Introduction

It has been over 15 years since we first heard that Lucozade Sport results in a 33% improvement in exercise capacity. Since this paper, there has been an explosion in the amount of products on the market, all designed with the intent of preventing hypoglycemia (low blood sugar) and providing additional CHO supply for energy production during exercise. This article will take a critical look at the classic and contemporary literature and try to answer the question, “Are sugary drinks still the key to prolonged performance”. The type of sugar will be addressed as well as the form (liquid, gel or solid) and the best rate of ingestion during a variety of sporting settings.

Background

Unlike the storage of fat, the body can only store a limited amount of carbohydrate. Classical studies have clearly demonstrated that the consumption of a high carbohydrate diet (8-10 g.kg⁻¹ body mass) is able to fully load muscle glycogen stores (approximately 100 mmol.kg⁻¹ wet weight, Figure 1), equating to approximately 300-400 g of muscle glycogen. Additionally, the body can store approximately 80-110 g of glycogen in the liver, giving a total glycogen storage capacity of only 400-500 g, enough to fuel approximately 60-90 minutes of high intensity exercise. The effects of commencing exercise with high glycogen stores on exercise performance and capacity are of course well documented. For example, classical studies from Bengt Saltin (Table 1), utilising biopsies from professional soccer players, demonstrated that some players started games with low muscle glycogen as a result of inadequate CHO intake in the days leading to the game and this had major detrimental effects on performance.

Carbohydrate Provision During Exercise

The limited capacity to store CHO presents a major problem for athletes. Exercising for approximately 60-90 minutes, (especially if
the exercise is intermittent high intensity exercise),
can deplete muscle glycogen stores resulting in
premature fatigue even if glycogen stores are full
prior to commencing exercise (Figure 2). In this
regard, it is therefore beneficial to provide exogenous
carbohydrates during exercise, so as to provide
additional substrate supply. Early studies during the
1924 and 1925 Boston marathons were, indeed, quick
to recognise that endurance performance was directly
related to blood glucose concentration, and more
importantly, these studies established that fatigue
could be delayed by simply providing exogenous CHO
during the race. Since these studies, there have been
numerous reports in the literature that exogenous
CHO can increase endurance capacity (time to
exhaustion) and decrease perceptions of effort (Figure 3).
The precise mechanisms underpinning enhanced performance with exogenous CHO provision
may be due to a combination of factors, including:
prevention of hypoglycaemia, maintenance of high
CHO oxidation rates, muscle glycogen sparing and
effects on the central nervous system (for a review
see Karelis et al.11)

How much CHO is required during exercise?
The amount of exogenous CHO given to an athlete
during exercise largely depends on the exogenous
oxidation rate of CHO. For many years, the general
advice has been to consume 30-60g of exogenous CHO
per hour and this figure is still recommended by many
sports nutritionists and cited in many leading
textbooks. The rationale for this figure is in accordance
with the fact that the maximum exogenous oxidation
rate of glucose is approximately 1g.min⁻¹, or 60g.hr⁻¹
(see Figure 4), although dietary surveys of elite
athletes have revealed that often endurance athletes
consume far in excess of 30-60 g.hr⁻¹. More recently,
researchers have become interested in whether the
maximal rates of exogenous CHO oxidation can be
augmented through co-ingesting different types of CHO
with the traditional intakes of glucose that is present in
most commercial sports drinks.

Source of CHO intake during exercise –
the emerging role of ‘multiple transporter’ carbohydrates.

