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RESEARCH ARTICLE

The Change in Kinematics and Lower Limb Muscle Activation Whilst Running after Cycling in a Triathlon and the Difference between Elite and Moderately Trained Triathletes: A Systematic Review

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Abstract

Background: Overuse injuries are very common in triathlon, especially in the running phase. It is important to understand biomechanical changes to establish risk factors for injury within the sport.

Aim: To understand the changes in biomechanics when running after cycling in triathletes and establish a link to injury. To determine a relationship between triathlon ability or experience and biomechanical change.

Study design: Systematic literature review.

Methods: Medline, Web of Science, Embase, Scopus and the Cochrane Library were searched using key terms relating to change in biomechanics in triathletes whilst running before and after cycling. A modified Downs and Black tool was used to quality assess included papers.

Results: 9 studies of which 5 were high quality were included. 5 studies focusing on moderately trained triathletes and 4 studies focusing on elite triathletes were identified. There is strong evidence that moderately trained triathletes are susceptible to kinematic changes and that less triathlon experience and ability is associated with a greater susceptibility to kinematic change. There is little difference between muscle activation in moderately trained versus elite triathletes whilst running after cycling. There is strong evidence that exercise related leg pain and neuromuscular changes are linked, however the causality of the link is unknown.

Conclusion: Many biomechanical changes, particularly an increased anterior pelvic tilt and increased tibialis anterior activity are likely to be associated with injury risk. There is currently insufficient data to make concrete associations between causality of biomechanical changes and risk of injury to establish interventions to prevent injury.

Introduction

Triathlon is a multi discipline endurance sport that involves the continuous completion of a swim, cycle and a run. There are various distance triathlons in which triathletes can compete, including: Sprint, Olympic and half or full Ironman distance. The sport has grown hugely in popularity and had its first introduction into the Olympics in year 2000 [1]. Its popularity is continuing to increase, according to the British Triathlon Federation the number of triathlon participants in Britain has increased by over 70,000 from 2009 to 2015 [1].

Being an endurance sport, triathlon has a high prevalence of injury particularly overuse injury. One study showed that 50% of triathletes sustained an injury during a 6-month pre season training programme and 37% during the 10-week competitive season with overuse injuries accounting for 68% and 78% of injury respectively [2]. Another study showed that 56% of triathletes suffered from an overuse injury during a 26-week training programme for an Ironman triathlon with the most common sites of injury being the knee (25%), lower leg (23%) and lower back (23%) [2]. It has been reported that approximately 73% of injuries are sustained in the running stage of the triathlon [3]. It is clear from recent literature that overuse injuries are a huge problem in the sport. It is important that we understand the risk factors for overuse injuries in order to determine means of prevention. Although there is limited evidence to suggest that overuse injuries are associated with a change in biomechanics, one study

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did find that more triathlon experience and previous injury were associated with overuse injuries, however there were no statistical associations between overuse injury and age, training hours during preseason training, pre-training warm up and post-training cool-down [4].

There has been great ambiguity surrounding the exact alteration of running kinematics and muscle activity when running after cycling [5,6]. It is important to understand these biomechanical changes to determine if this is a risk factor for overuse injuries within the sport. Therefore, the primary aim of this systematic review is to better understand the changes in running kinematics and muscle activity whilst running after cycling. A secondary aim is to determine whether there is a relationship between triathlon ability and triathlon experience and any biomechanical changes when running after cycling. The results of this systematic review will help inform future research into associations between biomechanical changes and risk factors for overuse injury. Previous research papers that focus on measuring the biomechanical changes of running after cycling will be summarised and quality assessed in this systematic review.

Methods

Search and evaluation strategy

Search strategy: Medline, Web of Science, Embase, Scopus and the Cochrane Library were searched from inception to 19th April 2016. Table 1 below shows the search terms used.

Inclusion and exclusion criteria are shown in Figure 1.

