The Effect of Long-Distance Overground Running on Foot Strike Patterns and Performance

Submitted by

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Abstract

Long distance running has seen increasing participation rates in recent years. Subsequently, there has been growing focus on running biomechanics and their individual effects on runners. Foot landing during a gait cycle, commonly referred to as foot strike pattern, has become a particular focus. Foot strike patterns and their prevalence, effects on performance and response to increasing distances in both professional and recreational overground runners is currently under-researched.

This work aimed to establish prevalence and performance data of foot strike patterns in long distance overground runners along with investigating the effect of increasing distance on foot strike patterns. For the purposes of this thesis, the term distance running, which lacks an accepted definition, included analysis of run data that was greater than or equal to 10 km.

A systematic review with meta-analysis was performed examining the literature concerning prevalence, performance, and effect of increasing distance on foot strike patterns in long distance overground runners. A follow up cross-sectional study investigating change in foot strike patterns and performance in recreational runners during a road race was also performed.

The literature suggests 79% of runners rearfoot strike early, with prevalence rising to 86% with increased distance. Approximately 11% of runners change foot strike pattern with increased distance, predominantly from non-rearfoot strike to rearfoot strike (84%). Results were mirrored in cross sectional analysis of recreational runners, with 76.9% and 91.0% being classified as rear foot strikers both early on and late into a 15 km run. Of those who ran with a non-rearfoot pattern strike early, 61% changed to a rearfoot strike pattern with increasing distance. The non-rearfoot strike pattern was also seen to have the fastest completion time.

The majority of runners rearfoot strike early during long distance overground running and prevalence of this pattern is seen to increase with distance. A portion of runners display a change in their foot strike pattern as run distance increases, with this change occurring from non-rearfoot strike to rearfoot strike in the majority of cases. Inconclusive evidence suggests that a non-rearfoot strike pattern is associated with a performance advantage.

Statement of authorship

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma.

No other person's work has been used without due acknowledgement in the main text of the thesis.

This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

Stephen Paul Bovalino

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List of publications

Chapter 2 has been published: Bovalino, SP and Kingsley, MIC. (2021) Foot Strike Patterns During Overground Distance Running: A Systematic Review and Meta-Analysis. Sports Medicine – Open. 7:82.

Chapter 3 has been published: Bovalino SP, Cunningham NJ, Zordan RD, Harkin SM, Thies HHG, Graham CJ, Kingsley MIC. (2020) Change in foot strike patterns and performance in recreational runners during a road race: A cross-sectional study. Journal of Science and Medicine in Sport. 23(6): 621-624.

Contributions to jointly authored work

The following table details contributions to jointly authored work that has been published or is currently under review for publication (Chapters 2 and 3).

Author	**Contribution to the conception or design**	**Contributed to acquisition, analysis or interpretation of data**	**Drafting of the manuscript**	**Editorial revision of the manuscript**
Chapter 2- Foot strike patterns during overground distance running: a systematic review and meta-analysis.				
Stephen Bovalino	60%	60%	90%	60%
Michael Kingsley	40%	40%	10%	40%
Chapter 3- Change in foot strike patterns and performance in recreational runners during a road race: a cross-sectional study.				
Stephen Bovalino	50%	25%	55%	30%
Neil Cunningham	50%	20%	15%	15%
Rachel Zordan	0%	15%	15%	15%
Samuel Harkin	0%	15%	0%	5%
Heidi Thies	0%	5%	0%	5%
Cameron Graham	0%	5%	0%	5%
Michael Kingsley	0%	15%	15%	25%

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Abbreviations

FFS	Forefoot strike
IAAF	International Association of Athletics Federations
MFS	Midfoot strike
NRFS	Non-rearfoot strike
RFS	Rearfoot strike
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
NIH	National Institute of Health

Chapter 1. Introduction

The sport of running has long served as a form of physical activity that is accessible to a wide array of individuals from varying backgrounds of social class, age and fitness levels. Compared to other sports, the relative requirements regarding equipment, or lack thereof, make running an attractive option for a broad demographic of individuals, allowing access to an affordable and convenient form of physical activity. Furthermore, its capacity to be undertaken at either the individual or group level, as well as its translation to a multitude of natural environments make running an incredibly versatile form of physical activity.

Participation rates of running as a leisure and/or competitive activity have increased over time; Australian figures suggest those who have reported jogging on a regular basis increased by 9.2% between 2006 and 2016 (Roy Morgan Research 2016). This trend is mirrored in participation rates of long distance running events, with year on year increases in individual marathon performances observed over the last ten years in Australia (not including 2020 due to the global COVID-19 pandemic) peaking in 2019 at 27,953 (Ausrunning 2020). This increase in the popularity of long-distance running has been reflected in the literature base, with recent elevated interest in running biomechanics and a surge in the number of publications pertaining to it (e.g., Almeida, Davis et al. 2015, Anderson, Bonanno et al. 2020, Xu, Yuan et al. 2021). Central themes of investigation relating to this particular sub-section of scientific discourse often include commentary on running economy, performance and injury rates in runners (Hamill and Gruber 2017). Coaches and healthcare professionals are constantly searching for ways to improve outcomes relating to these three domains. Of particular interest, has been the apparent importance of where a runner's foot first makes contact with the running surface during a gait cycle, which is commonly referred to as an individual's 'foot strike pattern'. The definitions surrounding these patterns has undergone continuing refinement, with uniform acceptance of what constitutes each of the specific patterns now being established for continuity and consistency of discussion (Hasegawa, Yamauchi et al. 2007, Larson, Higgins et al. 2011). Specifically, there are three commonly accepted foot strike patterns that can be applied to any runner, namely: (1) rearfoot strike (RFS), where initial contact is made somewhere on the heel or rear one-third of the foot; (2)

midfoot strike (MFS), where the heel and the ball of the foot contact nearly simultaneously; and (3) forefoot strike (FFS), where initial contact is made on the front half of the foot, after which heel contact follows (Hasegawa, Yamauchi et al. 2007, Larson, Higgins et al. 2011).

More recently, there appears to have been a push towards combining both the FFS and MFS patterns together in a unique sub-category known as 'non-rearfoot strike' (NRFS). The reason behind this trend in nomenclature in more recent publications (Hanley, Bissas et al. 2019, Hanley, Bissas et al. 2020) appears to centre around trends relating largely to prevalence. With increasing data now filtering through the literature base, it has become apparent that very few athletes are seen to habitually FFS or MFS when compared to RFS. As will be explored in Chapter 2 of this thesis, FFS prevalence is often reported to be <2% (e.g.Patoz, Lussiana et al. 2019) and sometimes is not observed at all (Kasmer, Liu et al. 2016, Murray, Beaven et al. 2019). The MFS pattern, while seen to be represented more so than FFS, is also far less common than the RFS pattern, a trend observed in both recreational level (Larson, Higgins et al. 2011) and elite (Hanley, Bissas et al. 2019) cohorts. Given this apparent under representation of both FFS and MFS patterns, researchers now often combine the categories as an effective means of comparison with the more prevalent RFS pattern. Because both the FFS and MFS patterns both rely on runners striking at the anterior aspect of the foot, they share similar muscle recruitment and kinematic sequelae (Hanley, Bissas et al. 2019). Two systematic reviews with meta-analyses looking at the effects of foot strike patterns on running biomechanics have been previously published, describing significant differences that exist between the NRFS patterns and the RFS pattern (Almeida, Davis et al. 2015, Xu, Yuan et al. 2021).

Given its apparent ease of administration within a tightly controlled laboratory environment, the treadmill has traditionally served as the key apparatus for researchers to conduct analyses on foot strike patterns. Through its use, the treadmill enables key variables to be manipulated in real time and their effects directly and easily observed in multiple planes. Undoubtedly, the use of treadmill running has led researchers to answer key questions pertaining to foot strike patterns and running biomechanics in general, with a multitude of examples being found within the literature base (e.g.,

Ardigò, Lafortuna et al. 1995, Boyer, Rooney et al. 2014, Breine, Malcolm et al. 2014). However, laboratory-based capture of foot strike patterns is not without significant drawbacks. Key criticism of the practice centres on the known systematic intra-individual changes that exist between treadmill and overground running (Wank, Frick et al. 1998), with sagittal plane kinematic differences at foot strike being particularly affected (Van Hooren, Fuller et al. 2020). Furthermore, relying on treadmill-based running deprives researchers of the ability to observe runners in their natural, overground environments; this brings into question the translatability of research performed outside of this context. Long distance running in particular, often undertaken over several hours, brings with it a unique sub-set of challenges for researchers aiming to conduct adequately powered analyses. This is particularly relevant for the field of running biomechanics pertaining to foot strike patterns.

With population prevalence rates for both FFS and MFS seen to be so low, as previously discussed, observing an adequate number of subjects becomes a critical factor in research study design. Prior to 2007, there was a lack of research investigating foot strike patterns in runners competing in long distance overground settings. Hasegawa et al. (2007) was the first to meaningfully capture a large number of runners and their resultant foot strike patterns within a long distance running event, employing high definition video capture analysis at the 15 km mark of an elite half marathon. These authors set the standard for future studies to build on and continue to investigate the impact of distance on foot strike patterns in overground running, opposed to the artificial confines of the treadmill and laboratory (e.g., Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Hanley, Bissas et al. 2019). This body of work has served to largely provide commentary on foot strike pattern prevalence as well as attempted to uncover any potential performance benefit that may be associated with particular foot strike patterns. Traditionally, scientific inquest relating to themes surrounding the linkage of particular foot strike patterns with performance has proven to be a point of contention (Hamill and Gruber 2017); however to date, these data have not yet been collated in a unified body of research making conclusions hard to reach with any sense of confidence.

The status of the current literature base pertaining to the analysis of foot strike patterns in overground distance running appears to display a clear bias towards distances >21.1 km. This is likely owing to the fact that traditional long distance running events take the form of either a half-marathon (21.1 km) or full marathon (42.2 km). However, no strict definitions exist surrounding what precisely constitutes 'long distance running', with runner experience level heavily playing into subjective interpretation. Increasingly, in response to the marked uptake in running as a sporting activity, events that fall between 10 km and 21.1 km in total distance have become increasingly prevalent, particularly for recreational level athletes new to the discipline of distance running. Interestingly, there appears to be a true paucity of research that has been conducted on this particular cohort of the running populous, especially concerning their potential trends regarding individual foot strike patterns. As such, this thesis choses to frame and define distance running at greater than or equal to 10km in total run length.

Traditionally, early studies investigating foot strike patterns in overground distance runners focused on prevalence as the primary outcome in question, with studies employing simple methodologies of single point capture during running events (Hasegawa, Yamauchi et al. 2007, Kasmer, Liu et al. 2013). While useful, single point prevalence data offered little in the way of informing researchers on the dynamic qualities of foot strike patterns. Whether or not individuals change their respective foot strike pattern as run distance increases, possibly a marker of fatigue, became an increasing focus of research design in subsequent studies (e.g.Larson, Higgins et al. 2011), with foot strike capture occurring at increasing distance check points. However, due to the complex and onerous task of multiple point foot strike capture at the intra-individual level, few studies exist that have attempted to use this method. As a result, the current literature base is sparse pertaining to the assessment of foot strike pattern change with increasing distance, creating the potential for erroneous conclusions to be made when studies are assessed individually. Careful collation of all pre-existing data within this field of foot strike pattern analysis would allow for more consistent, evidence-based conclusions to be made.

The central aims for this thesis and masters project were to:

1. Summarise the current status of the literature base as it relates to foot strike pattern prevalence in overground distance runners while simultaneously assessing the impact that increasing distance has on foot strike pattern change.

2. Assess whether or not there is a performance benefit associated with one foot strike pattern over another in overground distance runners.

3. Assess whether foot strike pattern change occurs at shorter distances than previously investigated.

Chapter 2. Foot Strike Patterns During Overground Distance Running: A Systematic Review and Meta-Analysis.

This chapter is available in published format as follows: Bovalino, S.P and Kingsley, MIC. (2021). "Foot Strike Patterns During Overground Distance Running: A Systematic Review and Meta-Analysis." Sports Medicine – Open. 7:82. In accordance with La Trobe University policy relating to thesis presentation, work that has been published is included in the thesis as published and has not been modified in content.

2.1. Abstract

Background: Investigations of foot strike patterns during overground distance running have foci on prevalence, performance and change in foot strike pattern with increased distance. To date, synthesised analyses of these findings are scarce.

Objective: The key objectives of this review were to quantify the prevalence of foot strike patterns, assess the impact of increased running distance on foot strike pattern change and investigate the potential impact of foot strike pattern on performance.

Methods: Relevant peer-reviewed literature was obtained by searching EBSCOhost CINAHL, Ovid Medline, Embase and SPORTDiscus (inception-2021) for studies investigating foot strike patterns in overground distance running settings (>10km). Random effects meta-analyses of prevalence data were performed where possible.

Results: The initial search identified 2,210 unique articles. After removal of duplicates and excluded articles, 12 articles were included in the review. Meta-analysis of prevalence data revealed that 79% of long-distance overground runners rearfoot strike early, with prevalence rising to 86% with increased distance. 11% of runners changed foot strike pattern with increased distance and of those, the vast majority (84%) do so in one direction, being non-rearfoot strike to rearfoot strike. Analysis of the relationship between foot strike pattern and performance revealed that 5 studies reported a performance benefit to non-rearfoot strike, 1 study reported a performance benefit to non-rearfoot strike in women but not men, 4 studies reported no benefit to non-rearfoot strike or rearfoot strike and no studies reported a performance benefit of rearfoot strike over non-rearfoot strike.

Conclusion: Most overground distance runners rearfoot strike early and the prevalence of this pattern increases with distance. Of those that do change foot strike pattern, the majority transition from non-rearfoot to rearfoot. The current literature provides

inconclusive evidence of a competitive advantage being associated with long distance runners who use a non-rearfoot strike pattern in favour of a rearfoot strike pattern.

2.2 Key points

- 79% of overground distance runners rear-foot strike early, with prevalence increasing to 86% as distance increases.
- 11% of overground distance runners change their foot strike pattern as distance increases, with the majority of them transitioning from a non-rearfoot strike pattern to a rearfoot strike pattern.
- The evidence in support of a non-rearfoot strike pattern conferring a competitive performance advantage over the rearfoot strike pattern is inconclusive.

2.3. Introduction

Foot strike patterns in runners are generally grouped into three categories: rearfoot strike (RFS), midfoot strike (MFS) and forefoot strike (FFS). Classification of runners into one of these three categories can be achieved by observing the first point of contact between the landing foot with its running surface. The point of initial contact can be categorised to have occurred in one of three anatomical loci, which serve to describe the overall observed pattern. Broadly, an RFS pattern is said to occur when initial contact is made on the heel or rear one third of the foot, MFS when the heel and ball of the foot contact nearly simultaneously, and FFS when first contact is made on the front half of the foot, after which heel contact follows (Hasegawa, Yamauchi et al. 2007, Larson, Higgins et al. 2011, Bovalino, Cunningham et al. 2020). Due to the relatively low prevalence rates of both MFS and FFS patterns, coupled with the fact that they both occur at the anterior aspect of the foot, a further sub-classification exists which combines the two. This combined category is sometimes referred to as an anterior foot strike pattern, but more commonly has been described in the literature as a non-rearfoot strike (NRFS) pattern (Bovalino, Cunningham et al. 2020).

Foot strike patterns and their relationships with running performance, injury and economy have served as topics for debate within the literature, with some authors suggesting that changing foot strike is not beneficial to runners (Hamill and Gruber

2017). Claims of improved running economy (Perl, Daoud et al. 2012) and reduced rates of injury (Daoud, Geissler et al. 2012) have been reported in those habitually using NRFS patterns compared to those employing RFS; however, it is important to note that these associations are equivocal and the potential benefit of using an NRFS pattern has been challenged in the literature (Gruber, Umberger et al. 2013, Hamill and Gruber 2017).

The tightly controlled nature of the laboratory environment confers a number of obvious key advantages when investigating foot strike patterns. The use of a treadmill allows for static analysis in multiple planes, with precise adjustment of speed as a variable easily administered. Many studies in the past have employed this technique when investigating foot strike patterns (Ardigò, Lafortuna et al. 1995, Boyer, Rooney et al. 2014, Ogueta-Alday, Morante et al. 2018). However, when compared to overground running, treadmill running has been shown to alter key elements of the kinematic gait cycle; differences have been reported in the angle between shoe sole and ground at foot contact as well as step length, stride frequency and foot contact time (Wank, Frick et al. 1998). When comparing novice and competitive runners, untrained individuals are more prone to this phenomenon, with novice runners showing larger kinematic adjustments in a fatigued state when compared to their competitive counterparts (Maas, De Bie et al. 2018). It follows that research pertaining to foot strike pattern analyses performed in a laboratory or using a treadmill might not be applicable outside these settings. Focusing analyses on overground running specifically omits this potential confounding and confers wide applicability to the significant cohort of runners who engage in overground distance running.

Foot strike patterns during overground distance running (>10 km) have become increasingly researched. Other than the preliminary work by Kerr et al in 1983 (Kerr, Beauchamp et al. 1983), the paper by Hasegawa et al was the first well-designed and executed attempt to quantify and analyse foot strike patterns in an overground distance running setting, where capture occurred at the 15 km distance of an elite half marathon event (Hasegawa, Yamauchi et al. 2007). This analysis by Hasegawa et al was the first to be conducted within the confines of an official long distance running event, with access to large numbers of participants subjected to the same race distance and environment providing optimal conditions for investigation. Since this work there have been

additional attempts to explore foot strike patterns during overground running, using similar methods. Sub analyses on the relationship between foot strike patterns and performance (Hanley, Bissas et al. 2019, Hanley, Bissas et al. 2020), as well as assessment of the role that fatigue plays on foot strike patterns (Larson, Higgins et al. 2011) are also offered within this setting, as access to published race results is often freely available and matching participants over multiple time points in an event is possible.

