understanding of effective movement.

Key biomechanical principles

It is important to remember that COD skills occur within a larger context during sports performance, where they are likely followed by a maximal acceleration and often preceded by a deceleration. Therefore, in combination with the technical principles below, coaches should appreciate execution of efficient acceleration and deceleration mechanics. Some of these mechanics still apply to the COD skills, such as an optimal balance between stiffness (for force application in acceleration), compliance (for force dissipation in deceleration), pre-activation and effective angle of force application via COM positioning.[12] However, it should be noted that compared to jumping, the task demands of sprinting require an asymmetrical arm/leg movement where the contralateral arm and leg are involved with the anterior and posterior leg action.

When considering the technical model of COD initiation movements, the principles which follow (on page 20) should be applied as they provide effective foundations to optimise movement execution in all planes of motion and contexts.

Figure 2. COD movements performed from a reactive (1 Plyo step, 2 Crossover step, 3 Drop step) or dynamic start (4 Cutting manoeuvre). a) Athletic position or penultimate step b) BOS and COM manipulation c) Plant step d) Propulsion step

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OPTIMAL COM HEIGHT AND BOS POSITIONING

a) COM should be lowered and moved to optimise force application during propulsion via positive shin angles (where the shin is leaning towards the desired direction of travel), force length relationships and sufficient time to produce force upon ground contact.[24,26] The COM should move towards the desired direction of travel and avoid any motion into the negative direction.[11]

b) BOS should be manipulated to ensure effective application of force outside of the COM and propulsion into the desired direction of travel.[6,17] This repositioning process occurs somewhat differently during different starting conditions (Figure 1). For example, a static reactive start where the athlete is not currently in an optimal position requires concurrent BOS and COM manipulation via an unweighted period.[6] Conversely, in a static start that is pre-planned, the athlete is likely to have already achieved an effective BOS and COM position. Finally, where an athlete is on the move, the BOS and COM manipulation should take place in the steps prior to the plant phase.[16]

ARM AND INSIDE LEG MOVEMENT CONTRIBUTING TO ROTATION AND DISPLACEMENT

a) Initial upper body movements should contribute to rotation and positive displacement of the COM with the shoulders and head turning to face the new direction. The arms should work asymmetrically (inside shoulder extension and outside shoulder flexion) and contralaterally with the lower body, in order to support the momentum of shoulder rotation; they should be kept close to the body to reduce rotational inertia.[12] The lead leg should also flex and externally rotate in order to contribute to rotational momentum and prepare for an effective propulsion step.[14] Where a maximal acceleration is not to be performed due to visual scanning demands, or the requirement for another immediate COD, this initial head and shoulder movement may not be prioritised and the athlete may lead the movement with the rotation of their hips.

INITIAL IMPULSE FROM THE OUTSIDE FOOT AIDING ROTATION AND COM DISPLACEMENT

a) Initial ground contact and impulse should occur with the outside (cross-over or drop-step) or rear foot (plyo step) in a position that enables a positive shin angle in relation to the intended direction of travel.[6,17] This plant step provides an impulse to create both angular momentum of the hips and maximal COM propulsion into the new direction.[16] This rotation/propulsion helps the athlete perform the following propulsion step with a positive shin angle and force contribution from hip extension rather than adduction.[1,21,22] Where a maximal acceleration is not required following the COD (due to visual scanning demands or a second immediate COD) and torso rotation is limited, the magnitude of hip rotation and subsequent hip extension force may be reduced, meaning less propulsive forces are able to occur during the following step.

HIP EXTENSION AS THE DOMINANT CONTRIBUTOR TO ACCELERATIVE IMPULSE DURING PROPULSION

a) In order to facilitate hip extension force application, the torso should be encouraged to rotate early.[18] This can further enable the hips to turn and the propulsion step to face the intended direction, resulting in the ability to rely on sagittal plane force production. These sagittal plane lower limb joint positions reduce ACL loading[5,21] and allow force application to be maximised. However, frontal plane moments may be unavoidable where perceptual scanning in the original direction remains, or where another COD is to be immediately performed, or when a high-speed cut is being used and time restrictions do not allow BOS manipulation or sufficient impulse from one plant step.

Change of direction technical models

PLYO STEP

The plyo step (sometimes called a false step) is usually performed when an athlete is in a static bilateral start: it consists of an athlete manipulating their BOS in order to provide propulsive impulse (augmented by the stretch shortening cycle) and a body position that encourages effective horizontal force application.[3,6] Without the plyo step, acceleration would only be capable once the athlete's COM has been rotated forwards by gravity (due to the need to be able to apply force horizontally), a process that would be time-consuming and sub-optimal compared to a more 'active' manipulation.[3,6] However, where an athlete is in a static pre-planned start with a split stance (aware that immediate acceleration may be required), the need for a plyo step is removed as the BOS is already in the position required to produce horizontal force (Figure 1). This would be similar when initiating a linear sprint from a back pedal, where the final step back provides deceleration and initial acceleration impulse.