Quality assessment

A modified Downs and Black checklist was used as a quality assessment tool because the literature reviewed were all non-randomised control trials [7]. Items 1-4, 6 and 7 that referred to the reporting of the study were included as well as the items reporting external (11-12) and internal validity (16,18,20, 25). Therefore, the quality index score was marked out of 12 rather than 32. This method of quality assessment has been used before in a systematic review looking at studies with a similar methodology [8]. The checklist has been reported to have a good test re-test (r = 0.88) and a good inter rate reliability (r = 0.75) and a high internal consistency [7].

Table 1: Search terms used.

Search Terms
Running OR Runner OR Jogging OR Jogger
AND
Cycling OR Cyclist
AND
Transition OR Changeover OR Conversion
AND
Kinematics OR Biomechanics OR Biomechanical Phenomena OR Mechanobiological Phenomena OR Electromyography OR EMG

Results

Figure 2 below shows the number of papers identified, screened and determined eligible for inclusion into the systematic review.

After screening the full text of the literature, 11 papers were quality assessed. 9 papers were deemed eligible for the systematic review. All nine papers were descriptive laboratory studies.

Papers with a quality index of over 70% (n = 5) were regarded as high quality and those with a quality index of less than 50% (n = 2) were regarded as low quality and excluded from the systematic review Table 2 and Table 3.

Altered running kinematics in moderately trained versus elite triathletes

Bonacci, et al. found moderate evidence that there was no change in running kinematics at group level after a 45-minute high intensity cycle when the definition for a change in kinematics is defined as a change in joint angle by > 2 degrees in flexion or extension. However, seven out of the eight triathletes who experienced a change in muscle recruitment also experienced a change in running kinematics. This kinematic change

Inclusion Criteria:

- Triathletes
- Any Age
- Any ability
- Male or Female
- English Language only
- Studies measuring running biomechanics after cycling

Exclusion Criteria:

- Studies without a relevant outcome measure including those measuring change in running efficiency, comparing the change in biomechanics between males and females and measuring influence on performance.
- Studies measuring extrinsic factors relating to a change in running kinematics for example seat tube angle on the bike.
- Studies done before the year 2000 because of technological advances in measuring kinematics and EMG.
- Reviews
- Abstracts
- Non-human subjects

Figure 1: Inclusion and exclusion criteria.