Multiple studies have been published that investigate foot strike patterns within the context of long-distance overground running. To date, no systematic review and meta-analysis has been published to collate and quantify this literature base. Through establishing key prevalence data, observing the impact of distance and assessing any potential performance benefit associated with foot strike patterns, runners and coaches are permitted access to a foundation of knowledge to which training applications can be based on. The aims of this systematic review were to: (1) establish the prevalence of RFS and NRFS patterns both early and late in overground distance running settings; (2) assess the impact of increased distance on foot strike pattern change and establish its direction; and (3) determine if the NRFS pattern confers a performance advantage over the RFS pattern in long distance overground running; defined as either a faster finishing time or better representation in finishing position.

2.4. Methods

This review was reported in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher, Liberati et al. 2009).

Search strategy

Articles from the literature were systematically identified by searching the following databases from inception to the 2nd of July 2021; EBSCOhost CINAHL, Ovid Medline, Embase and SPORTDiscus. The search strategy was designed using terms within the three major constructs related to the research question (runners, distance setting and foot strike patterns), combined with the AND operator. These three constructs were

chosen to ensure results were focused on populations of runners engaging in a distance sub-discipline where foot strike patterns were analysed. Similar key terms were entered, in parenthesis, and separated by the term OR and truncation was used (*) to capture all possible variations of the selected key terms. The following search strategy was used: (running (MeSH) OR jogging (MeSH) OR runner* OR jogger* OR run OR jog) AND (distance OR length OR "long distance" OR marathon OR "half marathon" OR "ultra marathon" OR "race") AND ("foot strike" OR forefoot OR midfoot OR rearfoot OR "ground contact" OR "foot contact" OR footfall OR "foot landing"). In addition to the database search, the reference lists of relevant articles were also reviewed. No filters were employed in the search. The literature search was undertaken by author SB.

Inclusion and exclusion criteria

Original cross-sectional cohort studies published in English from peer-reviewed journals between no date to 2nd of July 2021, that focused primarily on capturing foot strike patterns in distance overground running settings were included. Articles were excluded based on the following criteria: (1) study conducted in a laboratory or on a treadmill, (2) <10 km total run distance, (3) not available in English language, (4) not peer-reviewed original research, (5) foot strike patterns not observed, (6) study conducted on non-human animals, (7) foot strike captured before 2 km or within 1 km of the finish (so as to combat potential surges in speed which can influence foot strike pattern), (8) conference proceedings, (9) study conducted on a non-random sample of participants and (10) non-observational study (intervention administered). Title review was undertaken by 1 reviewer (SB), followed by independent review of the abstract and full text articles by 2 reviewers (SB & MK) using the pre-agreed inclusion and exclusion criteria (Cohen's Kappa = 0.823). Disagreements were resolved after discussion between the 2 reviewers.

Outcomes of interest

In line with the research question and search strategy, data relating to three main areas of interest were collected and reported on: (1) foot strike pattern prevalence (including asymmetry); (2) the influence of increased distance on individual matched foot strike patterns, which was defined as change from NRFS to RFS or the converse between the first and last checkpoints; and (3) the relationship between foot strike pattern and

performance. One author (SB) performed the data extraction and the other author (MK) confirmed accuracy of the extracted data with no disagreements encountered. Separate studies employed different methods to quantify the impact of foot strike pattern on performance (i.e., finishing time, finishing position or representation within specific finishing centiles). To combine these data, a binary transformation was applied to the performance results of each study as either NRFS being faster than RFS, RFS being faster than NRFS, or no difference.

Critical review of study quality

A critical analysis of the included literature was undertaken to determine study quality. Given all included articles were observational cross-section studies, an adapted version of the NIH Quality Assessment Tool for Observational and Cross-Sectional Studies was employed. The original tool allocated a maximum of 14 points for the highest quality study; it was established that sections 6, 13 and 14 of the original tool were not applicable to our particular cohort of studies and thus, our adapted tool allocated a maximum of 11 points for the highest quality studies. To score a point for question 2 relating to study population, standard of athlete and or event name had to be specified. A point was given for question 8 (exposure) when studies analysed running speed, sampled from bands of running speed or commented on markers of intensity/effort. All remaining points were given in accordance with the originally designed tool. It was determined that studies for this review that scored between 9-11 were of high quality, 7-8 moderate quality and <7 low quality. Quality assessment was performed by both authors SB and MK and disagreements were resolved by discussion.

Meta-analysis of prevalence data

Meta-analyses of prevalence data was generated using the software package MetaXL (Version 5.3; EpiGear International Pty Ltd, Australia) employing a random effects model with double arcsine transformation (Barendregt, Doi et al. 2013). The proportion of effects due to heterogeneity were assessed using the I^2 statistic, where low, moderate, and high levels of heterogeneity were determined by I^2 values of < 25%, 25–75%, and > 75%, respectively (Khoury, Lecomte et al. 2013).

2.5. Results

Search strategy

A total of 2,210 unique articles were identified during the initial search strategy and through searching of reference lists. Of these, 12 articles met the inclusion criteria and were included in the analyses (Figure 2.1). Table 1 summarises the study characteristics, research design, total race distance, checkpoint/foot strike prevalence data, performance analysis and effect of increased distance on foot strike patterns assessing for change.

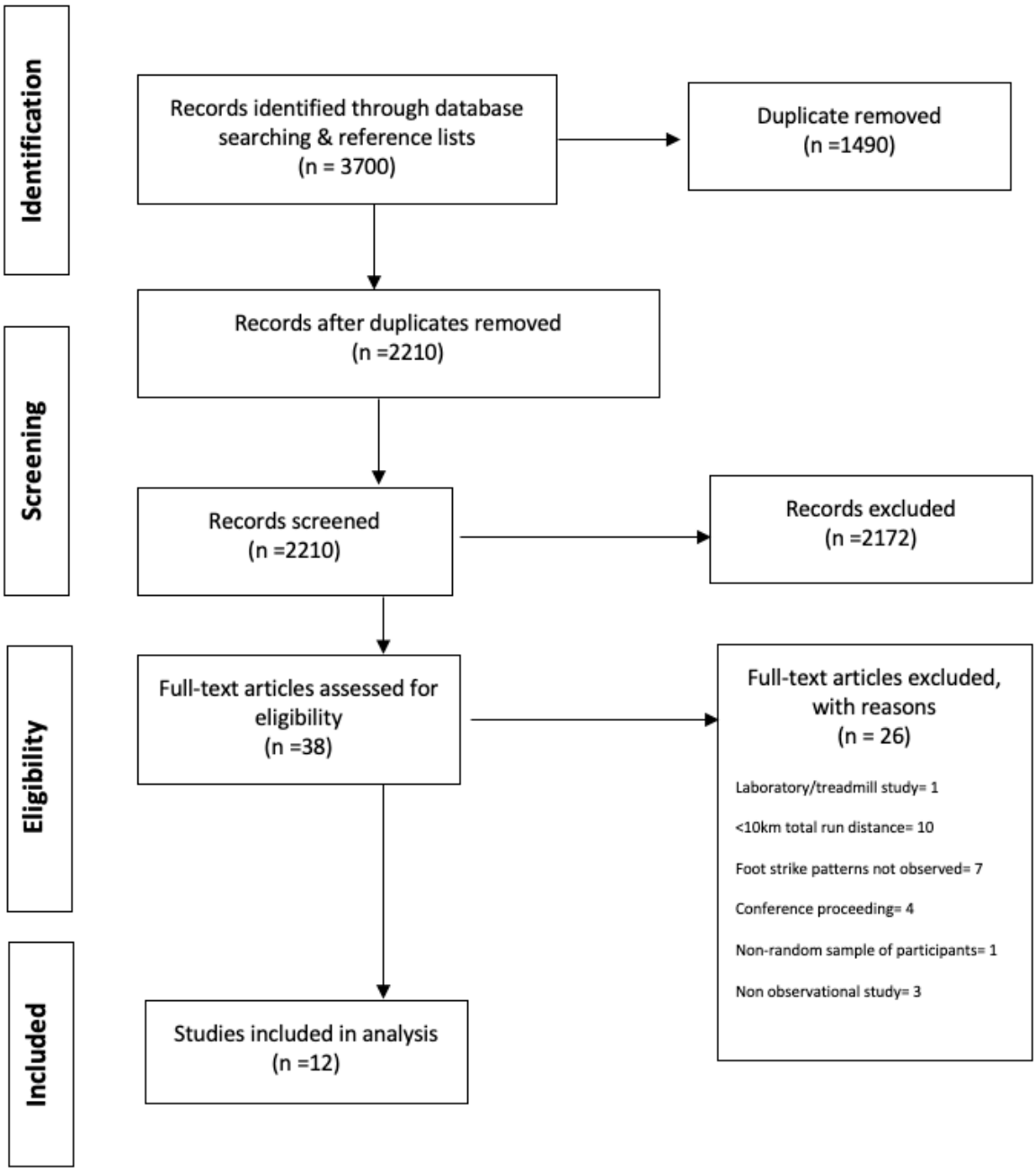

Figure 2.1. PRISMA flow diagram

Study design

Studies differed with regard to country of implementation, study design (sampling, recruitment, measurement methods) and primary outcomes (foot strike pattern, performance and change in foot strike pattern). Four studies were conducted in the USA, 2 in Singapore, 2 in the United Kingdom and with 1 study being conducted in each of Australia, Japan, New Zealand and Spain (Table 2.1). All studies were cross sectional cohort in their design. Sample sizes ranged from 12 participants (Hanley, Tucker et al. 2021) to 1,991 (Kasmer, Liu et al. 2013). Three studies were performed on entirely elite cohorts (Hasegawa, Yamauchi et al. 2007, Hanley, Bissas et al. 2019, Hanley, Tucker et al. 2021) while the remaining studies were all performed on recreational cohorts (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Kasmer, Wren et al. 2014, Latorre-Román, Jiménez et al. 2015, Kasmer, Liu et al. 2016, Murray, Beaven et al. 2019, Patoz, Lussiana et al. 2019, Bovalino, Cunningham et al. 2020, Hébert-Losier, Patoz et al. 2020). Total run distance varied from 10 km (Hanley, Tucker et al. 2021) to a 161.1 km ultramarathon (Kasmer, Wren et al. 2014). Five studies were performed within the confines of a traditional marathon distance (42.2 km) (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Hanley, Bissas et al. 2019, Patoz, Lussiana et al. 2019, Hébert-Losier, Patoz et al. 2020) and 2 at half-marathon distance (21.1 km) (Hasegawa, Yamauchi et al. 2007, Latorre-Román, Jiménez et al. 2015). The remaining studies were conducted over a 12km track run (Murray, Beaven et al. 2019), 15 km road run (Bovalino, Cunningham et al. 2020) and a 50 km trail run (Kasmer, Liu et al. 2016). All studies had at least one capture checkpoint for foot strike pattern analysis, with 4 studies employing two checkpoints (Larson, Higgins et al. 2011, Murray, Beaven et al. 2019, Bovalino, Cunningham et al. 2020, Hébert-Losier, Patoz et al. 2020) and 3 studies with more than two checkpoints (Kasmer, Wren et al. 2014, Hanley, Bissas et al. 2019, Hanley, Tucker et al. 2021). Studies that included 2 or more checkpoints enabled for assessment of the relationship between increased distance and change in foot strike pattern. Distances at which the various checkpoints occurred varied between studies (Table 2.1). All studies assessed for RFS, MFS and FFS prevalence at each checkpoint except for 1 study, which assessed for RFS and NRFS (combination of either FFS or MFS) (Bovalino, Cunningham et al. 2020). Seven studies assessed prevalence of asymmetrical foot strike patterns (difference between left and right foot strike) (Larson, Higgins et al. 2011, Kasmer, Liu et

al. 2013, Latorre-Román, Jiménez et al. 2015, Kasmer, Liu et al. 2016, Patoz, Lussiana et al. 2019, Hébert-Losier, Patoz et al. 2020, Hanley, Tucker et al. 2021). All studies assessed for impact of foot strike pattern on performance except 1 study (Murray, Beaven et al. 2019).

Table 2.1. Analysis of included studies

Study: Country	Sample (total N, location, athlete level)	Study Design	Distance (total)	Distance (checkpoint)	RFS	NRFS	MFS	FFS	Asymmetrical	Performance (NRFS vs RFS)	Change in foot strike pattern between first and last checkpoints (NRFS to RFS or RFS to NRFS)[c]
Bovalino et al. (2020): Australia [1]	N= 459 participants at the 2017 Melbourne City to Sea recreational running event (recreational)	Cross sectional	15km	3km	76.9%	22.0%	N/A	N/A	N/A	NRFS faster than RFS	N= 67/459 (14.6%) changed foot strike N= 64/67 (95.5%) changed from NRFS to RFS N= 3/67 (4.5%) changed from RFS to NRFS
				13km	91.0%	8.7%	N/A	N/A	N/A		
Hanley et al. (2021): United Kingdom[d] [19]	N=12 participants at the 2017 IAAF World Championships men's 10,000m final (elite)	Cross sectional	10km	4.18km	0%	100%	42%	50%	8%	N/A[d]	N= 0/12 changed foot strike (0%)[d]
				5.78km	0%	100%	50%	42%	8%		
				7.78km	0%	100%	50%	33%	17%		
Hebert-Losier et al (2020): Singapore [21]	N= 350 participants at the 2015 Standard Chartered Singapore Marathon (recreational)	Cross sectional	42.2km	10km	65%	24%	21%	3%	11%	NRFS NOT faster than RFS	N/A
				39km	77%	16%	15%	1%	8%		
Hanley et al. (2019): United Kingdom [14]	N= 149 participants at the 2017 IAAF World Championships marathon event (elite)	Cross sectional	42.2km	8.5km	60%	40%	36%	4%	N/A	NRFS NOT faster than RFS for men NRFS faster than RFS for women	N= 30/149 (20.1%) changed foot strike N= 24/30 (80%) changed from NRFS to RFS N= 6/30 (20%) changed from RFS to NRFS
				19km	64%	35%	31%	4%	N/A		
				29.5km	65%	35%	32%	3%	N/A		
				40km	70%	30%	27%	3%	N/A		
Hasegawa et al. (2007): Japan [2]	N= 283 participants at the 2004 47th Sapporo International Half Marathon (elite)	Cross Sectional	21.1km	15km	74.9%	25.1%	23.7%	1.4%	N/A	NRFS faster than RFS	N/A
Kasmer et al. (2016): USA [22]	N= 161 participants at the 2012 Ice Age Trail 50km race (recreational)	Cross sectional	50km	8.1km	85.1%	13.7%	13.7%	0%	1.2%	NRFS NOT faster than RFS	N/A
Kasmer et al. (2013): USA [20]	N= 1,991 participants at the 2011 Milwaukee Lakefront Marathon (recreational)	Cross sectional	42.2km	8.1km	93.7%	5.6%	5.1%	0.6%	0.7%	NRFS faster than RFS	N/A
Kasmer et al (2014): USA[a] [23]	N=316 participants at the 161.1km Western States Endurance Run (recreational)	Cross sectional	161.1km	16.5km	79.9%	11.1%	7.8%	0.3%	N/A	NRFS NOT faster than RFS	N= 23/316 (7.3%) changed foot strike pattern N= 17/23 (73.9%) changed from NRFS to RFS N= 6/23 (26.1%)) changed from RFS to NRFS
				90.3km	89%	6.8%	3.2%	1.1%	N/A		
Latorre-Roman et al. (2015) Spain[e] [24]	N=542 athletes who participated in the 2011 XVII International Half Marathon of Cordoba (recreational)	Cross sectional	21.1km	15km	95.4%	4.6%	3.5%	1.1%	25.9%	NRFS faster than RFS	N/A

Larson et al (2011): USA[b] [3]	N= 286 participants in the 2009 Manchester City Marathon (recreational)	Cross sectional	42.2km	10km	87.8%	4.5%	3.1%	1.4%	7.7%	NRFS NOT faster than RFS	N= 30/286 (10.5%) changed foot strike pattern N= 23/30 (76.7%) changed from NRFS to RFS N= 7/30 (23.3%) changed foot strike from RFS to NRFS
				32km	93%	3.5%	3.5%	0%	3.5%		
	N= 650 participants of the marathon relay and half marathon 2009 Manchester City Marathon (recreational)	Cross sectional	21.1km Marathon-Relay and Half Marathon cohort	10km	89.4%	5.5%	3.5%	2%	5.1%	NRFS NOT faster than RFS	N/A
Murray et al (2019): New Zealand [25]	N= 24 recreationally competitive runners (recreational)	Cross sectional	12km	3km	96%	4%	4%	0%	N/A	N/A	N= 1/24 (4%) changed foot strike pattern N= 1/1 (100%) changed from NRFS to RFS N= 0/1 (0%) changed from RFS to NRFS
				10km	100%	0%	0%	0%	N/A		
Patoz et al (2019): Singapore [26]	N= 940 participants of the 2015 Standard Chartered Singapore Marathon (recreational)	Cross sectional	42.2km	10km	71.1%	18.3%	16.6%	1.7%	10.6%	NRFS faster than RFS	N/A

[a]Kasmer et al 2014: four checkpoints included in study, but final checkpoint removed as it violated exclusion criteria of being within 1km of finish line. Checkpoint at 90.7km removed as it was downhill and deemed likely to impact foot landing position. Values do not add up to 100% due to different methods of foot strike categorisation used which could not always be adapted to fit table.