CROSSOVER STEP

A crossover step is performed when an athlete needs to accelerate in a direction approximately 90° to where he or she is facing (Figure 3). This will either be from a reactive or pre-planned static start, a lateral shuffle, a backpedal, or from a linear sprint where a 90° turn has been performed during deceleration (similar to that during a 505 test).[16] If performed from a reactive static start, a manipulation of the BOS is required to ensure effective force application, with the initial impulse coming from the outside foot in a 'plyo step' fashion. During the BOS manipulation, a lowering of the athlete's COM should be enough to allow optimal force production and direction, but be limited enough that movement speed and force application is not impaired (via optimal shin angles and force length relationships at lower body muscle groups).[24,26] This outside foot contact acts as a plant phase, which encourages initial COM movement and hip rotation, aiding a positive shin angle and hip extension during the propulsion step. However, if performed from a lateral shuffle, or a linear sprint to a 90° deceleration, the adjustment in the athlete's BOS should occur during the steps preceding the plant step but with the same desired outcome.[16] If the initiation movement is being performed from a pre-planned static start, the athlete should not require a BOS manipulation, due to having the time and information to organize their BOS into an advantageous position.

Upon completion of the plant step, the hips and shoulders should face the intended direction of travel in order to ensure that hip extension can be utilised during the propulsion step and effective acceleration mechanics can be executed.[17,21] Due to the large directional change, it is possible that the hips and torso may not have fully rotated before the propulsion step has to be applied. Although it can be recommended that propulsive force applied from medial rotation and adduction may be sub optimal for impulse generation and joint loading, it is less of a concern during the crossover step due to the lower COM position producing greater sagittal plane moments and less external ACL loading.[5,21] It may also be common to see these lower body movements where no immediate maximal acceleration is performed, due to a second immediate COD, or tracking other players' movements. When this is the case, the movement will be performed with greater rotation of the hips compared to the torso, as rotation of the torso will impede perceptual information and reduce the athlete's ability to return to their initial movement direction if required.

DROP STEP

A drop step is characterised by a turn where the athlete needs to initiate movement into a new direction of greater than 90° to where they are facing (Figure 3). When this is performed from a static bilateral and reactive start, an unweighting period to adjust the BOS and move the COM towards the intended direction via rotation and sagittal plane displacement is necessary.[6] Initial rotation momentum of the torso/shoulders is important and facilitated by a flexion-abduction and an extension-adduction moment of the outside and inside shoulders respectively, both of which should be kept close to the midline of the body to assist speed of rotation.[13,20]

During the BOS and COM adjustment, the outside foot should make contact with the ground approximately perpendicular to the desired direction of travel. This plant phase acts as a 'plyo step' and again provides some initial impulse and COM displacement, while simultaneously encouraging hip rotation in the intended direction. During scenarios where the athlete may need to perform this movement from a static pre-planned start, the COM and BOS should be in an appropriate position prior to initiation, removing the need for an unweighted period. However, it is likely that a small adjustment in foot position and weight distribution may still occur. For example, where an athlete is facing in one direction and the subsequent movement will necessitate a turn of more than 90° to accelerate, they are likely to be positioned in a more advantageous stance, with their COM leaning posteriorly towards their potential direction. When the athlete reacts to a temporal stimulus they will initiate rotation with an arm swing and a plant step. During the plant step, the foot shifts to be more perpendicular to the desired acceleration path. During a dynamic starting position such as a backpedal or a lateral shuffle, effective COM and BOS manipulation should again occur during the steps and arm motions prior to movement initiation.[16] The step and arm movement prior should be utilised to

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encourage rotation of the torso and the hips in more of a 'hip turn' fashion.[20] During all of these scenarios, it is important that the plant step impulse and torque facilitates the propulsion foot contact (inside foot) to occur behind the COM and to be pointing close to the intended direction of travel.[13]

When the propulsion step makes contact with the ground, the hips should be square to the intended direction of travel to enable effective hip extension and effective acceleration mechanics to be executed.[17] However, if the directional change required during this movement is large (as stated with the crossover step), the hips and torso may not fully rotate before the propulsion step has to be applied. However, the concern associated with medial rotation and adduction force production is lesser during this movement due to greater joint flexion and lower COM positioning during the propulsion step contact.[9,21]