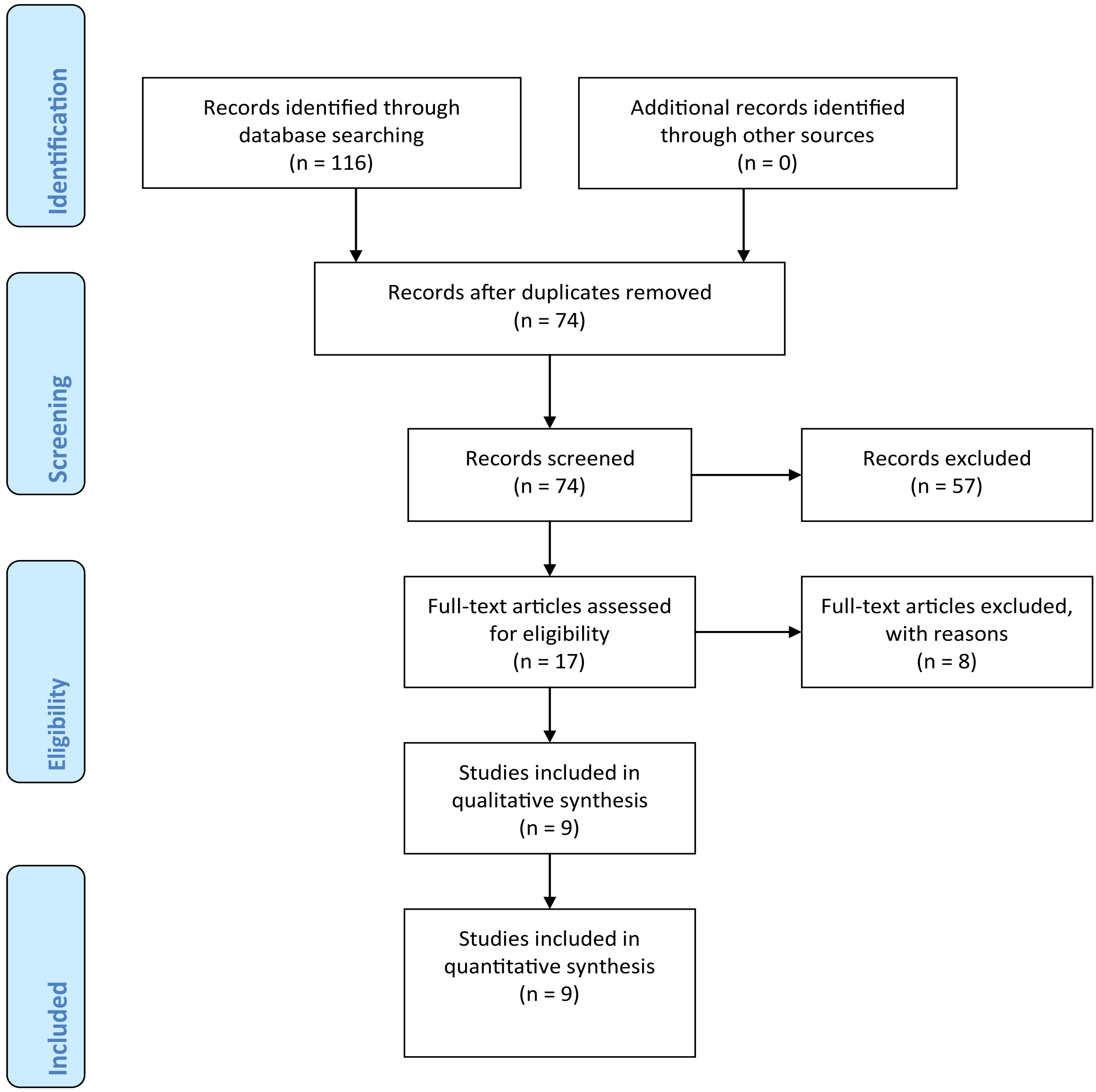

Figure 2: A prisma flow diagram summarising the returns for papers searched and the process of eliminating irrelevant papers.

was present at the knee, hip and ankle.

Rendos, et al. [9] also found strong evidence that there was no significant change in trunk flexion, knee flexion and ankle dorsiflexion whilst running after 30 minutes of cycling. They found strong evidence that participants with less than 2 years' experience showed significant increase in trunk flexion, spine extension, anterior pelvic tilt and hip extension. Triathletes with 2 or more years' experience only had a significant increase in spine extension angle and hip flexion angle [9] Table 4.

3 studies measured differences in stride length or stride time for moderately trained triathletes when running after cycling.

Connick, et al. [5] found moderate evidence that according to ANOVA analysis there was a significant decrease in mean stride length after 1-minute running after cycling *(F* = 3.127, *p* = 0.047). However the stride length increased after 9-minutes running after cycling to have no significant difference [5]. They found moderate evidence that with ANOVA analysis although there was no significant difference between mean stride length when running before and after cycling, there was moderate evidence for a significant association between increased mean stride length and increased distance ran for 5 Km after cycling. Rendos, et al. [9] found strong evidence that although there was no significant difference when using ANOVA in stride time measurements before and after cycling overall there was strong evidence for a significant decrease in stride time in a subgroup of triathletes with less than 2 years' experience (F = 3.075, p < 0.001) [9].

There are a number of similarities and differences in running kinematics after cycling when comparing

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Table 2: Results from the Downs and Black quality assessment.