[b]Larson et al 2011: Relay marathon and half marathon cohort table has been adapted from raw data within study by subtracting the pure marathon runner cohort 10km data (n= 286) from the combined marathon/relay and half marathon 10km data (n= 936) to create a novel dataset of N= 650 10km data for relay marathon and half marathon combined. "Change" foot strike data was adapted from the raw data set provided by original author which contained both left and right individual foot strike data between checkpoints. This data was re-categorized to accept change between checkpoints in either left or right foot, to be deemed as change in general to ensure data was congruent with other studies. In cases where different foot strike patterns were observed between feet, but this pattern did not change between checkpoints, a NO change categorization was given.

[c]% and N= values will not always correlate with values offered in publication due to constraints on available data. Relevant text or tables within the paper used to produce congruent and applicable values for the purposes of this review. Direction of foot strike pattern change only recorded as either NRFS to RFS or RFS to NRFS. Data not included if studies reported further sub-categorisation of FFS or MFS.

[d]Hanley et al 2021= 6 checkpoints included in study, first two checkpoints removed due to violating exclusion criteria of being within 2km of start line and final checkpoint removed as it violated exclusion criteria of being within 1km of finish line. Performance data considered to be N/A as no competitors recorded as RFS for comparison. Under the definition given of changed foot strike contained within the methods of this study, no participants were seen change from NRFS to RFS (please note original paper did observe sub-category change between FFS and MFS).

[e]Latorre-Roman et al 2015= values were re-categorised from individual foot strike patterns. Asymmetry value % not offered in context of other foot strike patterns in paper.

Abbreviations:
FFS= forefoot strike
MFS= midfoot strike
NRFS= non-rearfoot strike
N= number of subjects
RFS= rearfoot strike

Foot strike pattern prevalence

Overall RFS prevalence at the first (or only) checkpoint was 79% (95% CI: 0.70 - 0.86, I^2=98%; Figure 2.2) while overall prevalence for the RFS pattern at the final checkpoint (in studies that included more than one checkpoint) was 86% (95% CI: 0.85 - 0.88, I^2=96%; Figure 2.3).

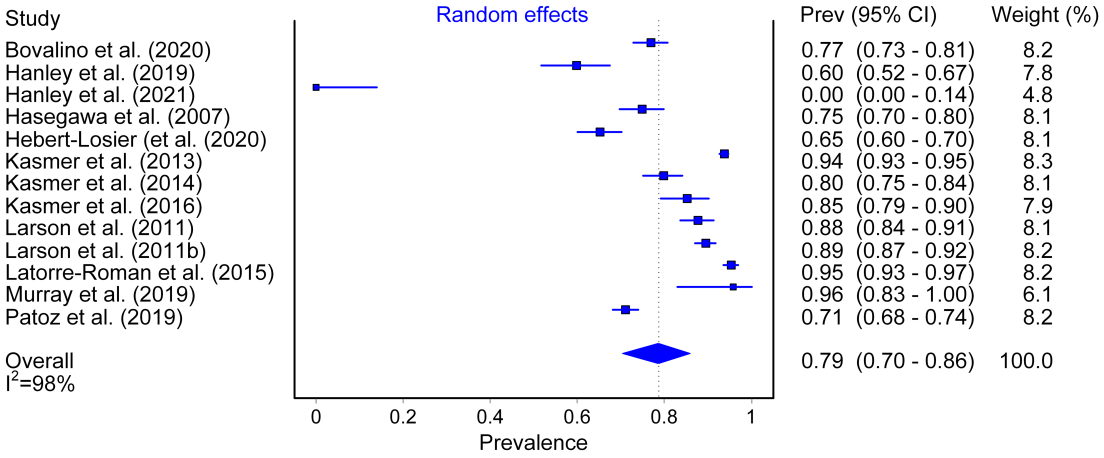

Figure 2.2. Prevalence of RFS measured at the first (or only) checkpoint

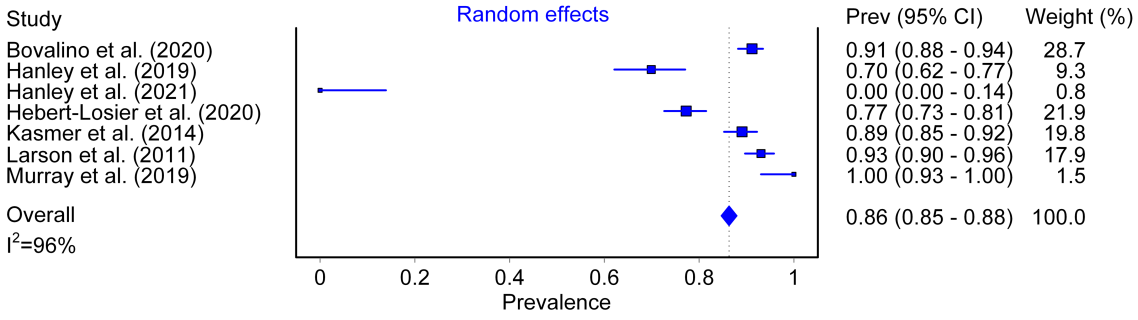

Figure 2.3. Prevalence of RFS measured at the final checkpoint in studies that utilized >1 checkpoint

Foot strike pattern change

Prevalence of total change in foot strike pattern was observed to be 11% (95% CI: 0.07 - 0.16, I^2=77%; Figure 2.4) and of this specific cohort the proportion seen to change from NRFS to RFS was 84% (95% CI: 0.70 – 0.94, I^2=67%). NRFS to RFS total prevalence was 10% (95% CI: 0.06 - 0.15, I^2=83%; Figure 2.5) while total prevalence of RFS to NRFS was 2% (95% CI: 0.01 – 0.03).

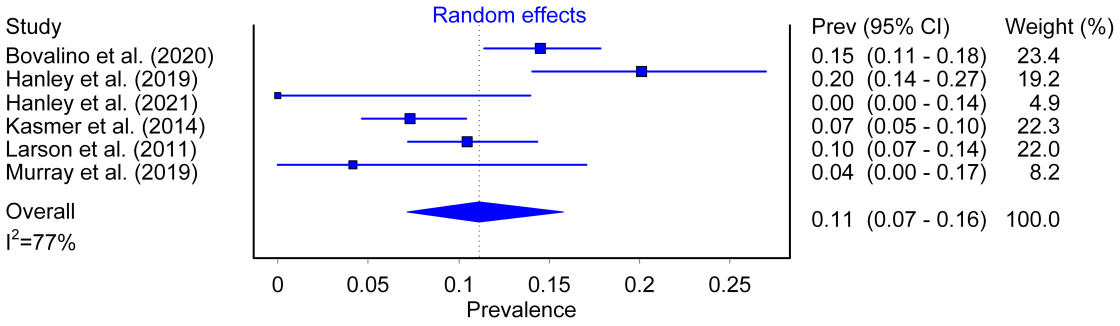

Figure 2.3. Prevalence of total change between first and last checkpoints

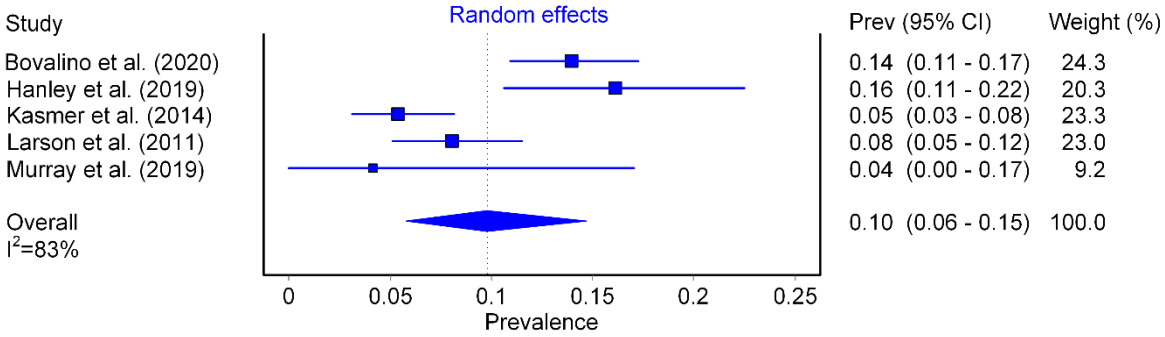

Figure 2.4. Prevalence of change from NRFS to RFS between first and last checkpoints

Foot strike pattern and performance

Of the studies that made an assessment of the relationship between foot strike pattern and performance, 5 found there to be a quantifiable difference in favour of the NRFS pattern being faster compared to RFS (Hasegawa, Yamauchi et al. 2007, Kasmer, Liu et al. 2013, Latorre-Román, Jiménez et al. 2015, Patoz, Lussiana et al. 2019, Bovalino, Cunningham et al. 2020), 1 study reported a performance benefit to NRFS in women but not men (Hanley, Bissas et al. 2019), 4 studies reported no benefit of either NRFS or RFS (Larson, Higgins et al. 2011, Kasmer, Wren et al. 2014, Kasmer, Liu et al. 2016, Hébert-Losier, Patoz et al. 2020) and no studies reported a performance benefit of RFS over NRFS (Table 2.1).

Asymmetry

Seven of the 12 included studies attempted to quantify and record asymmetry in foot strike pattern (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Latorre-Román, Jiménez et al. 2015, Kasmer, Liu et al. 2016, Patoz, Lussiana et al. 2019, Hébert-Losier, Patoz et al. 2020, Hanley, Tucker et al. 2021). These values ranged from as low as 0.7% prevalence in a recreational marathon (Kasmer, Liu et al. 2013), to as high as 25.9% in an event of the same distance and standard of athlete (Latorre-Román, Jiménez et al. 2015) (Table 2.1).

2.6. Discussion

This is the first review to assess and quantify the literature base pertaining to foot strike pattern prevalence, foot strike pattern change with increased distance and assessment of the interaction between foot strike pattern and performance within the context of overground long distance running. The vast majority of distance runners consistently run with an RFS pattern, the prevalence of which is seen to increase with distance. Furthermore, a proportion of runners appear to change foot strike pattern as distance increases and this pattern of change occurs almost exclusively in one direction (NRFS to RFS). Furthermore, inconclusive evidence exists of a performance advantage being associated with the NRFS pattern over the RFS pattern.

Across all studies, 79% (95% CI: 0.70 – 0.86) of runners were observed to use an RFS strike pattern early in a run (Fig. 2) and with increased distance, this prevalence became more pronounced, reaching a value of 86% (95% CI: 0.85 – 0.88; Figure 2). Foot strike pattern was first captured at different distances from the starting point, ranging from as early as 3 km (Murray, Beaven et al. 2019, Bovalino, Cunningham et al. 2020) to as far as 16.5 km (Kasmer, Wren et al. 2014) into the run. This was also true for the final checkpoint distance in studies that included more than one check point, ranging from 7.78 km (Hanley, Tucker et al. 2021) to 90.3 km (Kasmer, Wren et al. 2014). Disparities in foot strike capture location between studies demonstrates that there is no accepted standard in this particular field of research. However, it should be noted that despite this, all studies except 3 (Hasegawa, Yamauchi et al. 2007, Kasmer, Wren et al. 2014, Latorre-Román, Jiménez et al. 2015) placed their initial (or only) foot strike capture checkpoint at the 10 km mark or earlier. Of note, 2 of the included studies were conducted in trail running settings (Kasmer, Wren et al. 2014, Kasmer, Liu et al. 2016); a different terrain compared to road surface that has the potential to alter foot strike pattern and biomechanics (Horvais and Giandolini 2013, Giandolini, Pavailler et al. 2015). Furthermore, 3 studies were conducted on entirely elite running cohorts (Hasegawa, Yamauchi et al. 2007, Hanley, Bissas et al. 2019, Hanley, Tucker et al. 2021), a population with a greater tendency to use non-rearfoot striking patterns compared to recreational runners (Hanley, Bissas et al. 2019). These varying factors inherent within the cohort of studies included likely led to the high heterogeneity observed (Figure 2: I^2 = 98%); furthermore, the relatively small pool of literature meant that sub-analyses were not possible. While individual studies have previously attempted to quantify the proportion of athletes that run with each of the main categories of foot strike pattern (Hasegawa, Yamauchi et al. 2007, Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Kasmer, Wren et al. 2014, Latorre-Román, Jiménez et al. 2015, Kasmer, Liu et al. 2016, Hanley, Bissas et al. 2019, Murray, Beaven et al. 2019, Patoz, Lussiana et al. 2019, Bovalino, Cunningham et al. 2020, Hébert-Losier, Patoz et al. 2020, Hanley, Tucker et al. 2021); this review is the first to collate findings from the literature base for overground distance running and provides prevalence data representative of the global literature. As such, researchers, coaches and athletes along with key stakeholders such as shoe manufacturing companies can have greater confidence about the prevalence of foot strike patterns in their respective work.

The prevalence of runners who changed foot strike pattern between the first and last checkpoints was observed to be 11% (95% CI: 0.07 - 0.16). Six of the included studies were designed in a fashion to enable this analysis, each containing differences in total number of participants, total race distance and standard of athlete, which are all factors that might help to explain the heterogeneity observed between studies. Participant sample size in particular appears to be important when considering this phenomenon, with the observation approximating more consistent values when this is factored into the analysis. Of the 6 studies, 3 contained similar participant sample sizes of 286 (Larson, Higgins et al. 2011), 316 (Kasmer, Wren et al. 2014) and 459 (Bovalino, Cunningham et al. 2020) and provided similar prevalence estimates relating to total change in foot strike with 10%, 7% and 15%, respectively (Fig. 4). It has been postulated that highly trained athletes could be less prone to foot strike pattern change due to fatigue resistance in the plantar flexor muscle complex of the lower limb (Jewell, Boyer et al. 2017, Hanley, Bissas et al. 2019, Bovalino, Cunningham et al. 2020). This notion is both supported and challenged by the results of two studies using elite running cohorts; with 0% foot strike pattern change observed across a 10 km race (Hanley, Tucker et al. 2021) and 20% in a marathon (Hanley, Bissas et al. 2019). These incongruent results are potentially explained by the larger total race distance and increased demand of the muscle tendon units during a marathon event when compared to the shorter race [19]. However, with only 12 (Hanley, Tucker et al. 2021) and 149 (Hanley, Bissas et al. 2019) total participants included in these analyses, it is also possible that such observed results might simply be an artifact of the smaller sample sizes contained within these studies. A similar argument could be placed for the study that displayed a 4% prevalence in total change of foot strike pattern (Murray, Beaven et al. 2019), with this outlier containing only 23 participants in total. Due to the relatively infrequent prevalence of runners who are prone to changing foot strike with increased distance, a large enough sample appears to be requisite in order for this observation to surface reliably within data sets.

Foot strike pattern change with increased distance appears to usually occur in one direction, with 84% of runners who changed foot strike pattern doing so from NRFS to RFS; a phenomenon observed to be 5 times more prevalent than the converse. This observation seems apparent over multiple distance settings, including the marathon

(Larson, Higgins et al. 2011, Hanley, Bissas et al. 2019) and shorter format distance racing (Bovalino, Cunningham et al. 2020). An accepted mechanism to explain this observation is yet to be clarified in the literature. Possible explanations offered by authors currently revolve around the potential impacts that fatigue, running speed and experience have on foot strike patterns as running distance increases (Larson, Higgins et al. 2011, Hanley, Bissas et al. 2019, Bovalino, Cunningham et al. 2020). While the mechanism appears unclear, this review has now established the observation to be consistent in that the pattern of foot strike change, when it does occur, is reported most often in the same direction.

The relationship between foot strike pattern and running performance displayed inconclusive evidence in support of the NRFS pattern conferring a competitive advantage over the RFS pattern. Discussion around the potential improvements in performance garnered by using a non-rearfoot striking pattern have served as topics of debate in previously published literature (Perl, Daoud et al. 2012, Gruber, Umberger et al. 2013, Hamill and Gruber 2017, Hanley, Bissas et al. 2019, Bovalino, Cunningham et al. 2020, Hanley, Bissas et al. 2020). Individual studies have observed that top finishers of distance running events tend to use an NRFS pattern (Kerr, Beauchamp et al. 1983, Hasegawa, Yamauchi et al. 2007, Bovalino, Cunningham et al. 2020), while others have not been able to replicate the observation both in recreational (Larson, Higgins et al. 2011) and elite (Hanley, Bissas et al. 2019, Hanley, Bissas et al. 2020) running cohorts. Up until this point, no review of the literature pertaining to the interplay between foot strike patterns and performance in the overground distance running setting has been available. Papers reviewed in this analysis employed various methods of assessment in an attempt to quantify and report on the interaction, making comparison difficult on raw data alone. In an attempt to combine the results of these studies, a binary transformation was applied to the pre-existing data, reducing the findings of individual studies to either display RFS or NRFS patterns as being faster, or not as previously described. When quantified and applied to all standards of athlete, there appears to be an inconclusive bias in results towards the NRFS pattern being associated with a performance benefit over the RFS pattern.

Finally, asymmetry of foot strike pattern (difference between left and right feet) was seen to display inconsistent results. Prevalence of the asymmetrical running foot strike pattern within this cohort of studies ranged from 0.7% (Kasmer, Liu et al. 2013) to 25.9% (Latorre-Román, Jiménez et al. 2015), with the remaining studies displaying values falling between these two extremes (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2016, Patoz, Lussiana et al. 2019, Hébert-Losier, Patoz et al. 2020, Hanley, Tucker et al. 2021) (Table 1). Such high variability observed between studies suggests potential disparities exist regarding the categorisation and reporting of asymmetrical foot strike patterns. As such, it is presently difficult to consolidate this aspect of the literature and further research is required to more confidently account for asymmetry prevalence.