Over the past 10 years, there has been a growing
interest in the maximum rate of exogenous CHO
oxidation during exercise, leading to serious questions
being raised about the often cited 1g.min⁻¹ maximum
CHO oxidation rate. To understand maximum CHO
oxidation rates, it is important to understand what limits this. Recently, this question has been addressed in an eloquent series of studies from Asker Jeukendrup’s lab in Birmingham, which reported that it is the intestinal absorption of CHO, which is the rate-limiting step (for a review see Jeukendrup). The most crucial observation from these studies was that, whilst the glucose oxidation rate is limited by a sodium-dependent glucose transporter (SGLT1), other sugars, such as fructose, are limited by another transport mechanism (GLUT5 in the case of fructose). This observation therefore, explains why some athletes are able to tolerate (and benefit from) consuming more than 60 g.hr⁻¹ of exogenous CHO when they consume a drink that contains various sources of carbohydrate (see Figure 5). Many sports drinks now take advantage of this by producing products containing “multiple transporter carbohydrates” and in doing so, exogenous CHO oxidation rates can increase from 1 to in excess of 1.5g.min⁻¹. Such feeding strategies are perhaps most appropriate for ultra-endurance events, given that saturation of gut glucose transporters would be unlikely in athletes competing in shorter events, especially if access to additional CHO is limited (e.g. team sports where fluid breaks are limited to unscheduled breaks in play and half-time). A new set of guidelines have now been proposed regarding CHO provision during exercise, based on data presented on multiple transporter carbohydrates; for a review see Burke et al. As opposed to the original rigid guidelines, the new recommendations are dictated by the duration and type of exercise.

Solid, liquid or gel?
There does not appear to be any difference in the exogenous oxidation rates between gels, bars or drinks, so the form of the CHO provision is largely dependent upon the athlete and their own personal preference. It may therefore, be prudent to provide access to all 3 energy sources during exercise, so as to cater for individual athlete preferences and thus promote CHO intake (Figure 6). Liquid provision of CHO has the advantage of preventing dehydration at the same time as providing energy, whereas gels are easier to carry and can be consumed much quicker. Many athletes during ultra endurance events can get a feeling of nausea if the CHO is purely provided in drinks and gels and therefore, some carbohydrate containing foods (such as cereal bars or even white bread sandwiches) are recommended in such situations (Figure 7).

Practical advice regarding CHO intake in relation to length of exercise

**Events 1 hr or less** – Such events are unlikely to deplete muscle glycogen and therefore the need to provide CHO may not be necessary. However, it is very important for the S&C professional to consider what is the true duration of the exercise in question. For
example, a rugby game involves 2 x 40 minute periods of exercise, however, once a 30-minute warm up has been accounted for, plus 5 minutes per half of stoppage time, what could be classed as 80 minutes of exercise would be more like 120 minutes.

Despite the fact that CHO availability may not be limiting in events < 60 minutes, Carter et al., demonstrated that CHO infusion did not improve performance in short duration events but CHO ingestion did. This led to a fascinating hypothesis that, in such situations, CHO provision could be working through non-metabolic pathways, likely involving the CNS via receptors in the mouth and oral space modifying motor output. Studies have since reported that mouth rinsing with CHO beverages can improve performance during exercise lasting less than 1 hour. This has led to some athletes using CHO mouth washes during short duration exercise. However, it should be stressed that the performance enhancing effects of mouth rinsing are only apparent when the exercise is stressed that the performance enhancing effects of mouth rinsing are only apparent when the exercise is

Table 2. Recommended carbohydrate intake during a race and suggested type of carbohydrate for mountain bike riders.

<table>
<thead>
<tr>
<th>Race Length</th>
<th>Recommended Carbohydrate Intake</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short (less than 1hr)</td>
<td>0-30g/hr or even mouth wash</td>
<td>High GI (glucose or maltodextrin)</td>
</tr>
<tr>
<td>Medium (1-2 hrs)</td>
<td>60g/hr</td>
<td>High GI (glucose or maltodextrin) (1-2 x 500ml bottles of lucozade sport) or appropriate gels/food</td>
</tr>
<tr>
<td>Very Long (2+ hrs)</td>
<td>90g/hr</td>
<td>Combination of glucose and fructose (2:1 ratio), 60g glucose, 30g fructose</td>
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Events lasting 1-2 hours – In medium duration events, there is unquestionable evidence that exogenous CHO provision can delay fatigue. Provision of 60 g per hour in the form of glucose or maltodextrin is recommended. The form of the CHO is largely dependent upon personal preference and mode of exercise. For example, runners may prefer to ingest this in the form of drinks where as cyclists often utilise CHO gels and snack based foods.

Events lasting over 2 hours – During long duration events athletes may benefit from consuming 90 g.hr⁻¹ and therefore this must be composed of multiple transporter CHO. Studies have shown that a glucose/fructose combination in a 2:1 ratio (60g glucose with 30g fructose) improves performance more than the ingestion of glucose alone. Many products are now available in drinks, bars or gels, and it has been documented that such products are well tolerated by athletes.