Study	1) Is the hypothesis/aim/objective of the study clearly described?	2) Are the main outcomes to be measured clearly described in the Introduction or methods section?	3) Are the characteristics of the patients included in the study clearly described?	4) Are the interventions of interest clearly described?	6) Are the main findings of the study clearly described?	7) Does the study provide estimates of the random variability in the data for the main outcomes?	11) Were the subjects asked to participate in the study representative of the entire population from which they were recruited?	12) Were those subjects who were prepared to participate representative of the entire population from which they were recruited?	16) If any of the results of the study were based on “data dredging”, was this made clear?	18) Were the statistical tests used to assess the main outcomes appropriate?	20) Were the main outcome measures used accurate (valid and reliable)?	25) Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?	Quality Index Score (out of 12)	Quality Index %
Rendos, et al. [9]	1	1	1	1	1	0	1	1	1	1	1	0	10	83
Chapman, et al. [10]	1	1	1	1	1	0	1	1	1	1	1	0	10	83
Walsh, et al. [11]	0	1	1	1	1	0	1	1	1	1	1	0	9	75
Chapman, et al. [12]	0	1	1	1	1	0	1	1	1	1	1	0	9	75
Bonacci, et al. [6]	1	1	0	1	1	0	1	1	1	1	1	0	9	75
Connick, et al. [5]	1	1	1	1	1	0	0	0	1	1	1	0	8	67
Bonacci, et al. [13]	1	1	0	1	1	0	0	0	1	1	1	0	7	58
Gottschall, et al. [14]	1	1	0	1	1	0	0	0	1	1	1	0	7	58
Bonacci, et al. [15]	0	0	1	1	1	0	0	0	1	1	1	0	6	50
Poklikuha, et al. [16]	0	0	1	1	0	0	0	0	1	1	1	0	5	42
Bonacci, et al. [17]	0	0	0	1	1	0	0	0	1	1	1	0	5	42

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Table 3: A table summarising the details of participants, methods and results used in each study.

Study	N of subjects	Triathlete level	Mean Age	Initial time ran	Time cycled	Time ran in transition run	Outcome measures	Results
Rendos, et al. [9]	28	Moderately Trained	24.6 +/- 5.8	4 minutes	30 minutes	15 minutes	Change in sagittal plane running kinematics after cycling.	Running kinematic changes in the spine, pelvis and hip for 14 minutes after cycling.
Chapman, et al. [10]	16	Elite triathletes	30.2 +/- 3.2	10 minutes	20 minutes	30 minutes	Influence of cycling on running kinematics and muscle recruitment.	No changes in running kinematics. 5 triathletes experienced change in TA muscle activity.
Walsh, et al. [11]	6	Elite Triathletes	24.8 +/- 7.6	10 minutes	20 minutes	30 minutes	To examine changes in EMG patterns when running after cycling.	EMG patterns are not affected by prior cycling.
Chapman, et al. [12]	34	Elite triathletes	29.1 +/- 3.6	10 minutes	20 minutes	30 minutes	Influence of cycling on neuromuscular control. Comparison between those with exercise related leg pain (ERLP) and those without.	Triathletes with ERLP are more likely to experience changes in muscle recruitment. There were no changes in knee and ankle joint kinematics in all triathletes.
Bonacci, et al. [6]	7	Elite Triathletes	Not Specified	Not Specified	20 minutes and 50 minutes	30 minutes	Changes in neuromuscular control. Comparison between a low and high intensity cycle.	No changes in neuromuscular control in both cycle protocols.
Connick, et al. [5]	8	Moderately Trained	41.9 +/- 6	22 minutes	180 minutes	10 minutes	Changes in TA activation and lower limb range of motion (ROM) after cycling	No changes in ROM or TA activation. Decreased stride length in the transition run.
Bonacci, et al. [13]	15	Moderately trained	Not Specified	Not Specified	15 minutes	30 minutes	Change in neuromuscular control when running after cycling.	5 triathletes experienced changes in joint position. 1 triathlete experienced changes in muscle recruitment.
Gottschall, et al. [14]	10	Moderately Trained	Not Specified	5 Km	30 minutes	5 Km	Changes in step length and step frequency after cycling.	Smaller step length and greater step frequency. This gradually returned to normal as running time increased.
Bonacci, et al. [15]	17	Moderately Trained	Not Specified	4 minutes	45 minutes	4 minutes	Change in limb movement and muscle recruitment after cycling.	Running kinematics and muscle recruitment were altered in 46% of triathletes.

moderately trained triathletes versus elite triathletes.