2.7. Conclusion

The vast majority of distance runners use a rearfoot strike pattern and the proportion of runners who employ this pattern rises as distance increases. A proportion of runners display a change in foot strike pattern with increased distance, with this phenomenon occurring almost entirely from non-rearfoot strike to rearfoot strike. Finally, there appears to be inconclusive evidence to support a performance benefit associated with non-rearfoot striking over rearfoot striking. The inclusion of both recreational and elite cohorts, across multiple distances and terrains allows the current findings of this review to be applied to a broad population of runners.

Chapter 3. Change in foot strike patterns and performance in recreational runners during a road race: A cross-sectional study.

This chapter is available in published format as follows: S.P. Bovalino, N. J. Cunningham, R. D. Zordan, S. M. Harkin, H. H. G. Thies, C. J. Graham and M. I. C. Kingsley (2020). "Change in foot strike patterns and performance in recreational runners during a road race: A cross-sectional study." Journal of Science and Medicine in Sport 23(6): 621-624. In accordance with La Trobe University policy relating to thesis presentation, work that has been published is included in the thesis as published and has not been modified in content.

3.1. Abstract

Objectives: To characterise foot strike and observe change in foot strike patterns with increasing distance during a 15 km recreational running road race. To assess the impact of foot strike on running performance.

Design: Observational cross-sectional study.

Methods: Foot strike patterns were determined at the 3 km and 13 km checkpoints for 459 participants during the 2017 Melbourne City to Sea recreational running event. Foot strike patterns were categorised as either rearfoot strike (RFS) or non-rearfoot strike (NRFS) at both checkpoints and analyses were conducted on intra-individual change in foot strike as well as relationship to finishing time.

Results: The most prevalent foot strike pattern at 3 km and 13 km was RFS with 76.9% (95%CI: 73.2%-80.5%) and 91.0% (95%CI: 88.7%-93.1%) using this pattern, respectively. Of the 105 participants who ran with a NRFS at 3 km, 61% changed to RFS at 13 km. Race completion time differed by foot strike pattern, where mean time for consistent NRFS (62.64 ± 11.20 min) was significantly faster than consistent RFS (72.58 ± 10.84 min; $p<0.001$) and those who changed from NRFS to RFS between checkpoints (67.93 ± 10.60 min; $p=0.040$).

Conclusions: While the majority of recreational distance runners RFS within race settings, the fastest runners were those who consistently ran with a NRFS. In runners that use a NRFS early, a large proportion change to RFS as distance increases. Further research is warranted to determine whether interventions aimed at reducing muscular fatigue can attenuate this change and enhance running performance.

3.2. Keywords

Foot-strike, rearfoot strike, non-rearfoot strike, fatigue, biomechanics

3.3. Practical Implications

- Recreational runners who non-rearfoot strike are susceptible to foot strike pattern change within 13 km.
- Changing foot strike pattern during distance running might be associated with muscular fatigue and/or reduced running speed as distance increases.
- Although running fast is not necessarily contingent upon any particular foot strike pattern, recreational runners who employ a consistent non-rearfoot strike pattern are faster than those who use a rearfoot strike pattern.

3.4. Introduction

The number of people participating in running as a leisure and/or competitive activity has increased over time. For example, the number of Australians who reported jogging on a regular basis increased by 9.2% between 2006 and 2016 (Roy Morgan Research 2016). The increased popularity of running has been paralleled with an elevated interest in running biomechanics, evidenced by a surge in the number of publications investigating foot strike patterns in both elite (Hasegawa, Yamauchi et al. 2007, Hayes and Caplan 2012, Hanley, Bissas et al. 2019) and recreational (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013, Patoz, Lussiana et al. 2019) distance runners.

The point of initial foot contact with the ground during running is the main factor that is used to categorise foot strike. Despite variability between runners, foot strike is generally classified into three categories: (1) rearfoot strike (RFS), where initial contact is made somewhere on the heel or rear one-third of the foot; (2) midfoot strike (MFS), where the heel and ball of the foot contact nearly simultaneously; and (3) forefoot strike (FFS), where initial contact is made on the front half of the foot, after which heel contact follow (Hasegawa, Yamauchi et al. 2007, Larson, Higgins et al. 2011).

Interest in foot strike patterns stemmed largely from commentary relating to economy, performance and/or injury (Hamill and Gruber 2017). Anterior foot strike patterns (FFS or MFS, which are also categorised as non-rearfoot strike or NRFS) have been reported to provide an advantage in terms of energetic economy over rearfoot striking, presumably through greater storage and release of elastic energy in the achilles tendon and foot arches (Perl, Daoud et al. 2012, Hanley, Bissas et al. 2019); although, this relationship is not uniformly accepted (Gruber, Umberger et al. 2013). Similar disagreement in the literature exists for the association between foot strike pattern and injury risk profile, with evidence existing both in favour of the RFS pattern carrying increased injury risk for distance runners (Daoud, Geissler et al. 2012) and against it (Hamill and Gruber 2017). A number of studies have investigated kinematic properties and efficiency of particular foot strike patterns within a laboratory setting (Ardigò, Lafortuna et al. 1995, Boyer, Rooney et al. 2014, Ogueta-Alday, Rodríguez-Marroyo et al. 2014) and there has been increasing interest in whether these properties translate to road running.

Eight studies have investigated both foot strike pattern and performance in large samples of distance runners within race settings (>21km); five of which have been conducted over a traditional marathon race distance (42.2km) both historically (Kerr, Beauchamp et al. 1983, Larson, Higgins et al. 2011, Kasmer, Liu et al. 2013). and more recently (Hanley, Bissas et al. 2019, Patoz, Lussiana et al. 2019). The remaining literature relates to a half-marathon (21.1km) (Hasegawa, Yamauchi et al. 2007), 50km trail race (Kasmer, Liu et al. 2016) and a 161.1km ultra-marathon (Kasmer, Wren et al. 2014). Results from these studies demonstrate that the majority of runners employ a RFS pattern, with proportions at any given point in a race ranging from 60% in an elite marathon cohort (Hanley, Bissas et al. 2019) to almost 94% in midsize city marathon (Kasmer, Liu et al. 2013). The proportion of runners who use a NRFS has been observed from 4% at the 32km point during a recreational level marathon (Larson, Higgins et al. 2011) to 40% at 8.5km in an elite event (Hanley, Bissas et al. 2019). Although the majority of authors report that non-rearfoot striking is associated with better running performance across half (Hasegawa, Yamauchi et al. 2007), full (R. 1983, Kasmer, Liu et al. 2013, Patoz, Lussiana et al. 2019) and ultra-marathon (Kasmer, Wren et al. 2014);

other authors have reported that running performance is not influenced by foot strike pattern (Larson, Higgins et al. 2011, Kasmer, Liu et al. 2016, Hanley, Bissas et al. 2019).

Consistent running with a FFS has been associated with increased ankle plantar flexor work and fatigue within the contractile properties of muscle (Jewell, Boyer et al. 2017). In an attempt to assess the effect that increasing distance has on intra-individual foot strike within race settings, three studies have employed a repeated measures protocol (Larson, Higgins et al. 2011, Kasmer, Wren et al. 2014, Hanley, Bissas et al. 2019). Larson et al. classified the foot strike pattern of recreational level marathon runners at both 10 km and 32 km checkpoints in a race (Larson, Higgins et al. 2011). These authors reported that 92% of individual coded forefoot strikes at the 10 km point changed to either MFS or RFS by 32 km and 60% of individual midfoot strikes at 10 km were reclassified to RFS at the 32 km location (Larson, Higgins et al. 2011). Kasmer et al. reported that 7.8% of runners changed foot strike patterns (59% moved from NRFS to RFS and 41% moved from RFS to NRFS) between 16.1 km and 161.1 km of an ultra-distance event (Kasmer, Wren et al. 2014). Most recently, Hanley et al. found that less than one quarter of athletes changed foot strike pattern during an elite level IAAF marathon race (Hanley, Bissas et al. 2019).

The heterogeneity in these findings is likely to reflect different total race distance, distance at which the measurements are obtained, terrain, and level of athlete. Specifically, the findings reported by Kasmer et al (Kasmer, Wren et al. 2014) and Hanley et al (Hanley, Bissas et al. 2019) refer to ultra-distance and elite athletes, respectively, which limits transferability to the broader running community. Larson et al. (Larson, Higgins et al. 2011) offers the most applicable insight into the role that distance plays on foot strike patterns in recreational runners. However, given that the protocol assessed foot strike patterns at 10 km and 32 km, the potential exists that the originally adopted foot strike might have been altered by 10 km into a race (particularly in recreational runners). It follows that a gap in the literature exists pertaining to the analysis of change in the foot strike patterns of recreational level runners at shorter distances. The aims of this study were to: (1) characterise foot strike and observe change in foot strike patterns between the 3 km and 13 km checkpoints of a recreational level 15 km distance race; and (2) assess the impact of foot strike pattern on running performance.

3.5. Methods

Participants of the Sunday Age Melbourne City to Sea event (Melbourne, Victoria, Australia) were filmed on November the 12th 2017 at 3 km and at 13 km of the 15 km course. Runners were simultaneously filmed using two cameras: (1) panning camera was positioned to capture the race bib numbers of runners for identification purposes, and (2) GoPro Hero Black (200 frames per second), which was fixed to a tripod near ground level, oriented perpendicular to the runners in order to capture foot strike in the sagittal plane. The cameras were set up on a flat stretch of road with no incline or decline, so as not to influence gait. The width of road at both locations was approximately that of a single car lane, providing only minimal variability in distance of participants from the cameras. However, there were times during the event when a large number of participants passed through the checkpoints. During instances where either bib-number or foot strike were obscured, we did not classify the foot strike of runners.

All runners competing in the 15 km event were eligible to participate. The only exclusion criteria was a finishing time of ≥95 min, which corresponded to an average running speed of ≥2.63 m/s. In order to obtain a cross section of the running community, we convenience sampled a maximum of 101 participants in ten distinct time bands with five-minute increments, which started with the first participant through the capture location. Ethical approval to conduct the study was obtained from St Vincent's Hospital Melbourne Human Research Ethics Committee (LLR 197/17). Additionally, permission to film the participants in the race was also received from the race organisers.

Video from the panning camera and GoPro were synchronised using the respective time stamps and visualised in a split screen with commercial software (Final Cut Pro X; Apple Inc, US). Gender, age group, race number, race position, sex and finishing time were obtained from the online published race results. Video analysis was performed in QuickTime Player (Apple Inc, US), with the HD image (1,920 x 1,080 pixels) allowing visualisation of the initial point of foot contact with the road. Consistent with other researchers, we classified RFS to be where the first contact of the foot with the ground occurred on the heel or rear one-third of the sole (Hasegawa, Yamauchi et al. 2007, Hanley, Bissas et al. 2019) (Figure 3.1 (a)). Given that the initial point of contact for both MFS and FFS is the metatarsal heads of the forefoot (Breine, Malcolm et al. 2014), we

combined both of these strike patterns together in order to simplify analysis. A NRFS (either MFS or FFS) pattern was deemed to be one in which the first contact of the foot with the ground occurred anywhere on the front two-thirds of the sole (Figure 3.1 (b) and 3.1 (c)). Rather than differentiating between the right and left legs to look for asymmetry, we analysed the clearest frame of the strike to ascertain the pattern. Two authors (SB and SH) coded one half of the images each and based on a sample of 100 images, which were randomised and blinded, the inter-rater reliability was excellent (k = 0.93).

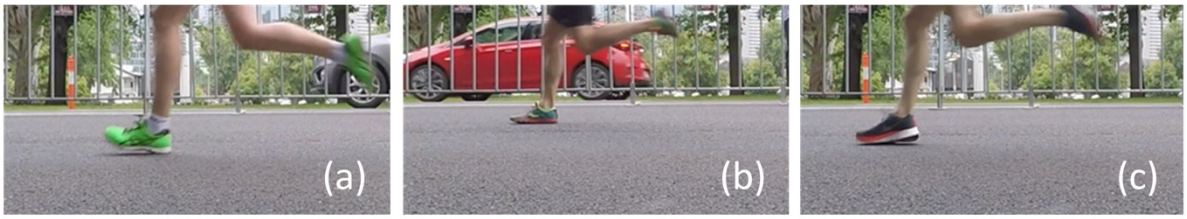

Figure 3.1. Sample images of foot strike patterns: (a) rearfoot strike (b) midfoot strike and (c) forefoot strike. Both (b) and (c) were coded as non-rearfoot strike.

Statistical analyses were performed using IBM SPSS Statistics for Windows (Version 25; IBM Corporation, USA) and differences were determined significant when $p < 0.05$. Group data are presented as mean and standard deviation. A one-way ANOVA was conducted to determine if differences in completion time existed between the three groups: (1) RFS- no change, (2) NRFS- no change, and (3) NRFS to RFS- changed. The category 'RFS to NRFS- changed' was not included in the analysis as the number identified with this pattern was too small (n=3). Post-hoc analyses were conducted using Tukey HSD tests.

3.6. Results

There were 5,498 entrants with 4,690 finishers (85.3%). The first finisher recorded a race completion time of 44.13 min (average speed 5.66 m/s). The first three time bands (44-<50 min, 50-<55 min and 55-<60 min) included 12, 22 and 82 participants, respectively. The seven remaining time bands included either 100 or 101 participants. In total, 820 participants were included in the sampled population. Participants were predominately male (n=557, 70.4%) and mean age was 35.8 years (SD ± 11 years). Foot strike type was

identified in 543 (66.2%) participants at checkpoint 1 (3 km) and 662 (80.7%) participants at checkpoint 2 (13 km). Of the sample, 459 (56.0%) participants were identified to have a recorded and categorised foot strike pattern at both checkpoints.

The most prevalent foot strike pattern at 3 km and 13 km was RFS with 76.9% and 91.0% using this pattern at the two time points, respectively. 22.0% of participants were identified as NRFS at 3 km, decreasing to 8.7% at the 13 km checkpoint. Foot strike was considered indeterminate for 1.1% and 0.3% of participants at 3 km and 13 km, respectively.

The majority of participants did not change their foot strike pattern from RFS between the 3 km and 13 km checkpoints (76.6%). 8.9% maintained a NRFS pattern at both 3 km and 13 km (Table 2). 64 of the 105 participants (61%) with a NRFS pattern at 3 km changed to RFS at 13 km.

Table 3.1. Foot strike pattern change between the 3 km and 13 km checkpoints for rearfoot strike (RFS) and non-rearfoot strike (NRFS).

	n	%	95% CI
Consistent foot strike			
RFS	354	76.6	72.7 - 80.3
NRFS	41	8.9	6.5 - 11.7
Changed foot strike			
NRFS to RFS	64	13.9	10.8 - 17.1
RFS to NRFS	3	0.6	0.0 - 1.5

n: number; 95% CI: 95% confidence interval

Race completion time differed by foot strike pattern [$F_{(2,456)} = 18.49$, $p < 0.001$], where mean time for the NRFS-no change group (62.64 ± 11.20 min) was significantly faster

compared to the RFS-no change group (72.58 ± 10.84 min). The NRFS to RFS-changed group mean time (67.93 ± 10.60 min) was also significantly faster compared to the RFS-no change group mean time. There was a significant difference between the mean time of NRFS-no change and the NRFS to RFS-changed group, with the former being faster (Figure 3.2).

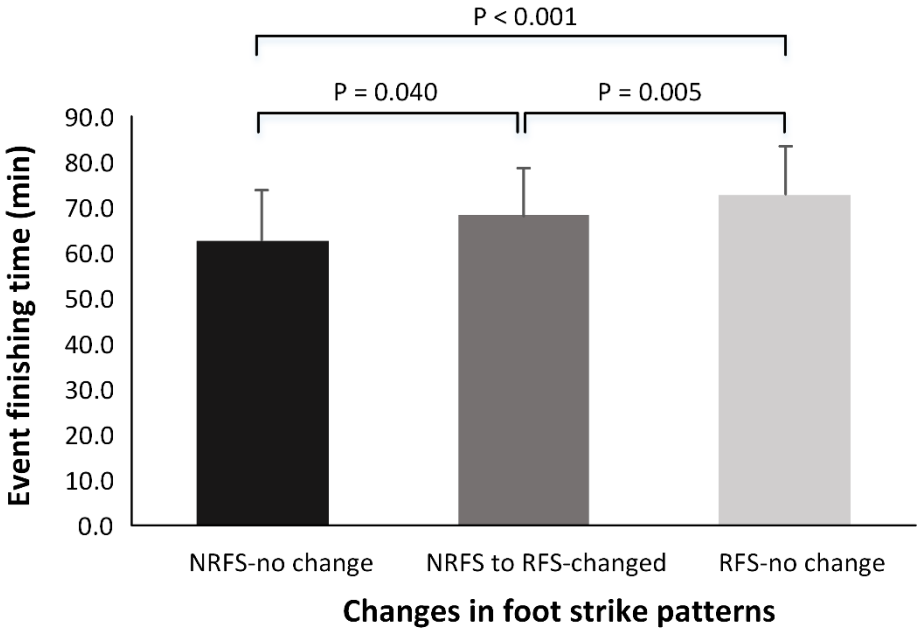

Figure 3.2. Race completion time for participants grouped by change in foot strike patterns between the 3km and 13km checkpoints. RFS: rearfoot strike; NRFS: non-rearfoot strike.