Conclusion

Although the provision of exogenous CHO during exercise to delay fatigue has been practiced for almost a century, recent advances in our understanding of CHO oxidation rates has provided exciting and fresh ideas. It could be stated that “sugary drinks” are still the key to enhancing athletic performance, although careful consideration to the design of the drink is clearly warranted. Furthermore, in some situations we may not even have to swallow the drink to achieve the performance benefit!

References

Lower Limb Asymmetry and Musculo-Skeletal Loading

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Introduction

The symmetrical structure of the human body is designed for efficient load distribution during functional activity. Anatomic asymmetry alters the distribution and magnitude of mechanical stress within the body, and skeletal imbalance influences the congruity of associated joints. Execution of sporting movement relies upon maintenance of balance and posture during anti-gravitational activity. Motor control is subject to lateral bias and conditioning that reinforces bias increases exposure to asymmetric stress. A combination of high training volume and mal alignment is indicated as an anatomic risk factor for overuse injury.

Nature of the Problem

Asymmetric musculo-skeletal development is attributed to the influence of genetic inheritance, limb dominance and environmental stimuli. For the athlete, individuality of physical development is inextricably tied to the development of technical ability in conjunction with exposure to the demands of the training and performance environment. Lower limb muscle imbalance can be addressed with specific rehabilitation and strength and conditioning sessions, however osseous asymmetry of the lower limb may present a complicating factor. Quantification of the contribution of asymmetric intrinsic and extrinsic factors to a dose response relationship within musculo-skeletal loading is problematic. Longitudinal studies relating the length of the femur and tibia to skeletal age have produced data which validates norm values, for growth of the lower limb. However norm values do not allude to the epidemiology of asymmetric development and aetiological research has not focused on lower limb asymmetry during ontogeny in the absence of identifiable pathology. Current research examining the causality of functional asymmetry conceives that pre-existing anatomic asymmetry may influence unilateral lower limb sports performance (see Figure 1).

![Figure 1. Theoretical model of factors associated with functional asymmetry in soccer (Fousekis et al 2010).]

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Conversely, research that correlates athletes from lateral dominant sports with skeletal asymmetry suggests that asymmetric lower body postures may influence the prevalence and magnitude of asymmetric anatomy. Therefore, where asymmetry is present the success of individually prescribed training intervention relies upon accurate identification and consideration of the relationship between musculo-skeletal loading and individual anatomy.

The strength and conditioning training environment is structured to facilitate optimal musculo-skeletal adaptation, however technical practice that subjects the athlete to prolonged exposure to asymmetric stress can effect chronic adaptation. The Functional Movement Screen has been developed to identify movement inefficiency requiring clinical or coach intervention. For the lower limb bilateral functional mobility and stability of the hips, knees and ankles is assessed by the ‘Hurdle Step’ (see Figure 2). Following assessment, accurate identification of the aetiology of functional asymmetry is key to appropriate management of lower limb inequality.

Movement efficiency may be compromised by leg length inequality (LLI) however LLI may manifest through structural or functional inequality. Detrimental biomechanical implications have been documented for the lumbar spine, and the hip, knee, and the foot. Leg length inequality (LLI) however LLI may manifest through structural or functional inequality. Detrimental biomechanical implications have been documented for the lumbar spine, and the hip, knee, and the foot. Anatomical short leg consists of an actual difference in length of the bony components of the lower limb. This may be compensated for by a functional adaptation at the ankle, knee, or hip.

Environmental LLI is a condition which afflicts road runners where inequality is attributed to the effect of running on a camber.

Incidence

Early research estimated that LLI occurred in between 4% and 8% of the general population but more recent investigation has found that LLI is a normal variant. Knutson’s review found that the prevalence of anatomic inequality was 90%; the left leg was anatomically longer more often; and that the mean magnitude of anatomic inequality was 5.2mm. Reports of LLI of up to 10mm are not uncommon; however there is not a stable relationship between magnitude of inequality and clinical significance. Rush and Steiner’s study of RAF servicemen, found that differences of 11mm or more were clinically significant whereas Knutson found that for most people, anatomic LLI did not become clinically significant until the magnitude reached approx 20mm. Association with musculo-skeletal dysfunction of the spine or lower extremity has however been found with a significantly lower, (5mm or less) LLI.