Chapman, et al. found that in 14 elite triathletes there was strong evidence for no significant change in running kinematics for 30 minutes after cycling [10].

Bonacci, et al. also found strong evidence that running kinematics were preserved in elite triathletes after a high intensity 50-minute cycle and a low intensity 20-minute cycle [6].

Altered lower limb muscle activity in moderately trained versus elite triathletes

Table 5 shows us that Bonacci, et al. [11-15] both found a change in muscle recruitment in 53% and 7% moderately trained triathletes respectively, however there was no significant change at group level. Connick, et al. showed moderate evidence that there was no significant change in tibialis anterior activity according to ANOVA analysis (F = 3.728, p = 0.079) after 1 minute and 9 minutes running after cycling in moderately trained triathletes [5].

Chapman, et al. found that group data of 14 elite triathletes showed no significant change in tibialis anterior activity whilst running before and after cycling. However at individual analysis there was strong evidence that 5 of the triathletes experienced a decrease in the amplitude of EMG readings for the tibialis anterior in the stance phase for the whole duration of the 30-minute run after cycling [10].

Chapman, et al. found strong evidence that there was a greater than 10% change in EMG readings when running after cycling in 5 out of 10 elite triathletes suffering from exercise related leg pain and 5 out of 24 of controlled elite triathletes. 24% of muscles measured in the exercise related leg pain group and 9.2% of muscles measured in the controlled group had a change in EMG readings [12].

Walsh, et al. found strong evidence that in 8 elite triathletes there was no significant change in mean EMG activity when running after moderate intensity cycling compared to an initial run. However there is moderate evidence that variability of muscle activity was greater throughout the run after cycling compared to the initial run in the following muscles: Gluteus medius, biceps femoris, vastus medialis, vastus lateralis, rectus femoris, gastrocnemius medialis, gastrocnemius lateralis and tibialis anterior [11].

Bonacci, et al. found that in 7 elite triathletes there was strong evidence for no significant change in muscle recruitment whilst running after both low and high intensity cycling when compared to an initial run [6].

Discussion

The aims of this literature review were to understand the changes in biomechanics when running after cycling and to make comparisons between these changes in elite and moderately trained triathletes. The literature review has been successful in collaborating the data to give reasonable evidence for biomechanical changes in triathletes and has made comparisons between these changes and triathlon ability.

Quality assessment findings

There is limited high quality research for measuring change in running biomechanics and muscle recruitment before and after cycling with only 5 of the 9 studies being high quality. There is little similarity between aims, protocol and statistical analysis between the studies. After assessing the full text of 17 studies, 8 were excluded from the systematic review for the following reasons: 2 studies had a modified Down and Black's quality index of less than 50% [16,17] and 6 studies did not comply with the systematic reviews inclusion and exclusion criteria when the full text was analysed [18-23].

Sample sizes in most studies were quite small because of the specificity of the participants to fit the inclusion criteria. All of the studies using moderately trained triathletes had a sample size of less than 30 and

Table 4: A table showing significant changes according to ANOVA analysis in joint position for moderately trained athletes.

Study	Joint movement	F Value	P Value
Rendos, et al. [9]	Spine extension increase	15.488	< 0.001
Rendos, et al. [9]	Anterior pelvic tilt increase	113.35	< 0.001
Rendos, et al. [9]	Hip flexion increase	11.675	< 0.001
Rendos, et al. [9]	Hip extension decrease	10.091	< 0.001
Connick, et al. [5]	Ankle ROM*	4.019	0.021
Connick, et al. [5]	Hip ROM*	3.633	0.030

*Significance in ANOVA analysis from 1 minute running after cycling compared to 9 minutes running after cycling.