3.7. Discussion

The current study evaluated changes in foot strike patterns across two checkpoints during a 15 km distance running event with more than three times the number of recreational participants represented in previous studies. The key findings demonstrated that the majority of runners ran with a RFS across both distance checkpoints and a large proportion of those who originally were seen to NRFS, transitioned to RFS before the end of the race. Furthermore, the fastest runners within the race were those who consistently employed a NRFS pattern. Including a wide cross section of runners (average running speed ranged from 2.63 m/s to 5.66 m/s) allows the current findings to be generalised to a broad population of recreational runners.

The proportion of runners who ran with a RFS in the current study at the 13 km checkpoint (91.0%) was greater than those observed within elite level cohorts at similar distances (Hasegawa, Yamauchi et al. 2007, Hanley, Bissas et al. 2019) but aligned with those previously reported in a recreational running cohort (Larson, Higgins et al. 2011). The proportion of runners who ran with a NRFS (8.7%) was higher than reported at 10 km of a marathon for similarly experienced runners (Larson, Higgins et al. 2011), but lower than elite athletes (Hasegawa, Yamauchi et al. 2007, Hanley, Bissas et al. 2019). Nevertheless, these results confirm that runners of any experience or performance level competing in a long distance running road race are more likely to RFS (Larson, Higgins et al. 2011, Hanley, Bissas et al. 2019, Patoz, Lussiana et al. 2019).

At 3 km, 76.9% and 22.0% of participants employed a RFS and NRFS pattern, respectively. These values represent lower proportions of rearfoot striking and higher proportions of non-rearfoot striking when compared to foot strike patterns observed by Larson et al. at 10 km in the 2009 Manchester City Marathon (87.8% RFS and 4.5% NRFS) (Larson, Higgins et al. 2011). Between-study differences in the location of the checkpoints and total race distance are likely to have influenced running speed and this might partially explain the higher proportion of participants who ran with a NRFS in the current study. In support of this statement, 45% of runners transition towards a more anterior foot strike as running speed increases (Breine, Malcolm et al. 2014). Within a recreational cohort, running 1 m/s faster has been shown to increase the odds of running with a FFS or MFS compared to RFS by 2.3 and 2.6 times respectively (Cheung, Wong et al. 2017). It follows that recreational runners competing in shorter distance events will maintain higher average running speeds, particularly early on, and are more likely to adopt a NRFS when compared to longer distance events such as the marathon.

Regarding change in foot strike, 61% of participants who were classified with a NRFS at 3 km changed to RFS at 13 km, while less than 1% of participants changed from RFS to NRFS over the same distance. This finding aligns with results from previous studies (Larson, Higgins et al. 2011, Hanley, Bissas et al. 2019). The inability for most recreational runners to maintain a NRFS as distance increases might be explained by the interaction between plantar flexor muscle fatigue and changing running speed.

Prolonged running has been demonstrated to fatigue the plantar flexor muscles and result in decreased force production (Jewell, Boyer et al. 2017). Coupled with potential advantages relating to carbohydrate oxidation (Gruber, Umberger et al. 2013) and improved energetics (Miller and Hamill 2015), transitioning from initial non-rearfoot striking to a RFS could be a function of mounting fatigue during distance running. An alternative explanation is that decreased running speed has a direct effect on foot strike biomechanics, as previously described (Breine, Malcolm et al. 2014, Cheung, Wong et al. 2017). As a result of accumulated fatigue, recreational runners will often reduce running speed during a race. It is possible, therefore, that a combination of plantar flexor muscle fatigue and reduced running speed will result in recreational runners assuming a more posterior foot strike towards the end of a distance race (Larson, Higgins et al. 2011). Without access to split times throughout the race, it is difficult to evaluate the influence of running speed on change in foot strike patterns. Regardless of the underlying mechanism, the current findings suggest that, at a recreational level, foot strike regression from NRFS to RFS occurs at earlier stages of a race than previously observed and future studies should account for this.

Our results showed that participants who ran with a RFS had slower finishing times (Figure 3.2). Runners who maintained a RFS at both check points were the slowest group, while runners who maintained a NRFS throughout the race were the fastest group. Runners with higher performance are more likely to be well trained for this race distance, likely to experience less muscular fatigue and more likely to be able to use a NRFS throughout the race. To the contrary, the slowest group consistently used a RFS pattern (RFS-no change) throughout the race. It is plausible that the group of runners who changed from a NRFS to RFS included those who were unable to maintain a NRFS between the 3 km and 13 km checkpoints as a consequence of muscular fatigue, or as a direct effect of lower running speed. Although foot strike variation can occur more frequently in less trained runners, or those running at a lower cadence (Lieberman, Castillo et al. 2015), the causes of foot strike variation are yet to be fully elucidated.

This study was not without limitations. Although our study evaluated the influence of running distance on foot strike, its design did not allow identification of the point at which any changes in foot strike occurred, the average speed before and after this

change, or other factors that might explain changes in foot strike pattern (e.g., measures of muscular fatigue, ratings of perceived exertion, cadence, stride length). RFS to NRFS-changed occurred so infrequently (n=3) it was not possible to include this group in the statistical analysis. As only one foot strike was captured at each checkpoint, assessment of foot strike asymmetry was not undertaken in this study. Nevertheless the prevalence of asymmetry in foot strike is relatively low and estimated to be present in up to 5.9% of runners (Larson, Higgins et al. 2011). Finally, it is possible that intermittent stumbles or ground irregularity might have influenced the foot strike patterns of runners confounding the results in our study.

3.8. Conclusions

Analyses of foot strike patterns within a recreational cohort showed that the majority of distance runners employ a rearfoot strike pattern across all distances within race settings. A large proportion of runners who made initial ground contact on either the mid or forefoot early in a race transitioned to a rearfoot strike pattern before completion. The fastest runners observed were those who consistently used a non-rearfoot strike pattern. Further research is warranted to determine whether interventions aimed at reducing muscular fatigue can attenuate this change and influence running performance.

3.9. Acknowledgements

The authors would like to thank Mr Daniel Bovalino and Mr Matthew Cunningham for their assistance with data collection and technical support. The authors would also like to state that there has been no financial assistance for the completion of this work.

Chapter 4. Discussion and conclusions

4.1. Integrated discussion of findings

The purpose of this thesis was to investigate the effect of long-distance overground running on key parameters pertaining to foot strike patterns, namely prevalence and change in pattern with increasing distance. Secondary aims of this work were to further investigate whether there exists any performance benefit relating to one foot strike pattern over another while also investigating the above-mentioned factors in the context of shorter distances within a recreational level cohort.

For the first time, the status of the current literature base pertaining to foot strike patterns in long distance overground running has been collated and quantified in a unified body of research. Prevalence rates for each of the three respective foot strike patterns can now be more confidently quoted as being reflective of the entire literature base, opposed to a reliance on individual studies. Given the relatively narrow literature base previously published (12 studies identified fitting inclusion criteria in Chapter 2) there existed the potential for biased conclusions to be drawn from individual studies. Furthermore, there appears to be inconsistency between studies relating to study design, namely total run distance, terrain and athlete performance level. This being the case, athletes and run coaches alike were previously prone to erroneous interpretations and conclusions based off study design. These disparate individual analyses have now been unified to provide a more global interpretation of foot strike prevalence, with a key finding of Chapter 2 being that across all published literature on the topic, 79% of runners rearfoot strike early in an overground setting with this figure rising to 86% with increasing distance. These results have wider implications for athletes, coaches and even shoe manufacturing companies as it is abundantly clear that the vast majority of runners aggregate towards the utilisation of one particular foot strike pattern, namely RFS. Given the known biomechanical differences that exist between each of the respective foot strike patterns (Almeida, Davis et al. 2015, Xu, Yuan et al. 2021), there exists the potential for shoe manufacturers to tailor their products that serve the needs of the majority of the running populous. Similarly, coaches should refer to these figures in the consideration of injury prevention, a hotly debated topic that falls outside of the scope of this thesis (Hamill and Gruber 2017).

Through the generation of the systematic review and meta-analysis performed in Chapter 2, it was established that total prevalence of the RFS pattern began at 79% early in a distance run and went to 86% as distance increased. Six of 12 included studies employed suitable study procedures to allow for intra-individual foot strike change analysis, which required a repeated measures protocol whereby individual runners' foot strike patterns are identified at multiple checkpoints. From these raw data, at the individual level, it was established that 11% of runners change their foot strike pattern within an event, and that the direction of this change occurs almost always from NRFS to RFS (84%). This finding was replicated in Chapter 3 within a recreational level cohort at a shorter run distance than had previously been reported in the literature, with 13.9% of runners changing foot strike pattern from NRFS to RFS as distance increased with only 0.6% going from RFS to NRFS. The findings of Chapter 3 also suggested that the majority (61%) of recreational level distance runners who utilise a NRFS pattern early, will eventually change to a RFS pattern by the end of a distance run somewhat reflecting the results of Chapter 2. The reasoning behind these observations at this stage are still considered to be speculative in nature. While previous researchers have strongly suggested that fatigue of the plantar flexor muscles with increasing run distance is the potential causative mechanism (Larson, Higgins et al. 2011), future work is required to confidently establish a causal relationship. These findings have significant implications for athletes, run coaches and health care professionals. While further work is most certainly required, this sub-group of runners who are seen to change foot strike pattern as run distance increases represent an exciting cohort for future analysis. Of particular interest is whether or not these individuals are potentially more prone to injury as they are exposed to a wider sub-set of biomechanical pressures compared to those maintaining consistent foot strike patterns.

Regarding performance, while not conclusive, the results of this thesis suggested that there does exist a trend towards non-rearfoot striking individuals being faster than their rearfoot striking counterparts. When the totality of evidence was considered in the work of Chapter 2, results did display a bias towards a performance benefit being associated with the NRFS pattern. Similarly, the results of Chapter 3 displayed a clear performance benefit conveyed to the sub-group of runners that were able to maintain a NRFS pattern throughout the duration of the event. This particular area of research has traditionally

drawn close attention, with recent work suggesting that at the elite level no such performance benefits are seen (Hanley, Bissas et al. 2019, Hanley, Bissas et al. 2020). As discussed in detail within Chapter 3, careful consideration needs to be paid to the key dynamic biomechanical changes that seem to occur when runners transfer through phases of increasing running speeds, with the mechanism behind observations potentially being a by-product of run speed opposed to any inherent benefits associated with the foot strike pattern itself (Breine, Malcolm et al. 2014, Cheung, Wong et al. 2017). Further appropriately designed research that focuses on gait retraining with tight control of confounders is warranted before any conclusive recommendations can be made regarding foot strike patterns and performance. Key take away messages for athletes, coaches and sport scientists are not that running fast is necessarily contingent upon the utilisation of anterior strike patterns, but rather there possibly exists some inherent biomechanical and or economical advantage to NRFS patterns over RFS patterns in certain sub-sections of the population. Most certainly, it seems that the more advanced an athlete becomes in their run experience and athlete level, the less of an impact foot strike patterns seems to have on performance per se.

Finally, the work contained within this thesis and in particular, that is contained within Chapter 3, has thoroughly investigated foot strike pattern characteristics at shorter total race distances than previously researched. While it is true that two previous papers employed a similar protocol of analysis with a total run distance of 12km (Murray, Beaven et al. 2019) and 10km (Hanley, Tucker et al. 2021), sample sizes offered were far too small to draw any conclusive observations from. The findings of Chapter 3 are the first to present analysis of foot strike patterns in overground runners at a distance more representative of recreational standards (15 km). Consequently, the results contained within can be applied to a wider population of runners, serving as a springboard for future research to build off of. Furthermore, recreational level athletes appear to be more prone to the effects of foot strike pattern change with increasing distance, health professionals in particular should pay attention to this when considering the biomechanical factors that could potentially be contributing to running related injury and stressors. Previous to this research, it could have potentially been assumed, erroneously so, that considerable run distance would have been required in order to accumulate sufficient loads and fatigue states to generate true biomechanical change.

This research suggests that as early as between 3 km and 13 km, sufficient loads are generated to induce foot strike pattern alteration in recreational level athletes.

4.2 Limitations

Limitations of each of the respective studies contained within this thesis have been individually explored in their relevant chapters (Chapter 2 and Chapter 3). As such, this section will instead focus on the broad limitations on the thesis as a whole.

Firstly, given the true relevant paucity of research published in this niche field, a small pool of studies exist that fit the key inclusion criteria for the systematic review and meta-analysis. As such, in order to collate and compare data metrics, certain potential confounders between studies were not able to be adequately accounted for, as their exclusion would have left too few studies for comparison. Race terrain in long distance overground events can vary between off road, track and on road. Each of these terrains would in theory exert varying biomechanical loads on a runner's body, hence potentially impacting the foot strike pattern utilised. Similarly, not all studies employed the same total race distance, with the variance of spread in this regard ranging from 10 km all the way to 161.1 km (Table 2.1). While the majority of studies investigated did congregate around either the half-marathon or full marathon race distance, this spread of total run distance between studies is undeniably a potential confounder in analysis. Unfortunately, this limitation is likely due to the fact that 'distance running' is a vague term devoid of tight definition. In general, distance running is usually seen as any form of running that is predominantly aerobic in nature with respect to the utilisation of energy systems. This put in the context of athletics running delivers a demarcation and crossover point that is usually considered to be any distance beyond 3000 meters (Encyclopedia Britannica 2017). It is evident, therefore, that due to the wide interpretation of what precisely defines distance running, a large amount of heterogeneity exists in the literature base concerning its investigation.

Due to the disparate methods employed by individual studies to measure run performance as an endpoint, a binary transformation was applied to simplify analysis and enable comparison between studies. Whether or not the NRFS pattern conferred a performance advantage over RFS, or not, was the only logical transformation to the pre-

existing data that enabled common parlance and comparison between studies in Chapter 2. While ostensibly useful, binary transformations create limitations in analysis by way of potential oversimplifications and loss of nuance within data sets. This proved to be a limitation of the thesis' ability to confidently draw links between individual foot strike patterns and run performance.

Key markers of running fatigue such as split times, ratings of perceived exertion, cadence and stride length appear to not be consistently measured co-variables in this field of research. Unfortunately, this creates the inability to confidently attribute observed changes in foot strike patterns as distance increases with fatigue. This is a key limitation that appears to permeate research within this field as a whole, making for speculative conclusions. While tempting to draw the logical parallel between increasing run distance and the potential for fatigue, without directly measured metrics researchers are prone to making erroneous conclusions regarding the interplay between foot strike patterns and distance.

4.3 Recommendations for future research

Given the aforementioned limitations and key findings of this thesis, a series of recommendations for future research pertaining to the analysis of foot strike patterns in overground distance running can be confidently made.

In general, there is a need for more studies within this field of research. While an onerous task, when compared to treadmill-based analysis, the investigation of foot strike patterns in true overground distance run settings provides invaluable real-world application. Researchers should also consider that single point capture of foot strike patterns offers little in the way actionable results and would be strongly encouraged to capture foot strike patterns of individual runners along multiple checkpoints of increasing distance. Through the use of this particular study design, the signals established within the body of this thesis can be further established and built upon. Future research should also continue to stratify analysis based on varying run terrain,

distance and athlete level in an effort to parse out key differences that may or may not be present between these key variables of analysis.

Of particular importance, is the need for future research to build off of the key finding of foot strike pattern change with increasing distance. As displayed in both Chapters 2 and 3, significant percentages of runners appear to change from a NRFS pattern to RFS as run distance increases, offering an exciting cohort for sub-analysis. Whether these changes are owing to fatigue accumulation or not is still a poorly understood phenomenon that further research could quite easily shed light on through the analysis of additional key metrics. Furthermore, whether or not this sub-section of runners that change foot strike pattern are at an increased risk of running related injury is also in need of addressing. If so, there are rather impactful ramifications for health care professionals and run coaches, as individuals could be potentially screened for increased injury risk prior to the injury occurring through simply looking for this pattern of change pre-emptively.

Future research in this particular field should also focus efforts on better understanding foot strike pattern asymmetry between feet. Chapter 2 revealed inconsistent and widely variable results between studies that performed this sub-analysis, hinting towards potential methodological inconsistency between studies. A true prevalence rate of the asymmetrical foot strike pattern, along with its impact on the abovementioned key discussion points is currently poorly understood. More research is needed to elucidate the potential relationships that exist between those who strike differently on each foot compared to more commonly observed homologous foot strike patterns.

Finally, regarding the potential performance associations associated with particular foot strike patterns, there appears a need for future research to no longer rely on association analysis retrospectively, as has been traditionally been the case. This method fails to address key confounders and relies far too heavily on correlation as an end point. In order to more confidently draw conclusions surrounding this question, future research should aim to keep co-variables tightly accounted for that are known to impact performance outcomes independently. In particular, a randomised control trial with cross-over design of gait retrained individuals with pre and post intervention performance analysis would be of particular use in answering this question more

confidently. Furthermore, stratification between experienced and recreational athletes in this regard would also be of further value.

4.4. Conclusions

All studies conducted within this thesis can be replicated using the same simple principles of study design which are well-established and accepted within this field of research. Namely, through the utilisation of high-definition sagittal plane videography used to ascertain the foot strike patterns of individuals runners in overground settings. The widespread availability of high-definition motion capture cameras that are seemingly ubiquitous in modern day smart phone technology can permit sports coaches, scientists and athletes to easily assess foot strike patterns in day-to-day settings and apply the results of this thesis as they see fit.

The conclusions of this thesis can be summarised as follows:

- The vast majority of overground distance runners rearfoot strike and this prevalence increases with distance.