CUTTING

Cutting manoeuvres are also very common during a range of invasion sports. A cut is characterised by the desire to evade an opponent via adjusting a path of travel whilst continuing in an attacking direction (Figure 3). The method of executing a cut depends on the desired cutting angle, the athlete's movement velocity and their individual force characteristics. For example, when moving at high speeds the time available to produce force at ground contact is extremely limited. Subsequently, the capability for a large COD is hindered.[29] This high-speed cut is likely to occur when an environment allows more open space and a large distance between the attacker and the opposing player. In order for the cut to be executed, the individual must adjust their BOS during the running stride to allow for a plant step to be applied lateral to their COM with the outside foot. However, where time constraints do not allow BOS adjustments, an inside foot (crossover cut) may be utilised. Although the angle of directional change is small, torso rotation will still occur in order to facilitate the propulsion step to be performed with hip extension as the dominant method of force production.[21] It is possible that the torso does not always lead the rotation during competition as a delayed torso movement may make it easier to deceive a defender.[2] However, this technique should be reserved for higher performing athletes, due to the potential to create a greater level of hip abduction and increased ACL loading during the plant phase;[22] it can also negatively impact the propulsion step due to a reduced ability to apply force from hip extension.

When the environment requires a cut of a greater angle, deceleration is required in order to control running velocity. A reduction in running velocity involves an athlete lowering their COM (improved force length relationships at the lower limb) and allows for the use of a plant step with a longer ground contact time and thus greater impulse and COD. To perform this cut effectively, the athlete must use the strides prior to the plant step to modify their COM/BOS position and movement velocity (breaking forces with a negative shin angle). This may be completed in a single step or with multiple steps, depending on the athlete's strength capabilities[28] and the amount of directional change required.[10] When the plant step (ideally with the outside foot to optimise impulse application) has

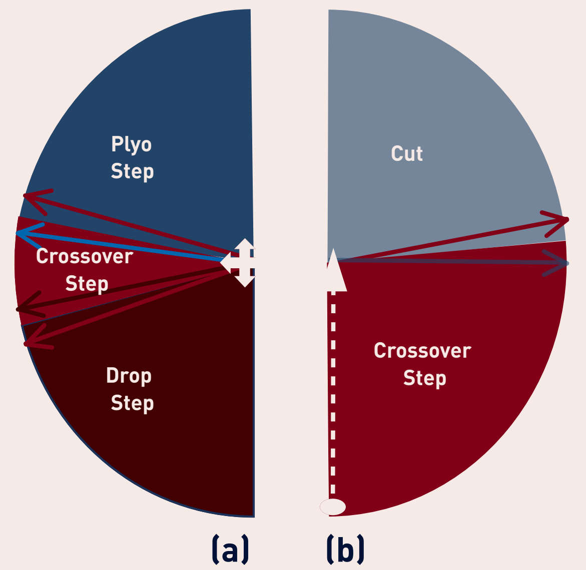

Figure 3.
a) Likely initiation movements expressed from a static or jockeying position while facing forwards (up).
b) Likely initiation movements expressed from a linear sprint forwards (up)

been executed the subsequent propulsion step should prioritise effective hip extension to create maximum ground reaction forces and acceleration in the new direction.[17] However, it is common during large angular cuts that once a cut has been executed, the athlete may subsequently re-adjust their running direction back into the original direction via another cutting manoeuvre. This may be due to the large angular change from the initial cut, potentially resulting in a sub-optimal direction of travel to gain ground in invasion-based sports. If this is the case, it is possible that the athlete may limit their hip/torso rotation in order to minimise the rotational moment velocity of the trunk, which could inhibit their ability to re-adjust back into the initial direction.

Practical applications

An understanding of the key principles that underpin COD movements means that a range of techniques and contexts can be understood and coached effectively, without the need for an extensive range of individual technical models. Understanding these key principles will also help coaches decipher between components of an athlete's technical execution that inhibit performance and components that may be attributed to the athlete's individual characteristics or performance context.