Table 5: A table that compares triathlete level and the number of participants exhibiting a change in muscle activity after cycling.

Study	Triathlete Level	Number of Triathletes	% of Triathletes showing a change in muscle activity
Bonacci, et al. [15]	Moderately Trained	17	53
Bonacci, et al. [13]	Moderately Trained	15	7
Chapman, et al. [12]	Elite	34	29
Walsh, et al. [11]	Elite	8	0
Chapman, et al. [10]	Elite	14	36 (only TA)

the majority of studies using elite triathletes had a sample size of less than 15 with one high quality study with a sample size of 34 [12]. Most studies did not report a power calculation to determine sample size. There was great variability in the mean age of participants with one study having a mean age of 24 [9] and one study recruiting subjects with a mean age of 41 [5]. There was a lot of similarity between the definition of moderately trained triathletes and elite triathletes. The majority of studies defined moderately trained triathletes as triathletes with at least 3 years' experience who train for at least 30 minutes around 3 times a week. Elite triathletes were defined as triathletes who competed in events at national level and those who have been successful in qualification for the Triathlon World Championship.

Individual data for most triathletes were not included in the some of the studies with most studies represented data at group level rather than an individual level, which made it hard to draw conclusions from the data. Confounding variables and methodological limitations were described in the majority of studies. Stationary cycling not replicating cycling in competition and training in terms of terrain and effort level and also using healthy/uninjured participants meaning no link to injury risk were the two main limitations of most studies. Only 1 of the 9 studies measured reproducibility of data [12]. This meant it was hard to establish for the other 8 studies if the data had adequate precision.

Limitations to this review included: Only using papers written in English, not being able to do a meta-analysis, not looking at grey literature, low participant numbers and methodological weaknesses in some of the studies.

Changes in running kinematics and muscle activation in moderately trained triathletes after cycling

There is strong evidence to suggest that some moderately trained triathletes experience a change in kinematics when running after cycling. 2 studies agreed that there was a change when measuring data at group level [5,9] and one study found that although there was no change at group level, there was a change when looking at individuals [15]. Strong evidence suggests that moderately trained triathletes are most likely to experience a change in kinematics in the following movements: Increased spine extension, increased anterior pelvic tilt, increased hip flexion and decreased hip extension for at least 14 minutes [9] and there is also moderate evidence that there is an increased hip and ankle range of motion after 9 minutes running compared to 1 minute running after cycling [5]. However Connick, et al. used older and more experienced participants and used a longer cycle time (3 hours) compared to a 30 minute cycle time in the Rendos, et al. study. From this it is difficult to draw conclusions from the comparison of these two studies. Older age, greater experience or a longer time cycled could all be factors that influence the biomechanical changes in the transition run. Rendos, et al. used a different marker placement method as compared to other studies in this systematic review. They used a cluster marker on the sacrum and then a static calibration method to determine the right and left superior iliac spine. The conventional method for measuring hip range of motion is to have motion analysis markers on the right and left anterior and posterior superior iliac spines. Connick, et al. only recorded motion analysis after 1-minute and 9-minutes during the transition run compared to Rendos, et al. who recorded motion analysis at more regular intervals which gives us a greater understanding of the relationship between transition running time and kinematic change. Connick, et al. also did not specify the time it took for the participants to transition from cycling to running as if this was prolonged it could be a reason why there was no change in kinematics after 1 minute in the transition run when compared to the control run.