- A proportion of overground distance runners change foot strike pattern as distance increases and this pattern of change occurs almost exclusively from non-rearfoot strike to rearfoot strike.

- While the mechanism is unclear and needs further work, there appears to be inconclusive evidence of there being a performance benefit associated with the non-rearfoot strike pattern when compared with the rearfoot strike pattern.

Chapter 5. Appendices

5.1 Meta-data for Chapter 2

PREVALENCE OF RFS AT FIRST CHECKPOINT			
Study name	N	Cases	Qi
Bovalino et al. (2020)	459	353	1
Hanley et al. (2019)	149	89	1
Hasegawa et al. (2007)	283	212	0.888889
Kasmer et al. (2016)	161	137	0.777778
Kasmer et al. (2013)	1991	1865	0.888889
Kasmer et al. (2014)	316	252	1
Larson et al. (2011)	286	251	0.818182
Larson et al. (2011)	650	581	0.888889
Murray et al. (2019)	24	23	1
Patoz et al. (2019)	940	668	0.888889

PREVALENCE OF RFS AT SECOND CHECKPOINT			
Study name	N	Cases	Qi
Bovalino et al. (2020)	459	418	0.82
Hanley et al. (2019)	149	104	0.82
Hasegawa et al. (2007)	283	N/A	0.73
Kasmer et al. (2016)	161	N/A	0.64
Kasmer et al. (2013)	1991	N/A	0.73
Kasmer et al. (2014)	316	281	0.82
Larson et al. (2011)	286	266	0.82
Larson et al. (2011)	650	N/A	0.73
Murray et al. (2019)	24	24	0.82
Patoz et al. (2019)	940	N/A	0.73

PREVALENCE OF NRFS AT FIRST CHECKPOINT			
Study name	N	Cases	Qi
Bovalino et al. (2020)	459	101	0.82
Hanley et al. (2019)	149	60	0.82
Hasegawa et al. (2007)	283	71	0.73
Kasmer et al. (2016)	161	22	0.64
Kasmer et al. (2013)	1991	111	0.73
Kasmer et al. (2014)	316	35	0.82
Larson et al. (2011)	286	13	0.82
Larson et al. (2011)	650	36	0.73
Murray et al. (2019)	24	1	0.82
Patoz et al. (2019)	940	172	0.73

PREVALENCE OF NRFS AT SECOND CHECKPOINT			
Study name	N	Cases	Qi
Bovalino et al. (2020)	459	40	0.82
Hanley et al. (2019)	149	45	0.82
Hasegawa et al. (2007)	283	N/A	0.73
Kasmer et al. (2016)	161	N/A	0.64
Kasmer et al. (2013)	1991	N/A	0.73
Kasmer et al. (2014)	316	21	0.82
Larson et al. (2011)	286	10	0.82
Larson et al. (2011)	650	N/A	0.73
Murray et al. (2019)	24	0	0.82
Patoz et al. (2019)	940	N/A	0.73

ATHLETE LEVEL	
Study name	Level
Bovalino et al. (2020)	Recreational
Hanley et al. (2019)	Elite
Hasegawa et al. (2007)	Elite
Kasmer et al. (2016)	Recreational
Kasmer et al. (2013)	Recreational
Kasmer et al. (2014)	Recreational
Larson et al. (2011)	Recreational
Larson et al. (2011)	Recreational
Murray et al. (2019)	Recreational
Patoz et al. (2019)	Recreational

PERFORMANCE	
Study name	Performance
Bovalino et al. (2020)	NRFS faster than RFS
Hanley et al. (2019)	NRFS NOT faster than RFS for Men, NRFS faster than RFS for women
Hasegawa et al. (2007)	NRFS faster than RFS
Kasmer et al. (2016)	NRFS NOT faster than RFS
Kasmer et al. (2013)	NRFS faster than RFS
Kasmer et al. (2014)	NRFS NOT faster than RFS
Larson et al. (2011)	NRFS NOT faster than RFS
Larson et al. (2011)	NRFS NOT faster than RFS
Murray et al. (2019)	N/A
Patoz et al. (2019)	NRFS faster than RFS

MATCHING/CHANGE IN FOOT STRIKE PATTERN BETWEEN FIRST AND LAST CHECKPOINTS							
Study name	N=total	N=changed	% changed	N= NRFS to RFS	% NRFS to RFS	N= RFS to NRFS	% RFS to NRFS
Bovalino et al. (2020)	459	67	14.6%	64	95.50%	3	4.50%
Hanley et al. (2019)	149	30	20.10%	24	80%	6	20%
Murray et al. (2019)	24	1	4%	1	100%	0	0%
Kasmer et al. (2014)	316	23	7%	17	73.90%	6	26.10%
Larson et al. (2011)	286	30	10.50%	23	76.70%	7	23.30%

STUDY QUALITY SCORE														
Study	1	2	3	4	5	6	7	8	9	10	11	Total (Max: 11)	9	**<<--max score in list**
Bovalino et al. (2020)	1	1	1	1	0	1	1	1	1	1	0	9	1	
Hanley et al. (2019)	1	1	1	1	0	1	1	1	1	1	0	9	1	
Hasegawa et al. (2007)	1	1	1	1	0	1	1	1	0	1	0	8	0.888889	
Kasmer et al. (2016)	1	0	1	1	0	1	1	1	0	1	0	7	0.777778	
Kasmer et al. (2013)	1	1	1	1	0	1	1	1	0	1	0	8	0.888889	
Kasmer et al. (2014)	1	1	1	1	0	1	1	1	1	1	0	9	1	
Larson et al. (2011)	1	1	1	1	0	1	1	1	1	1	0	9	1	
Larson et al. (2011)	1	1	1	1	0	1	1	1	0	1	0	8	0.888889	
Murray et al. (2019)	1	1	1	1	1	1	0	1	1	1	0	9	1	
Patoz et al. (2019)	1	1	1	1	0	1	1	1	0	1	0	8	0.888889	

5.2 Meta-data for Chapter 3

Subject	Bib	Finish Time	Place	Gender	Division	Band	Station 1 0=Other 1=Rear Foot 3=Indeterminant	Station 2 0=Other 1=Rear Foot 3=Indeterminant
1	46	0:44:08	1	M	M30-39	44--50	0	
2	50	0:44:09	2	M	M20-29	44--50	0	
3	154	0:46:06	3	M	M20-29	44--50	0	
4	29	0:46:29	4	M	M30-39	44--50	0	
5	129	0:46:30	5	M	M30-39	44--50	0	
6	21	0:47:17	6	M	M30-39	44--50	0	0
7	43	0:47:21	7	M	M30-39	44--50	0	0
8	40	0:47:46	8	M	M30-39	44--50	0	0
9	32	0:48:38	9	M	M30-39	44--50	0	0
10	44	0:48:45	10	M	M20-29	44--50	1	0
11	36	0:48:51	11	M	M30-39	44--50	0	0
12	26	0:49:13	12	M	M20-29	44--50	0	1
13	730	0:50:16	13	M	M30-39	50--55	1	0
14	20	0:50:24	14	M	M20-29	50--55	0	0
15	42	0:51:08	15	M	M20-29	50--55	0	0
16	158	0:51:12	16	M	M20-29	50--55	0	
17	145	0:51:40	17	M	M20-29	50--55	1	
18	27	0:51:44	18	M	M16-19	50--55	0	
19	30	0:52:07	19	M	M30-39	50--55	0	
20	147	0:52:28	20	M	M20-29	50--55	0	
21	125	0:52:41	21	M	M16-19	50--55	1	1
22	28	0:52:43	22	M	M30-39	50--55	1	1
23	41	0:53:16	23	M	M20-29	50--55	0	1
24	155	0:53:17	24	M	M30-39	50--55	0	1
25	45	0:53:22	25	M	M30-39	50--55	1	1
26	35	0:53:26	26	M	M30-39	50--55	1	1
27	47	0:53:31	27	M	M40-49	50--55	0	1
28	110	0:53:33	28	M	M20-29	50--55	1	1
29	150	0:53:48	29	M	M30-39	50--55	1	1
30	18	0:54:08	30	M	M30-39	50--55	0	0
31	151	0:54:16	31	M	M20-29	50--55	0	0
32	142	0:54:24	32	M	M30-39	50--55	0	0
33	127	0:54:31	33	M	M40-49	50--55	1	1
34	6254	0:54:46	34	M	M40-49	50--55	1	1
35	124	0:55:03	35	M	M30-39	55--60	1	1
36	130	0:55:03	36	M	M40-49	55--60	0	0
37	12	0:55:03	37	M	M20-29	55--60	1	1
38	117	0:55:08	38	M	M30-39	55--60	1	1

39	7536	0:55:10	39	M	M20-29	55--60	0	1
40	140	0:55:27	40	M	M20-29	55--60	1	1
41	697	0:55:29	41	M	M40-49	55--60	0	1
42	108	0:55:31	42	M	M30-39	55--60	0	1
43	131	0:55:35	43	M	M30-39	55--60		1
44	282	0:55:44	44	M	M30-39	55--60	1	1
45	675	0:55:46	45	M	M50-59	55--60	1	1
46	7957	0:55:49	46	M	M20-29	55--60		1
47	121	0:55:57	47	M	M40-49	55--60	1	1
48	103	0:56:03	48	M	M30-39	55--60	0	0
49	7693	0:56:09	49	M	M20-29	55--60	1	1
50	112	0:56:12	50	M	M30-39	55--60	1	1
51	662	0:56:19	51	M	M16-19	55--60		1
52	113	0:56:25	52	M	M20-29	55--60	0	0
53	137	0:56:29	53	M	M30-39	55--60	0	0
54	22	0:56:35	54	M	M30-39	55--60	0	1
55	152	0:56:37	55	M	M40-49	55--60		1
56	153	0:56:38	56	M	M40-49	55--60	1	1
57	334	0:56:52	57	M	M30-39	55--60	1	1
58	15	0:56:55	58	M	M40-49	55--60	1	1
59	19	0:56:56	59	F	F40-49	55--60	0	0
60	481	0:56:56	60	M	M40-49	55--60	0	1
61	101	0:56:59	61	M	M40-49	55--60	1	1
62	139	0:57:07	62	M	M30-39	55--60	1	1
63	116	0:57:11	63	M	M30-39	55--60	0	1
64	133	0:57:17	64	M	M30-39	55--60	0	1
65	106	0:57:28	65	M	M30-39	55--60		1
66	156	0:57:32	66	F	F20-29	55--60	0	0
67	134	0:57:33	67	M	M30-39	55--60	1	1
68	109	0:57:39	68	M	M30-39	55--60	1	
69	681	0:57:44	69	M	M30-39	55--60	1	1
70	7767	0:57:47	70	M	M20-29	55--60		1
71	118	0:57:48	71	M	M20-29	55--60		1
72	10674	0:57:49	72	M	M30-39	55--60		
73	6886	0:57:50	73	M	M20-29	55--60		1
74	160	0:57:51	74	M	M50-59	55--60	0	1
75	114	0:57:54	75	M	M40-49	55--60	1	1
76	536	0:57:54	76	M	M30-39	55--60	1	1
77	349	0:57:59	77	M	M30-39	55--60	1	1
78	135	0:58:00	78	M	M30-39	55--60	0	0
79	126	0:58:02	79	M	M40-49	55--60	0	1
80	5139	0:58:02	80	M	M20-29	55--60		
81	377	0:58:08	81	M	M30-39	55--60	1	1

82	547	0:58:08	82	F	F16-19	55--60	1	1
83	8024	0:58:09	83	M	M20-29	55--60	1	1
84	501	0:58:15	84	M	M30-39	55--60	1	1
85	399	0:58:15	85	M	M30-39	55--60	1	1
86	440	0:58:25	86	M	M40-49	55--60	1	1
87	323	0:58:32	87	M	M16-19	55--60	1	1
88	8137	0:58:35	88	M	M20-29	55--60		
89	6579	0:58:39	89	M	M20-29	55--60		1
90	107	0:58:42	90	M	M40-49	55--60		1
91	7094	0:58:42	91	M	M40-49	55--60	1	
92	624	0:58:47	92	M	M40-49	55--60	1	1
93	11	0:58:51	93	M	M30-39	55--60	0	1
94	7677	0:58:51	94	M	M30-39	55--60	1	1
95	111	0:58:54	95	M	M40-49	55--60	1	1
96	731	0:59:00	96	M	M20-29	55--60	1	1
97	8070	0:59:05	97	M	M13-15	55--60		1
98	310	0:59:05	98	M	M20-29	55--60	0	1
99	8172	0:59:05	99	M	M13-15	55--60	1	1
100	429	0:59:12	100	M	M20-29	55--60	1	1
101	677	0:59:17	101	M	M30-39	55--60	1	1
102	614	0:59:17	102	M	M20-29	55--60	0	1
103	619	0:59:23	103	M	M16-19	55--60	1	1
104	711	0:59:26	104	M	M30-39	55--60	1	1
105	383	0:59:33	105	M	M50-59	55--60	0	
106	7295	0:59:34	106	M	M30-39	55--60	1	1
107	271	0:59:37	107	M	M20-29	55--60		1
108	395	0:59:41	108	M	M40-49	55--60	1	1
109	276	0:59:44	109	M	M30-39	55--60	1	1
110	161	0:59:46	110	M	M30-39	55--60	1	1
111	7021	0:59:54	111	M	M13-15	55--60	1	1
112	7187	0:59:54	112	M	M20-29	55--60	1	1
113	5837	0:59:56	113	M	M20-29	55--60	1	1
114	115	0:59:58	114	M	M30-39	55--60	1	1
115	157	0:59:59	115	M	M20-29	55--60	1	
116	48	1:00:00	116	F	F30-39	55--60	0	1
117	420	1:00:05	117	M	M20-29	60--65	0	0
118	573	1:00:15	118	M	M30-39	60--65	1	1
119	8198	1:00:16	119	M	M30-39	60--65	1	
120	357	1:00:19	120	M	M30-39	60--65		
121	8218	1:00:19	121	M	M40-49	60--65	3	1
122	6841	1:00:22	122	M	M20-29	60--65	0	
123	6313	1:00:22	123	M	M30-39	60--65		1
124	8116	1:00:22	124	F	F20-29	60--65		1
125	600	1:00:27	125	M	M30-39	60--65	1	1

126	4018	1:00:29	126	F	F50-59	60--65		
127	507	1:00:33	127	M	M20-29	60--65	1	1
128	5523	1:00:41	128	M	M20-29	60--65	1	
129	6016	1:00:43	129	M	M30-39	60--65		1
130	8319	1:00:44	130	M	M20-29	60--65		1
131	5885	1:00:46	131	M	M30-39	60--65	1	
132	5685	1:00:47	132	M	M20-29	60--65	1	
133	6064	1:00:52	133	M	M30-39	60--65		1
134	408	1:00:53	134	M	M20-29	60--65	1	1
135	475	1:00:55	135	M	M40-49	60--65	1	1
136	669	1:00:56	136	M	M20-29	60--65		1
137	7618	1:00:57	137	M	M20-29	60--65	0	1
138	664	1:01:00	138	M	M20-29	60--65	1	1
139	313	1:01:05	139	M	M40-49	60--65	1	
140	6359	1:01:05	140	M	M30-39	60--65	1	1
141	608	1:01:08	141	M	M40-49	60--65	0	1
142	5023	1:01:14	142	M	M20-29	60--65		1
143	5856	1:01:15	143	M	M20-29	60--65	0	
144	516	1:01:20	144	M	M40-49	60--65	1	1
145	6678	1:01:26	145	M	M20-29	60--65		1
146	476	1:01:31	146	M	M50-59	60--65	1	1
147	480	1:01:37	147	M	M40-49	60--65	1	1
148	409	1:01:41	148	M	M50-59	60--65	0	1
149	3893	1:01:45	149	F	F20-29	60--65	1	1
150	434	1:01:46	150	M	M30-39	60--65	0	1
151	333	1:01:46	151	M	M50-59	60--65	1	1
152	240	1:01:50	152	M	M50-59	60--65	0	1
153	557	1:01:52	153	M	M20-29	60--65		1
154	722	1:01:54	154	M	M40-49	60--65	0	1
155	5714	1:01:54	155	M	M20-29	60--65		1
156	39	1:01:56	156	F	F30-39	60--65	0	0
157	727	1:01:58	157	M	M30-39	60--65	0	0
158	4165	1:02:01	158	M	M20-29	60--65	1	1
159	226	1:02:01	159	M	M60-69	60--65	0	1
160	141	1:02:08	160	F	F30-39	60--65	0	0
161	6624	1:02:14	161	M	M20-29	60--65	1	1
162	132	1:02:16	162	F	F40-49	60--65	0	1
163	515	1:02:20	163	M	M40-49	60--65	0	1
164	497	1:02:20	164	M	M30-39	60--65	1	1
165	5374	1:02:24	165	M	M40-49	60--65		
166	718	1:02:25	166	M	M30-39	60--65	0	0
167	230	1:02:27	167	M	M30-39	60--65	1	1
168	5831	1:02:33	168	M	M20-29	60--65	1	1
169	7184	1:02:36	169	M	M13-15	60--65	1	1