Leg Length Inequality

There are three types of LLI and accurate identification is distinguished by observation of anatomical characteristics rather than symptoms.  

1 Anatomical short leg

Anatomical short leg consists of an actual difference in length of the bony components of the lower limb. This may be compensated for by a functional adaptation at the ankle, knee, or hip.  

2 Functional short leg

Functional short leg is not a difference in bone length but an inequality that occurs secondary to a rotated pelvis and is accompanied by associated postural characteristics.

3 Environmental LLI

Environmental LLI is a condition which afflicts road runners where inequality is attributed to the effect of running on a camber.

Assessment

Leg length inequality may be detected within the pre-habilitation screening process or during an assessment of injury. Detection and accurate measurement of unequal leg length has been subject to a number of clinical procedures. The instrument most commonly used for anthropometric measurements is the tape. Anatomical landmarks act as points of reference and leg length is recorded as the distance between anterior superior iliac spine and the tip of the medial malleolus. This method attempts to identify anatomical short leg by requiring the athlete to lay supine on a couch during measurement. On the couch the influence of weight bearing on postural characteristics is removed therefore reliability of measurement is enhanced.

Leg length measurements taken in standing athletes measure the distance from superior anterior iliac spine to the floor. This method is unable to measure the discrepancy between the bones of the lower limb but can reveal LLI that presents as a postural manifestation. Asymmetry due to functional short leg may also be identified during assessment that utilises closed kinetic chain exercise or a functional movement screen. Additionally the Strength and Conditioning Coach may become aware of related postural deficiencies when coaching movement. During assessment the reliability of normal standing posture may be compromised by unequal weight distribution through the feet due to pain, therefore injury status must be verified.  

Assessment of LLI in lying and standing both depend upon accurate location of superficial bony points and can therefore be prone to inter trial and inter examiner variability. Muscular development or obesity can hinder accurate identification of bony prominences, whilst the effect of inequalities of calcification on one side of the body due to injury cannot be quantified. Inability to palpate the heads of the femur necessitates the use of the anatomy of the pelvis as the proximal
marker. Whilst inclusion of iliac crest palpation as a selection factor may improve the possibility of discrepancy detection, ironically this method relies upon presupposition of symmetry of the iliac. Examination of the anatomy of the pelvis has found that iliac asymmetries are highly common (see Figure 3). Attempts to improve the accuracy of tape measurement led to the design of a pelvic levelling device. This was intended to remove the influence of posture on pelvic tilt, however radiological comparison found that this method was also limited by the difficulty in locating anatomical points through subcutaneous tissue. Presupposition of symmetry of the iliac remains a barrier to reliability and accurate measurement can also be threatened by an incorrect attempt to level asymmetric anatomy. Even if the pelvis is symmetric and anatomical landmarks are accurately identified, error can still be caused by the path of the tape through bowing, due to inequalities in muscle girth.

Re-measurement studies have challenged the reliability of measurement with the anthropometric tape, identifying measurement error of + or - 10mm. However orthopaedic examinations continue to use the tape because of its simplicity, and research has confirmed that where the examiner is trained and the athlete is asymptomatic the tape method is reliable.

Environmental LLI is less prevalent and may not be identifiable through assessment with the tape.
asymmetric stress causes musculo-skeletal dysfunction and postural adaptation leads to LLI as a secondary condition.

Research using electromyography has demonstrated a significant increase in the activity of several muscle groups where LLI was less than 10mm, making it impossible to maintain a complete resting position. Whilst analysis demonstrates a possible association between relatively small LLI and asymmetric paraspinal muscle activities, research examining the aetiology of backache presented with common clinical symptoms suggests that for the general population LLI is not a significant causal factor.

### Biomechanical Implications of Asymmetry for the Sports Performer

Asymmetry of motion segments and muscles create imperfect torsions which manifest as scoliosis deformities. A higher incidence of functional scoliosis has been reported for athletes, the development of which is thought to be secondary to increased unilateral torque forces. Biomechanical assessment of a group of footballers found that in 16 subjects who exhibited a marked scoliosis, 12 of them kicked only or a group of footballers found that in 16 subjects who exhibited a marked scoliosis, 12 of them kicked only or mainly with one foot. Research has found that in swimmers there are adaptive changes in muscles to meet specific repetitive functional demands.