There is also strong evidence that less experienced triathletes are more susceptible to greater changes in joint positioning [9]. These changes in running kinematics can not only cause changes in joint positioning but also changes in muscle activity. Bonacci, et al. found that although at group level there was no change in running kinematics, when looking at individuals, 7 out of the 8 triathletes who experienced a change in muscle activation also experienced a change in running kinematics [15]. Other evidence suggests that an anterior pelvic tilt will lower the body's centre of mass and also maximise the propulsive phase horizontal force whilst running [24]. It has also been found that an increased anterior pelvic tilt can have implications on the spine, which can cause an increase lumbar lordosis [25]. There is also evidence that an anterior pelvic tilt has a positive correlation with hip extension and prolonged trunk flexion can cause an increase in hip flexion [26,27]. From the research available it is quite clear that when a change in joint position occurs it has multiple effects on surrounding joints and musculature.

These changes in joint positioning have previously been linked to running related injuries. An anterior pelvic tilt and a decreased hip extension have been shown to increase hamstring injuries and lower back pain in runners [28,29].

The evidence from 3 studies suggests that as the running distance or time increases after cycling the stride length increases or the stride time decreases [5,9,14]. As mentioned above, the methodology between the Rendos, et al. and the Connick, et al. study varies in some respects. There is however conflicting evidence in regard to a significant difference in stride length or time when initially starting the run after cycling. Although Connick, et al. found that there was a significant difference between stride length when running before and after cycling, Gottschall, et al. and Rendos, et al. did not find a significant difference in stride length or time. This is most likely because the two studies have recruited similar participants and using a similar methodological approach whereas the Connick, et al. study used older participants with more triathlon experience and who also completed a higher intensity cycle. Previous studies suggest that when running after cycling the neuromuscular system is unable to quickly adapt to change the neural firing rate from cycling and therefore maintaining the rate for cycling during the initial running phase [14]. From the evidence it is likely that the longer the cycle phase the greater the difference in stride length in the running phase.

Change in running kinematics in elite triathletes compared to moderately trained triathletes

Only 2 studies measured the change in kinematics in running before and after cycling in elite triathletes [6,10]. Both studies agreed that the data showed that there was no change in running kinematics, therefore providing strong evidence that as triathlete experience or ability increases there is less susceptibility to a change in running kinematics after cycling. One study had 14 participants and the other study had 7 participants so there is a small sample size for both studies meaning there is poor reliability for the data. The methodology in the Bonacci, et al. study differs from the Chapman, et al. with regards to the cycle protocol. Bonacci, et al. used a cycle protocol that involved cycling in intervals and the participants in the Chapman, et al. study had to cycle for 20 minutes continuously. The methodology in the Bonacci, et al. study may mean that the neural firing rate may differ in the transition run as cycling in intervals may allow time for the neuromuscular system to quickly adapt from cycling to running. The methodology in the Chapman, et al. study has a short cycle protocol, however the continuous cycle better replicates a triathlon competition.

Change in lower limb muscle activation in elite triathletes after cycling

4 studies looked at measuring change in muscle activation when running after cycling in elite triathletes [6,10-12]. 3 of the studies agreed that there was no significant change in muscle activity at group level when running after cycling in elite triathletes [6,10,11]. However individual analysis data showed that some elite triathletes experienced a significant change in muscle activity, particularly for the tibialis anterior muscle [10]. The tibialis anterior muscle is the largest dorsiflexor muscle that not only controls ankle positioning but also plays a huge part in force regulation of the leg [30]. Therefore changes in tibialis anterior activity will affect bone and soft tissue loading which could cause the tissues loading capacity to be exceeded and also cause micro damage to bone tissue leading to overuse injury [10,30]. Chapman, et al. found strong evidence that elite triathletes suffering from exercise related leg pain are more susceptible to significant changes in muscle activity whilst running after cycling and that it is more likely that triathletes in this cohort experience this change in a greater number of muscles [12]. The design of the study meant that it was impossible to determine if the altered neuromuscular control was a causative factor or if altered neuromuscular control was caused by pain and injury. The results of this study could imply that musculoskeletal pain or injury impedes the triathletes' ability to switch from cycling to running [12]. From the evidence from these two studies we can establish that it is important to include neuromuscular control and learning programmes in elite triathlete training as it may reduce injury [10,12].