170	708	1:02:37	170	F	F20-29	60--65	1	1
171	702	1:02:38	171	M	M40-49	60--65	1	1
172	6294	1:02:39	172	M	M20-29	60--65	1	1
173	638	1:02:40	173	M	M30-39	60--65	0	0
174	7495	1:02:41	174	M	M13-15	60--65	1	
175	3726	1:02:45	175	M	M30-39	60--65	1	1
176	532	1:02:46	176	M	M30-39	60--65	1	1
177	635	1:02:46	177	M	M30-39	60--65	1	1
178	511	1:02:48	178	M	M30-39	60--65	0	0
179	452	1:02:48	179	M	M30-39	60--65	0	0
180	484	1:02:49	180	M	M20-29	60--65	1	1
181	6941	1:02:49	181	M	M40-49	60--65	1	
182	7734	1:02:49	182	M	M20-29	60--65	1	
183	220	1:02:52	183	M	M30-39	60--65	0	1
184	485	1:02:53	184	M	M30-39	60--65	1	1
185	278	1:02:53	185	M	M40-49	60--65	1	1
186	574	1:02:59	186	M	M16-19	60--65	0	0
187	733	1:03:00	187	M	M30-39	60--65		0
188	523	1:03:02	188	M	M40-49	60--65		1
189	7848	1:03:07	189	M	M20-29	60--65	0	
190	5486	1:03:13	190	F	F20-29	60--65		
191	8246	1:03:19	191	F	F30-39	60--65	1	
192	6721	1:03:21	192	M	M20-29	60--65	1	1
193	6155	1:03:22	193	M	M20-29	60--65	1	
194	321	1:03:26	194	M	M30-39	60--65	1	1
195	3009	1:03:27	195	M	M30-39	60--65		
196	428	1:03:28	196	M	M40-49	60--65		1
197	143	1:03:29	197	M	M40-49	60--65		1
198	4052	1:03:29	198	M	M30-39	60--65		
199	144	1:03:30	199	M	M40-49	60--65	3	1
200	210	1:03:31	200	M	M30-39	60--65	1	1
201	120	1:03:33	201	M	M40-49	60--65		1
202	309	1:03:35	202	M	M20-29	60--65	1	1
203	7593	1:03:36	203	M	M40-49	60--65	1	1
204	642	1:03:37	204	M	M40-49	60--65	3	1
205	7564	1:03:37	205	M	M16-19	60--65	0	0
206	644	1:03:38	206	M	M16-19	60--65	1	1
207	207	1:03:40	207	M	M30-39	60--65	1	1
208	637	1:03:41	208	M	M40-49	60--65	0	1
209	7145	1:03:45	209	M	M40-49	60--65	1	1
210	13	1:03:46	210	F	F40-49	60--65	1	1
211	685	1:03:47	211	M	M40-49	60--65	1	
212	447	1:03:50	212	M	M20-29	60--65	1	1
213	128	1:03:51	213	F	F20-29	60--65	0	1

214	335	1:03:54	214	M	M30-39	60--65		1
215	555	1:03:56	215	M	M30-39	60--65	0	0
216	398	1:03:57	216	M	M40-49	60--65	1	1
217	6019	1:05:01	258	M	M20-29	65--70	1	1
218	219	1:05:01	259	M	M40-49	65--70	1	1
219	286	1:05:02	260	M	M30-39	65--70		1
220	6718	1:05:04	261	M	M20-29	65--70		1
221	4096	1:05:07	262	M	M40-49	65--70	1	1
222	5464	1:05:08	263	M	M30-39	65--70	3	1
223	8154	1:05:09	264	M	M30-39	65--70	0	1
224	8155	1:05:09	265	M	M20-29	65--70	1	1
225	618	1:05:11	266	M	M30-39	65--70	1	1
226	489	1:05:11	267	M	M40-49	65--70	1	1
227	580	1:05:12	268	M	M30-39	65--70	0	
228	483	1:05:13	269	F	F30-39	65--70	1	1
229	7764	1:05:13	270	M	M20-29	65--70	1	
230	7682	1:05:14	271	M	M40-49	65--70	0	1
231	448	1:05:15	272	M	M30-39	65--70	1	1
232	7980	1:05:18	273	F	F30-39	65--70	1	1
233	8181	1:05:18	274	M	M30-39	65--70	1	1
234	486	1:05:21	275	M	M40-49	65--70	1	1
235	6431	1:05:24	276	M	M30-39	65--70		1
236	262	1:05:27	277	M	M50-59	65--70		1
237	463	1:05:27	278	M	M50-59	65--70	1	1
238	612	1:05:28	279	M	M40-49	65--70	1	1
239	10652	1:05:30	280	M	M20-29	65--70		
240	5098	1:05:31	281	M	M30-39	65--70	1	1
241	518	1:05:31	282	M	M30-39	65--70		1
242	331	1:05:32	283	F	F40-49	65--70	1	1
243	7979	1:05:35	284	M	M40-49	65--70	0	0
244	5611	1:05:36	285	F	F30-39	65--70		
245	415	1:05:36	286	M	M30-39	65--70	1	1
246	251	1:05:38	287	M	M40-49	65--70	1	1
247	8166	1:05:38	288	M	M20-29	65--70		
248	5201	1:05:39	289	M	M20-29	65--70	0	1
249	561	1:05:40	290	M	M30-39	65--70		1
250	7489	1:05:41	291	M	M40-49	65--70	1	1
251	253	1:05:41	292	M	M30-39	65--70	1	1
252	6191	1:05:42	293	M	M30-39	65--70	1	1
253	6590	1:05:42	294	M	M13-15	65--70	1	1
254	508	1:05:42	295	M	M20-29	65--70	1	1
255	8257	1:05:43	296	M	M30-39	65--70		1
256	34	1:05:45	297	F	F30-39	65--70		3

257	362	1:05:45	298	M	M40-49	65--70	1	1
258	5027	1:05:46	299	M	M20-29	65--70	1	1
259	500	1:05:47	300	M	M30-39	65--70	1	1
260	680	1:05:48	301	M	M30-39	65--70	1	1
261	284	1:05:50	302	M	M50-59	65--70	1	1
262	672	1:05:51	303	M	M40-49	65--70		1
263	10604	1:05:52	304	F	F20-29	65--70		1
264	649	1:05:52	305	M	M30-39	65--70	1	1
265	671	1:05:54	306	F	F40-49	65--70	1	1
266	427	1:05:54	307	M	M16-19	65--70	1	1
267	8262	1:05:55	308	M	M30-39	65--70	1	1
268	378	1:05:56	309	M	M40-49	65--70	1	1
269	316	1:05:56	310	M	M30-39	65--70	0	1
270	6897	1:06:01	311	M	M20-29	65--70		
271	704	1:06:01	312	M	M30-39	65--70	1	1
272	348	1:06:03	313	F	F40-49	65--70		0
273	694	1:06:04	314	M	M20-29	65--70	1	1
274	338	1:06:05	315	F	F20-29	65--70		1
275	597	1:06:05	316	M	M30-39	65--70	1	1
276	237	1:06:07	317	M	M40-49	65--70	1	1
277	627	1:06:08	318	M	M20-29	65--70	1	1
278	7802	1:06:08	319	M	M20-29	65--70	1	1
279	735	1:06:09	320	M	M30-39	65--70	0	1
280	337	1:06:09	321	M	M40-49	65--70	1	1
281	496	1:06:10	322	M	M20-29	65--70	1	1
282	7412	1:06:11	323	M	M20-29	65--70	1	1
283	575	1:06:11	324	M	M20-29	65--70	1	1
284	206	1:06:14	325	M	M40-49	65--70	0	1
285	8314	1:06:15	326	M	M30-39	65--70	1	1
286	5153	1:06:15	327	M	M30-39	65--70	1	1
287	7399	1:06:16	328	M	M20-29	65--70	1	1
288	3501	1:06:18	329	M	M40-49	65--70	1	1
289	6876	1:06:18	330	F	F20-29	65--70		1
290	7209	1:06:18	331	M	M13-15	65--70	1	
291	3795	1:06:19	332	M	M20-29	65--70	1	1
292	569	1:06:21	333	M	M50-59	65--70	1	1
293	315	1:06:22	334	F	F30-39	65--70	0	0
294	433	1:06:22	335	F	F40-49	65--70		1
295	8233	1:06:22	336	M	M40-49	65--70	1	1
296	632	1:06:22	337	F	F20-29	65--70	1	1
297	6420	1:06:25	338	M	M30-39	65--70	1	1
298	320	1:06:26	339	M	M30-39	65--70	1	1
299	8350	1:06:29	340	M	M30-39	65--70		1

300	682	1:06:30	341	F	F20-29	65--70	1	1
301	519	1:06:32	342	M	M40-49	65--70		1
302	266	1:06:32	343	M	M50-59	65--70		1
303	734	1:06:33	344	M	M30-39	65--70	1	1
304	243	1:06:36	345	F	F50-59	65--70	0	1
305	6589	1:06:36	346	M	M50-59	65--70	1	1
306	7970	1:06:38	347	F	F30-39	65--70	1	1
307	247	1:06:39	348	M	M40-49	65--70	1	1
308	659	1:06:40	349	M	M50-59	65--70	0	1
309	717	1:06:48	350	M	M30-39	65--70	1	1
310	6513	1:06:50	351	M	M40-49	65--70		1
311	235	1:06:52	352	M	M40-49	65--70	0	0
312	5887	1:06:52	353	M	M20-29	65--70	1	1
313	146	1:06:53	354	F	F30-39	65--70	1	1
314	576	1:06:54	355	M	M20-29	65--70		1
315	5597	1:06:57	356	M	M40-49	65--70		
316	6519	1:06:57	357	M	M20-29	65--70	1	1
317	6448	1:07:04	358	M	M30-39	65--70		
318	8026	1:10:01	552	F	F50-59	70--75	1	1
319	7723	1:10:01	553	F	F16-19	70--75	0	1
320	287	1:10:01	554	F	F20-29	70--75		1
321	8088	1:10:02	555	F	F20-29	70--75	1	
322	248	1:10:03	556	M	M40-49	70--75	1	1
323	665	1:10:03	557	M	M60-69	70--75	1	1
324	416	1:10:04	558	M	M30-39	70--75		1
325	8075	1:10:04	559	M	M20-29	70--75	1	
326	10646	1:10:05	560	M	M20-29	70--75	0	1
327	318	1:10:05	561	M	M50-59	70--75	1	
328	5295	1:10:07	562	F	F30-39	70--75		
329	298	1:10:07	563	F	F60-69	70--75		1
330	7420	1:10:08	564	M	M20-29	70--75	1	
331	7421	1:10:08	565	F	F20-29	70--75	1	
332	3738	1:10:08	566	M	M30-39	70--75	0	1
333	530	1:10:08	567	F	F30-39	70--75		1
334	7951	1:10:08	568	M	M50-59	70--75	1	1
335	721	1:10:09	569	F	F16-19	70--75	1	1
336	5884	1:10:10	570	M	M20-29	70--75		1
337	359	1:10:10	571	F	F20-29	70--75	1	1
338	10733	1:10:11	572	M	M20-29	70--75		1
339	414	1:10:13	573	F	F20-29	70--75	1	1
340	5270	1:10:14	574	M	M30-39	70--75	1	
341	421	1:10:14	575	F	F30-39	70--75	1	1
342	676	1:10:14	576	F	F30-39	70--75	1	1

343	10649	1:10:16	577	F	F30-39	70--75		
344	6355	1:10:16	578	M	M50-59	70--75	1	1
345	5753	1:10:17	579	M	M30-39	70--75		
346	400	1:10:17	580	M	M40-49	70--75	1	1
347	5299	1:10:19	581	M	M30-39	70--75		1
348	236	1:10:19	582	F	F50-59	70--75	0	1
349	7183	1:10:20	583	M	M40-49	70--75	1	
350	4023	1:10:20	584	M	M40-49	70--75	1	1
351	656	1:10:21	585	M	M30-39	70--75	0	1
352	7529	1:10:21	586	M	M30-39	70--75	1	1
353	8341	1:10:22	587	F	F20-29	70--75		
354	678	1:10:25	588	M	M30-39	70--75	0	0
355	5767	1:10:26	589	M	M40-49	70--75	1	1
356	687	1:10:26	590	M	M50-59	70--75	1	1
357	623	1:10:26	591	M	M40-49	70--75		1
358	462	1:10:27	592	M	M40-49	70--75		1
359	2003	1:10:27	593	F	F30-39	70--75		1
360	512	1:10:27	594	M	M30-39	70--75	1	1
361	216	1:10:28	595	M	M50-59	70--75	1	1
362	3642	1:10:29	596	M	M30-39	70--75	1	1
363	7686	1:10:29	597	M	M30-39	70--75	1	1
364	346	1:10:29	598	M	M30-39	70--75	1	1
365	7885	1:10:30	599	F	F20-29	70--75		1
366	5387	1:10:32	600	M	M30-39	70--75	1	1
367	634	1:10:32	601	M	M30-39	70--75	1	1
368	641	1:10:32	602	M	M40-49	70--75	1	1
369	6447	1:10:33	603	M	M30-39	70--75		1
370	7062	1:10:34	604	M	M40-49	70--75	1	1
371	7548	1:10:36	605	M	M20-29	70--75		
372	407	1:10:38	606	F	F40-49	70--75	1	1
373	690	1:10:40	607	M	M40-49	70--75		1
374	6091	1:10:40	608	M	M40-49	70--75	1	1
375	7242	1:10:41	609	F	F20-29	70--75		1
376	5744	1:10:42	610	M	M50-59	70--75	0	0
377	7111	1:10:42	611	M	M40-49	70--75	0	1
378	8119	1:10:42	612	M	M20-29	70--75		
379	710	1:10:44	613	M	M40-49	70--75	1	1
380	3932	1:10:44	614	M	M40-49	70--75		1
381	7379	1:10:44	615	M	M13-15	70--75	1	
382	709	1:10:44	616	M	M30-39	70--75	1	1
383	6751	1:10:44	617	M	M30-39	70--75	1	
384	625	1:10:44	618	M	M40-49	70--75	0	1
385	713	1:10:45	619	M	M20-29	70--75	1	1

386	8255	1:10:46	620	M	M30-39	70--75		1
387	5620	1:10:47	621	M	M16-19	70--75		0
388	8130	1:10:47	622	M	M20-29	70--75		1
389	5113	1:10:47	623	M	M20-29	70--75	1	
390	8176	1:10:47	624	M	M20-29	70--75	0	1
391	5280	1:10:47	625	M	M20-29	70--75		
392	222	1:10:48	626	M	M50-59	70--75	1	1
393	343	1:10:49	627	F	F30-39	70--75	1	1
394	7836	1:10:49	628	M	M50-59	70--75	3	1
395	7335	1:10:50	629	M	M30-39	70--75	1	
396	487	1:10:53	630	M	M30-39	70--75		1
397	8190	1:10:54	631	M	M30-39	70--75	0	0
398	698	1:10:55	632	F	F30-39	70--75	0	0
399	8087	1:10:56	633	M	M40-49	70--75	1	1
400	6356	1:10:58	634	M	M16-19	70--75	1	1
401	5757	1:10:58	635	M	M30-39	70--75	1	1
402	268	1:11:00	636	F	F30-39	70--75	1	1
403	5229	1:11:00	637	M	M40-49	70--75		
404	441	1:11:01	638	M	M40-49	70--75		
405	7757	1:11:03	639	F	F20-29	70--75		1
406	590	1:11:04	640	M	M30-39	70--75	1	1
407	10734	1:11:04	641	M	M20-29	70--75	1	1
408	688	1:11:05	642	M	M40-49	70--75	1	1
409	425	1:11:07	643	M	M30-39	70--75	1	1
410	5854	1:11:07	644	M	M20-29	70--75	1	
411	7866	1:11:08	645	M	M40-49	70--75	0	0
412	372	1:11:08	646	F	F30-39	70--75	1	1
413	477	1:11:09	647	M	M30-39	70--75	1	1
414	410	1:11:09	648	F	F30-39	70--75	1	1
415	7271	1:11:12	649	M	M50-59	70--75	3	1
416	589	1:11:13	650	M	M30-39	70--75	1	1
417	8152	1:11:13	651	M	M40-49	70--75	1	1
418	6116	1:15:00	1000	M	M20-29	75--80	1	1
419	201	1:15:01	1001	F	F40-49	75--80		1
420	4282	1:15:01	1002	M	M50-59	75--80	1	
421	5240	1:15:02	1003	M	M30-39	75--80	1	1
422	3822	1:15:02	1004	M	M20-29	75--80	1	1
423	4094	1:15:02	1005	M	M30-39	75--80	1	
424	3758	1:15:02	1006	M	M30-39	75--80	1	1
425	4264	1:15:03	1007	M	M30-39	75--80		1
426	8358	1:15:03	1008	M	M30-39	75--80		1
427	7795	1:15:04	1009	M	M30-39	75--80		1
428	5817	1:15:05	1010	F	F40-49	75--80		1