For author biographies and photos, please see the June issue

References

1. Boden, BP, Dean, GS, Feagin, JA, & Garrett, WE. Mechanisms of anterior cruciate ligament injury. *Orthopedics*, 23(6): 573-578. 2000.
2. Brault, S, Bideau, B, Craig, C, & Kulpa, R. Balancing deceit and disguise: how to successfully fool the defender in a 1 vs. 1 situation in rugby. *Hum Mov Sci*, 29(3): 412-425. 2010.
3. Cusick, JL, Lund, RJ, & Ficklin, TK. A comparison of three different start techniques on sprint speed in collegiate linebackers. *J Strength Cond Res*, 28(9): 2669-2672. 2014.
4. Davids, KW, Button, C, & Bennett, SJ. Dynamics of skill acquisition: A Constraints-led approach. Champaign: *Human Kinetics*. 2008
5. Fleming, BC, Renstrom, PA, Beynnon, BD, Engstrom, B, Peura, GD, Badger, GJ, & Johnson, RJ. The effect of weightbearing and external loading on anterior cruciate ligament strain. *J Biomech*, 34(2): 163-170. 2001.
6. Frost, DM, Cronin, JB, & Levin, G. Stepping backward can improve sprint performance over short distances. *J Strength Cond Res*, 22(3): 918-922. 2008.
7. Gabbett, TJ, & Mulvey, MJ. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J Strength Cond Res*, 22(2): 543-552. 2008.
8. Haff, G, & Triplett, NT (Eds.). Essentials of Strength Training and Conditioning: *Human Kinetics*. 2017.
9. Havens, KL, & Sigward, SM. Joint and segmental mechanics differ between cutting maneuvers in skilled athletes. *Gait Posture*, 41(1): 33-38. 2015a.
10. Havens, KL, & Sigward, SM. Whole body mechanics differ among running and cutting maneuvers in skilled athletes. *Gait Posture*, 42(3): 240-245. 2015b
11. Hewett, TE, Torg, JS, & Boden, BP. Video analysis of trunk and knee motion during non-contact anterior cruciate ligament injury in female athletes: lateral trunk and knee abduction motion are combined components of the injury mechanism. *Br J Sports Med*, 43(6): 417-422. 2009.
12. Hewit, J, Cronin, J, Button, C, & Hume, P. Understanding Deceleration in Sport. *Strength Cond J*, 33(1): 47-52. 2011.
13. Hewit, J, Cronin, J, & Hume, P. Understanding Change of Direction Performance: A Technical Analysis of a 180 Arial Catch and Turn Task. *Inter Sports Sci Coaching*, 7(3): 503-514. 2012.
14. Hewit, J, Vronin, JB, Hume, PA, & Button, C. Understanding Change of Direction Performance via the 90° turn and sprint test. *Strength Cond J*, 32(6): 82-88. 2010.
15. Jeffreys, I. Gamespeed: Movement Training for Superior Sports Performance: *Coaches Choice*. 2006.
16. Jindrich, DL, Besier, TF, & Lloyd, DG. A hypothesis for the function of braking forces during running turns. *J Biomech*, 39(9): 1611-1620. 2006.
17. Mann, R, & Herman, J. Kinematic Analysis of Olympic Sprint Performance: Men's 200 meters. *Intl J Sports Biomech*, 1(2): 151-162. 1985.
18. Marshall, BM, Franklyn-Miller, AD, King, EA, Moran, KA, Strike, SC, & Falvey, É. Biomechanical factors associated with time to complete a change of direction cutting maneuver. *J Strength Cond Res*, 28(10): 2845-2851. 2014.
19. Matthew, D, & Delextrat, A. Heart rate, blood lactate concentration, and time-motion analysis of female basketball players during competition. *J Sports Sci*, 27(8): 813-821. 2009.
20. McCormick, BT, Hannon, JC, Newton, M, Shultz, B, Detling, N, & Young, W, B. A Comparison of the Drop Step and Hip turn Techniques for Basetball Defense. *Int J Sports Sci Coaching*, 9(4): 605-613. 2014.
21. McLean, SG, Huang, X, Su, A, & Van Den Bogert, AJ. Sagittal plane biomechanics cannot injure the ACL during sidestep cutting. *Clin Biomech*, 19(8): 828-838. 2004.
22. McLean, SG, Huang, X, & van den Bogert, AJ. Association between lower extremity posture at contact and peak knee valgus moment during sidestepping: implications for ACL injury. *Clin Biomech*, 20(8): 863-870. 2005.
23. Nimphius, S. Increasing Agility. In D. Joyce & D. Lewington (Eds.), *High-Performance Training for Sports*. Human Kinetics. 2014. pp. 185-193
24. Rassier, DE, MacIntosh, R, & Herzog, W. Length dependence of active force production in skeletal muscle. *J Appl Physiol* (1985), 86(5): 1445-1457. 1999.
25. Rouissi, M, Chtara, M, Owen, A, Chaalali, A, Chaouachi, A, Gabbett, T, & Chamri, K. "Side-stepping maneuver": not the more efficient technique to change direction amounst young elite soccer players. *Int J Perf Analys Sport*, 15: 749-763. 2015.
26. Shimokochi, Y, Ide, D, Kokubu, M, & Nakaoji, T. Relationships among performance of lateral cutting maneuver from lateral sliding and hip extension and abduction motions, ground reaction force, and body center of mass height. *J Strength Cond Res*, 27(7): 1851-1860. 2013.
27. Spencer, M, Lawrence, S, Rechichi, C, Bishop, D, Dawson, B, & Goodman, C. Time-motion analysis of elite field hockey, with special reference to repeated-sprint activity. *J Sports Sci*, 22(9): 843-850. 2004.
28. Spiteri, T, Cochrane, JL, Hart, NH, Haff, GG, & Nimphius, S. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci*, 13(6): 646-652. 2013.
29. Xu, D, Carlton, LG, & Rosengren, K, S. Anticipatory postural adjustments for altering direction during walking. *J Mot Behav*, 36(3): 316-326. 2004.