Change in lower limb muscle activity in moderately trained triathletes compared to elite triathletes

3 studies measured a change in lower limb muscle activity when running after cycling in moderately trained triathletes [5,13,15]. Connick, et al. found at group level there was no significant difference in change in tibilais anterior activity whilst running after cycling, individual data was not provided [5]. The difference between these results and the results in the elite triathletes in the Chapman, et al. study could be also due to the Connick, et al. study having a much longer cycling protocol which was completed at a lower intensity. This could have an influence in the activity of the muscles, as they are providing a smaller force through the pedals. Research has found that the stage of most effective force application is at the 300-degree point of the 360-degree pedal cycle [31]. It has been found that the tibialis anterior muscle contraction begins at 270-degrees of the pedal cycle and therefore has a large influence on the amount of force applied through the pedals [31].

Although Bonacci, et al. and Bonacci, et al. studies didn't measure any significant change at group level, 31% of individuals experienced a change after 30 minutes cycling [13,15]. From the data it has been calculated that 31% of moderately trained triathletes experience a change in muscle recruitment compared to 27% of elite triathletes. Although the cycle protocol in studies looking at moderately trained triathletes is generally longer than the studies looking at elite triathletes, the results show that triathlon experience and ability is not a major factor in determining a change in muscle recruitment whilst running after cycling in triathlon.

Clinical implications and areas for future research

One study has focused on establishing a link between a change in kinematics and muscle recruitment and risk of injury in elite triathletes [12]. Future research should focus on designing a study to determine whether injury is a causative factor for altered neuromuscular control or whether an altered neuromuscular control is a causative factor for injury. There should be more studies done in moderately trained triathletes as well as elite triathletes to further determine if less triathlon ability or experience means you are more susceptible to injury. Different types of overuse injury should also be considered in the study design. A randomised control trial to determine the design of a training programme to reduce neuromuscular changes in triathletes when running after cycling can be done to explore methods of injury reduction.

Conclusion

The exact alteration of kinematics and muscle activity whilst running after cycling is a topic that is developing. Moderately trained triathletes are susceptible to a change in kinematics, particularly in the following movements: Increased spine extension, increased anterior pelvic tilt, increased hip flexion and decreased hip extension. An increased anterior pelvic tilt has been reported to cause multiple surrounding joint and musculature alterations that have been related to running related injury. Moderately trained triathletes with less triathlon experience are also more susceptible to these changes thus supporting the theory that you can train to reduce neuromuscular changes whilst running after cycling. Elite triathletes have also been shown to have no changes in running kinematics after cycling and therefore also support this theory. There is strong evidence that as distance run after cycling increases then stride length increases or stride time decreases in moderately trained triathletes. This is most likely because of the neuromuscular system being unable to quickly adapt to change the neural firing rate from cycling and therefore maintaining the rate for cycling during the initial running phase. This is why it is likely that a longer more intense cycle is associated with a greater difference in stride length in the initial part of the running phase. Muscle activity change whilst running after cycling was present in 31% of moderately trained triathletes. In comparison, 27% of elite triathletes experienced altered muscle activity, which shows that triathlon experience or ability has little effect on muscle activity changes whilst running after cycling. The tibialis anterior muscle was one of the key muscles that experienced a change in muscle activity and could be a factor relating to bone overuse injury and injury risk from excessive loading. There is strong evidence that exercise related leg pain and neuromuscular changes are linked, however the causality of the link is unknown.

This review has given insight into the change in kinematics and lower limb muscle activation whilst running after cycling in triathletes and its association with injury risk. Limited high quality research and flaws in methodology means that is difficult to determine exact biomechanical alterations in triathletes. However, overuse injury is clearly a problem within the sport and the current evidence does suggest that altered biomechanics is linked to overuse injury risk both at elite and amateur level. Future research should look into further understanding injury risk and its association with altered biomechanics and also training methods to reduce biomechanical changes.

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