Biomechanical implications compel further study, for research has shown that in functional scoliosis that compensates for LLI, side bending compresses the concave side of the disc and coupled with axial rotation this presents a load that is known to be damaging to the disc. Giles found a significant difference between lumbosacral facetal joint angles (mean=7.1) on the long leg side and the short leg side in patients with a LLI. Friberg’s research suggests that asymmetric stress is likely and this may be a cause of chronic low back pain, which could cause further degenerative changes in the spine.

Scoliosis begins to form between the ages of 7 and 10. As LLIs are common in the general population and subtle scoliosis is frequently associated, identification may only be significant for individuals who are subject to high levels of asymmetric stress at an early age.

Research suggests that an examination of musculo-skeletal symmetry of the spine for athletes that are subject to asymmetric stress but do not present a LLI, could identify the existence of a causal relationship between asymmetric stress, lower back pain and functional LLI.

As a functional LLI is established the existence of pain and fatigue is attributed to functional attempts to level the pelvis. Research examining the precise mechanics of functional adaptation offers varying explanations. Gurney et al. suggest that quadriceps activity increases in an attempt to reduce disparity by maintenance of slight flexion during the stance phase, whilst Gofton states that the presence of abductor stress with osteo-arthritis of the hip suggests a causal relationship with LLI due to the increased force exerted by the abductors when weight is borne on the longer leg. Abnormal gait through LLI subjects the hip joint of the longer leg to abnormal adduction stress resulting in osteo-arthritis of the hip joint and leads to a significant increase of arthritis of the knee on the long side which is attributed to over stressing by the hip on the short side. LLI has also been linked to the outcome and location of stress fracture. Where the performance athlete is subject to intense exposure to high levels of mechanical stress successful management requires management and/or correction of asymmetric stress that causes anatomic deviation from normal symmetry.

### Intervention

Surgical intervention for anatomic short leg during growth is problematic. The efficacy of surgical lengthening is reduced by an inability to accurately predict the resultant rate of growth of the epiphyseal plate, whilst the accuracy of epiphysedosis is undermined by the ability to ensure cessation of growth prior to permanent fusion. Successful treatment of anatomic short leg relies upon the use of a lift under the foot of the short leg to improve disparity and relieve pain.

Pre and post natal studies suggest that lateralisation, preference for use of one foot or leg, results from a combination of asymmetric brain development and preferential repetition. Although neuromuscular plasticity remains, children enter movement education with structural asymmetries and differential competence in lateral fundamental motor skills having already developed competence in lateralised preferences, (the choice for one side of the body to learn or perform motor skills).

Examination of young athletes lower muscle morphology has demonstrated significant differences compared to non-athletes. Young athletes exhibit larger mean values for total quadriceps values and although values are similar between sides, individual muscle volumes differ significantly. Tate et al’s sample demonstrated that in the dominant leg vastus medialis exhibited larger muscle volume, whereas in the non-dominant leg, vastus lateralis presented larger volume, thus inferring a relationship between the development of asymmetric functional efficiency and lateral preference task dependency. Although the development of lateral preference is influenced by...
gender, developmental characteristics and task complexity, in the lower limb preference changes due to task complexity, because bimanual foot use requires bilateral collaboration between the mobilising and stabilising functions of each leg. This process poses significant challenge to the coach as s/he works to improve performance.

To aid this process the author has used Kimmerle’s Laterality Model to derive a Participant Development Laterality Model (PDLM) and thus facilitate high performance for both participant and coach. The PDLM demonstrates inter-relationships between participant, coach and context, positions the coach as the pivot in the developmental process, and proposes pedagogic priorities at each stage of participation.

The coach must identify athlete lateral preference and recognise his/her responsibility to expose the participant to a balanced range of motor experience. What the coach may not perceive is the extent to which his/her own lateral preference has been influenced by the right biased world and how this now impacts upon his/her coaching practice.

Pedagogical studies have demonstrated that there is a right bias to demonstration causing athletes to expect demonstrations from the right and to practice more on the right. For the Strength and Conditioning Coach this has specific relevance to practice and s/he must promote optimal lateral balance within training and performance by coaching reps, sets and directional movements that start and finish using alternate side selection. Consequently combinations should challenge right biased athletic and sports coaching conventions that threaten to increase injury potential.

By the time an athlete has chosen to specialise in a specific sport, lateral preference is usually well established and differences between lower limbs may be resistant to structural change. Sport specific demands require performers to develop competent functional asymmetry and a reciprocal coaching style must recognise each individuals physiological, psychological, technical and tactical needs. Ultimately facilitation of optimal performance relies upon skilled stabilising and mobilising function in the lower limbs, through development of bilateral collaboration. This has specific implications for the Strength and Conditioning Coach who must appreciate how coaching intervention can impact structural and/or functional asymmetry of the lower limb.

In cycling, pedalling asymmetry is related to limb preference and the preferred leg tends to be capable of producing greater force regardless of changes in cadence. Symmetry has been shown to improve when performers pedal at significantly higher frequencies or with increased force. In running, symmetry is correlated with level of performance, distance and running speed and reduced by contextual interference from ground surface irregularity. This presents a dichotomy for the Strength and Conditioning Coach for the evidence related to these activities suggests that the appearance of symmetrical kinematics may only manifest towards the extremes of capacity. As a consequence any intervention in technique for the improvement of symmetry must be carefully coached to ensure that increased load in joints, connective tissue and muscles does not increase injury risk. In running, foot pronation compensates for anatomical abnormality by movement of the sub-talar joint to attenuate shock. Therefore one way that the coach can prevent injury is to ensure that each participant

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Figure 5. Participant Development Laterality Model Turner 2011, (derived from Kimmerle 2010).
does not practice or perform in worn down footwear.41 This will help facilitate rear foot symmetry and avoid reinforcement of asymmetric stress.42 Where a shoe raise is used, results show that the effect on scoliosis seems subject to age related flexibility of the lumbar spine and a positive effect on angle of curvature has been observed.27 An effective orthotic will reduce pelvic torsion and lower proprioceptive triggers, relieving painful muscular contraction.43 This remedy must however be used cautiously. Altered joint congruency can lead to contra indication and osteophyte formation in the hip has been shown to hinder replacement of the head of the femur to its normal position with correction by a lift often leading to groin pain.20 Ultimately effective management requires accurate and timely identification. When structural asymmetry is suspected assessment should attempt to eliminate leg-length alignment asymmetry due to supra-pelvic muscular hypertonicity (increased tension) before attending to treatment of anatomic leg-length inequality.24,26 Where hypertonicity is present the Strength and Conditioning Coach may need to work in partnership with a Physiotherapist to ensure release of the paired hypotonic muscle, (the muscle held on stretch). For the corresponding hypertonic muscle restoration of contractile function will then facilitate effective strengthening.

Conclusion
When planning to strengthen sports specific function the Strength and Conditioning Coach must consider the symmetry of musculo-skeletal development and functional demand. Development of fundamental movement skill is essential to build the foundation of balance and motor control and progression to athletic and technical practice must include lateral and directional development. Transition to sport specialisation may then be accompanied by the development of functional asymmetry where strength and conditioning programme design ensures balanced levels of musculo skeletal loading. Functional asymmetry will develop in response to three different types of demand: directional (left vs. right), fluctuating (dominant vs. non dominant) and absolute (left vs. right).20 Optimal physical preparation will rely upon needs analysis that identifies the kinesiological implications of sport specific functional asymmetry and conditioning that recognises the significance of musculo skeletal loading for the individual athlete.

Where movement dysfunction is present the need for accurate detection of anatomic asymmetry becomes critical. Reliable assessment must examine a range of musculo-skeletal factors. Scoliosis, pelvic tilt, hip, knee and ankle joint asymmetries signify the multifatorial nature of anatomic asymmetry and LLI. For the athlete the relationship between intrinsic and extrinsic aetiological factors demonstrates a process that can be accelerated beyond a threshold value that precludes injury, in response to the level of athletic training and performance.41 Injury risk will be determined by the interaction between predisposition of the musculo-skeletal system and the level of asymmetric functional demand. Early identification and management of causal factors is paramount for treatment of movement dysfunction with a shoe raise commonly only addressing symptoms once degenerative change has already occurred.

References