429	4035	1:15:05	1011	M	M40-49	75--80	1	1
430	7533	1:15:06	1012	M	M20-29	75--80	1	1
431	6043	1:15:07	1013	M	M20-29	75--80		0
432	7500	1:15:07	1014	M	M40-49	75--80	1	1
433	3537	1:15:07	1015	F	F30-39	75--80	1	
434	7034	1:15:07	1016	M	M20-29	75--80		
435	4271	1:15:08	1017	M	M40-49	75--80	1	1
436	7779	1:15:08	1018	F	F30-39	75--80	1	
437	8147	1:15:10	1019	M	M20-29	75--80		
438	8043	1:15:10	1020	M	M20-29	75--80	1	
439	6946	1:15:11	1021	F	F40-49	75--80	1	1
440	6245	1:15:13	1022	F	F20-29	75--80		1
441	306	1:15:13	1023	F	F20-29	75--80	1	1
442	5801	1:15:14	1024	M	M20-29	75--80	1	1
443	5927	1:15:14	1025	F	F50-59	75--80		
444	3504	1:15:15	1026	F	F30-39	75--80	1	1
445	5293	1:15:15	1027	M	M30-39	75--80	1	
446	7976	1:15:15	1028	M	M40-49	75--80		0
447	5552	1:15:16	1029	M	M30-39	75--80	1	1
448	474	1:15:16	1030	F	F20-29	75--80	1	1
449	6198	1:15:18	1031	F	F20-29	75--80		
450	455	1:15:19	1032	F	F20-29	75--80		1
451	6769	1:15:21	1033	M	M20-29	75--80	1	
452	10602	1:15:22	1034	M	M20-29	75--80	1	
453	10676	1:15:24	1035	M	M30-39	75--80	1	
454	4268	1:15:25	1036	M	M50-59	75--80	0	1
455	6231	1:15:26	1037	M	M40-49	75--80	1	1
456	4210	1:15:26	1038	F	F20-29	75--80	1	1
457	6176	1:15:26	1039	M	M50-59	75--80		1
458	5400	1:15:27	1040	M	M20-29	75--80		
459	5804	1:15:27	1041	F	F40-49	75--80	1	1
460	454	1:15:28	1042	F	F30-39	75--80	1	1
461	549	1:15:28	1043	M	M30-39	75--80	1	1
462	3905	1:15:29	1044	M	M40-49	75--80	1	
463	7684	1:15:29	1045	M	M30-39	75--80		
464	7422	1:15:29	1046	M	M40-49	75--80	1	1
465	7685	1:15:29	1047	F	F30-39	75--80	1	
466	7974	1:15:29	1048	M	M30-39	75--80		
467	5994	1:15:30	1049	M	M40-49	75--80	0	0
468	3600	1:15:30	1050	M	M40-49	75--80	1	1
469	5993	1:15:30	1051	F	F40-49	75--80	0	1
470	3721	1:15:31	1052	M	M50-59	75--80	0	1
471	10628	1:15:32	1053	F	F30-39	75--80	1	1

472	6860	1:15:33	1054	M	M30-39	75--80	1	1
473	5838	1:15:35	1055	M	M50-59	75--80		1
474	5448	1:15:35	1056	F	F20-29	75--80	1	
475	5055	1:15:35	1057	M	M30-39	75--80		
476	256	1:15:37	1058	M	M50-59	75--80	0	1
477	5841	1:15:38	1059	F	F50-59	75--80		
478	6951	1:15:38	1060	F	F20-29	75--80		
479	693	1:15:38	1061	M	M30-39	75--80	1	1
480	5703	1:15:39	1062	M	M30-39	75--80		1
481	3943	1:15:40	1063	M	M40-49	75--80	1	1
482	6509	1:15:40	1064	M	M00-12	75--80	0	1
483	3944	1:15:41	1065	F	F16-19	75--80	1	1
484	5961	1:15:41	1066	F	F20-29	75--80		1
485	7186	1:15:41	1067	M	M30-39	75--80		1
486	7886	1:15:41	1068	M	M40-49	75--80	1	1
487	546	1:15:41	1069	F	F40-49	75--80	1	1
488	7702	1:15:41	1070	M	M20-29	75--80	1	1
489	7530	1:15:43	1071	M	M40-49	75--80		1
490	3668	1:15:44	1072	F	F20-29	75--80	1	1
491	10726	1:15:44	1073	M	M30-39	75--80		1
492	3511	1:15:45	1074	F	F20-29	75--80	1	
493	6491	1:15:46	1075	M	M50-59	75--80	1	1
494	10606	1:15:46	1076	M	M30-39	75--80	1	
495	4092	1:15:46	1077	F	F30-39	75--80	1	1
496	270	1:15:47	1078	M	M30-39	75--80	1	1
497	7630	1:15:47	1079	F	F40-49	75--80		
498	7376	1:15:47	1080	M	M13-15	75--80		1
499	7160	1:15:47	1081	M	M16-19	75--80	1	1
500	7265	1:15:48	1082	F	F13-15	75--80	1	1
501	5875	1:15:48	1083	M	M30-39	75--80	1	1
502	7945	1:15:49	1084	M	M80-99	75--80		
503	8144	1:15:50	1085	M	M40-49	75--80		1
504	524	1:15:50	1086	F	F40-49	75--80	1	1
505	8143	1:15:50	1087	F	F40-49	75--80		
506	689	1:15:52	1088	F	F40-49	75--80	1	1
507	5167	1:15:52	1089	M	M30-39	75--80	1	1
508	663	1:15:52	1090	F	F40-49	75--80		1
509	5476	1:15:53	1091	M	M40-49	75--80		1
510	4100	1:15:53	1092	F	F30-39	75--80	1	
511	329	1:15:53	1093	M	M60-69	75--80	1	1
512	7577	1:15:54	1094	M	M30-39	75--80	1	1
513	7653	1:15:55	1095	M	M30-39	75--80		1
514	5617	1:15:56	1096	M	M30-39	75--80	0	1

515	7397	1:15:56	1097	M	M40-49	75--80		0
516	10736	1:15:58	1098	M	M30-39	75--80		1
517	292	1:15:58	1099	M	M40-49	75--80	1	1
518	6301	1:15:58	1100	M	M30-39	75--80	1	
519	8156	1:20:00	1538	F	F30-39	80--85	1	1
520	5272	1:20:01	1539	F	F20-29	80--85		1
521	6747	1:20:01	1540	F	F20-29	80--85	1	1
522	6746	1:20:02	1541	M	M40-49	80--85	1	1
523	7931	1:20:03	1542	F	F16-19	80--85		1
524	10388	1:20:03	1543	M	M20-29	80--85		1
525	7152	1:20:03	1544	M	M00-12	80--85		1
526	5382	1:20:04	1545	F	F40-49	80--85	1	1
527	3692	1:20:04	1546	F	F20-29	80--85	1	1
528	5621	1:20:05	1547	F	F30-39	80--85		
529	7153	1:20:06	1548	M	M40-49	80--85		1
530	5935	1:20:06	1549	F	F20-29	80--85		
531	2015	1:20:07	1550	M	M13-15	80--85		1
532	6432	1:20:07	1551	M	M20-29	80--85		
533	7792	1:20:07	1552	F	F30-39	80--85		1
534	3559	1:20:08	1553	M	M60-69	80--85	1	
535	6427	1:20:08	1554	M	M20-29	80--85		1
536	4245	1:20:09	1555	F	F40-49	80--85	1	1
537	7106	1:20:09	1556	M	M50-59	80--85		
538	3695	1:20:10	1557	M	M13-15	80--85	1	1
539	7128	1:20:10	1558	F	F40-49	80--85	1	1
540	10567	1:20:10	1559	M	M40-49	80--85	1	
541	3874	1:20:11	1560	F	F30-39	80--85	0	
542	3524	1:20:12	1561	M	M50-59	80--85	1	1
543	5142	1:20:13	1562	M	M20-29	80--85		1
544	4186	1:20:14	1563	F	F30-39	80--85		1
545	4187	1:20:14	1564	F	F40-49	80--85	1	1
546	3806	1:20:15	1565	M	M30-39	80--85	1	
547	6102	1:20:15	1566	M	M30-39	80--85		
548	8032	1:20:16	1567	M	M40-49	80--85	0	1
549	5843	1:20:17	1568	M	M40-49	80--85	0	0
550	7725	1:20:18	1569	F	F20-29	80--85	1	1
551	204	1:20:19	1570	M	M40-49	80--85	1	1
552	6804	1:20:20	1571	F	F20-29	80--85		1
553	7291	1:20:20	1572	F	F30-39	80--85		
554	4228	1:20:20	1573	F	F20-29	80--85	1	1
555	6855	1:20:21	1574	M	M30-39	80--85	1	
556	6117	1:20:21	1575	F	F20-29	80--85		1
557	4255	1:20:21	1576	M	M50-59	80--85	1	

558	4258	1:20:21	1577	M	M50-59	80--85	0	1
559	4270	1:20:21	1578	M	M40-49	80--85	0	1
560	8103	1:20:22	1579	F	F30-39	80--85		0
561	6370	1:20:22	1580	M	M50-59	80--85		1
562	5018	1:20:22	1581	M	M50-59	80--85		
563	374	1:20:22	1582	F	F30-39	80--85	1	1
564	7846	1:20:22	1583	M	M40-49	80--85	1	
565	5489	1:20:23	1584	F	F20-29	80--85	1	1
566	3685	1:20:24	1585	M	M40-49	80--85	1	1
567	4171	1:20:24	1586	M	M30-39	80--85	1	1
568	3707	1:20:24	1587	M	M40-49	80--85	1	1
569	6166	1:20:26	1588	M	M30-39	80--85	1	1
570	4163	1:20:26	1589	M	M40-49	80--85	1	1
571	4196	1:20:27	1590	M	M50-59	80--85	0	1
572	7753	1:20:27	1591	F	F20-29	80--85	1	1
573	3014	1:20:28	1592	F	F20-29	80--85		
574	8006	1:20:28	1593	M	M20-29	80--85		1
575	7950	1:20:28	1594	F	F20-29	80--85	1	1
576	7754	1:20:28	1595	M	M20-29	80--85	1	1
577	7942	1:20:28	1596	M	M20-29	80--85		1
578	7597	1:20:29	1597	F	F40-49	80--85	0	0
579	4041	1:20:29	1598	M	M20-29	80--85	1	
580	5510	1:20:31	1599	M	M40-49	80--85		
581	7816	1:20:32	1600	F	F40-49	80--85		
582	10068	1:20:32	1601	F	F20-29	80--85		
583	6848	1:20:32	1602	M	M30-39	80--85		1
584	7035	1:20:33	1603	F	F30-39	80--85		
585	5706	1:20:33	1604	M	M40-49	80--85	1	
586	7862	1:20:34	1605	F	F30-39	80--85	1	1
587	5707	1:20:34	1606	F	F40-49	80--85	1	1
588	3928	1:20:35	1607	M	M50-59	80--85	1	1
589	3929	1:20:35	1608	M	M30-39	80--85		1
590	6676	1:20:35	1609	F	F30-39	80--85	1	1
591	7063	1:20:36	1610	F	F20-29	80--85	1	
592	6937	1:20:37	1611	M	M30-39	80--85	1	
593	3821	1:20:37	1612	F	F20-29	80--85	1	
594	6218	1:20:38	1613	F	F30-39	80--85		1
595	4257	1:20:38	1614	M	M50-59	80--85	1	1
596	6219	1:20:38	1615	F	F40-49	80--85		1
597	7130	1:20:39	1616	M	M30-39	80--85		
598	7095	1:20:39	1617	F	F40-49	80--85	1	1
599	4119	1:20:39	1618	M	M40-49	80--85	1	1
600	7649	1:20:39	1619	F	F20-29	80--85		1

601	6435	1:20:40	1620	M	M20-29	80--85	1	1
602	8310	1:20:42	1621	M	M30-39	80--85		1
603	7168	1:20:42	1622	M	M30-39	80--85		
604	7665	1:20:42	1623	M	M30-39	80--85		1
605	7664	1:20:43	1624	M	M30-39	80--85		1
606	5686	1:20:43	1625	F	F20-29	80--85		
607	10314	1:20:44	1626	F	F30-39	80--85		1
608	3634	1:20:45	1627	F	F70-79	80--85	1	1
609	6808	1:20:47	1628	M	M40-49	80--85	1	1
610	3516	1:20:48	1629	M	M40-49	80--85	1	1
611	4140	1:20:48	1630	F	F20-29	80--85	1	1
612	6430	1:20:48	1631	M	M40-49	80--85		1
613	4209	1:20:48	1632	F	F20-29	80--85	1	1
614	3820	1:20:49	1633	M	M40-49	80--85		
615	8073	1:20:49	1634	M	M60-69	80--85	1	1
616	5851	1:20:50	1635	M	M40-49	80--85		
617	3655	1:20:50	1636	F	F30-39	80--85	1	1
618	4099	1:20:50	1637	F	F50-59	80--85	1	1
619	4225	1:20:50	1638	M	M50-59	80--85	1	1
620	7148	1:25:00	2122	F	F30-39	85--90	1	1
621	4230	1:25:02	2123	F	F30-39	85--90		1
622	7661	1:25:02	2124	M	M20-29	85--90	1	1
623	6109	1:25:03	2125	M	M16-19	85--90		
624	7738	1:25:03	2126	F	F40-49	85--90	1	1
625	7007	1:25:03	2127	F	F50-59	85--90		1
626	7189	1:25:04	2128	M	M30-39	85--90		1
627	3974	1:25:04	2129	M	M40-49	85--90	1	
628	7916	1:25:04	2130	M	M30-39	85--90	1	1
629	5559	1:25:04	2131	F	F30-39	85--90	1	1
630	5698	1:25:04	2132	M	M30-39	85--90		
631	6328	1:25:05	2133	M	M40-49	85--90		1
632	5736	1:25:05	2134	M	M40-49	85--90	1	1
633	6918	1:25:05	2135	F	F30-39	85--90		0
634	7211	1:25:05	2136	M	M40-49	85--90	1	1
635	7324	1:25:05	2137	F	F50-59	85--90		1
636	7161	1:25:06	2138	F	F20-29	85--90		1
637	4159	1:25:06	2139	M	M50-59	85--90	1	
638	5811	1:25:06	2140	M	M60-69	85--90	1	1
639	7154	1:25:07	2141	M	M50-59	85--90		0
640	3950	1:25:07	2142	F	F40-49	85--90		1
641	4069	1:25:07	2143	F	F40-49	85--90	1	
642	3761	1:25:07	2144	M	M50-59	85--90	1	1
643	6303	1:25:07	2145	M	M30-39	85--90		

644	7212	1:25:08	2146	M	M60-69	85--90		1
645	5850	1:25:08	2147	M	M30-39	85--90		1
646	6686	1:25:09	2148	F	F30-39	85--90	0	1
647	4238	1:25:09	2149	F	F50-59	85--90	1	1
648	4217	1:25:09	2150	F	F40-49	85--90	1	1
649	7270	1:25:09	2151	M	M40-49	85--90	1	1
650	7591	1:25:10	2152	F	F30-39	85--90		1
651	3775	1:25:11	2153	F	F40-49	85--90	1	1
652	7571	1:25:11	2154	M	M50-59	85--90		1
653	7930	1:25:11	2155	M	M20-29	85--90		1
654	7089	1:25:11	2156	F	F30-39	85--90		
655	4201	1:25:11	2157	F	F20-29	85--90		1
656	3921	1:25:12	2158	M	M60-69	85--90	1	1
657	3885	1:25:12	2159	M	M60-69	85--90		1
658	3852	1:25:12	2160	M	M40-49	85--90	1	1
659	3957	1:25:13	2161	F	F30-39	85--90	1	1
660	5260	1:25:13	2162	M	M20-29	85--90	0	1
661	3947	1:25:13	2163	M	M30-39	85--90	0	1
662	6968	1:25:13	2164	M	M30-39	85--90		
663	6705	1:25:13	2165	M	M40-49	85--90		1
664	6706	1:25:14	2166	F	F30-39	85--90		0
665	10554	1:25:15	2167	M	M30-39	85--90	1	
666	7971	1:25:16	2168	M	M30-39	85--90		
667	6087	1:25:16	2169	F	F40-49	85--90		1
668	3930	1:25:16	2170	M	M40-49	85--90	0	1
669	6894	1:25:16	2171	F	F40-49	85--90	1	1
670	3908	1:25:16	2172	F	F40-49	85--90		
671	8100	1:25:18	2173	F	F50-59	85--90		1
672	6108	1:25:18	2174	M	M30-39	85--90		
673	8094	1:25:18	2175	F	F40-49	85--90		1
674	3830	1:25:19	2176	F	F20-29	85--90		1
675	3546	1:25:20	2177	M	M50-59	85--90		1
676	5644	1:25:20	2178	M	M20-29	85--90	1	1
677	6877	1:25:21	2179	M	M40-49	85--90		1
678	6069	1:25:22	2180	M	M20-29	85--90		1
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681	5420	1:25:24	2183	F	F20-29	85--90	1	1
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683	5431	1:25:25	2185	F	F30-39	85--90		1
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685	7386	1:25:25	2187	M	M40-49	85--90	1	1
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687	3828	1:25:26	2189	M	M30-39	85--90	0	1
688	3507	1:25:26	2190	M	M30-39	85--90		
689	6820	1:25:26	2191	F	F30-39	85--90		1
690	6991	1:25:26	2192	M	M40-49	85--90		0
691	8040	1:25:27	2193	F	F30-39	85--90	1	1
692	6960	1:25:27	2194	M	M40-49	85--90		1
693	6685	1:25:27	2195	M	M30-39	85--90		1
694	10677	1:25:27	2196	M	M20-29	85--90	1	
695	10751	1:25:28	2197	M	M20-29	85--90	1	1
696	8021	1:25:28	2198	F	F30-39	85--90		1
697	3780	1:25:28	2199	F	F40-49	85--90	0	1
698	5641	1:25:28	2200	F	F30-39	85--90		1
699	6947	1:25:29	2201	M	M30-39	85--90		1
700	6983	1:25:30	2202	F	F20-29	85--90		1
701	3913	1:25:30	2203	F	F20-29	85--90	0	1
702	7191	1:25:30	2204	F	F40-49	85--90	1	
703	7514	1:25:31	2205	F	F20-29	85--90	1	1
704	7915	1:25:32	2206	M	M30-39	85--90		
705	7099	1:25:32	2207	M	M30-39	85--90		1
706	10356	1:25:33	2208	F	F20-29	85--90	1	1
707	8012	1:25:33	2209	F	F20-29	85--90	1	1
708	7079	1:25:35	2210	M	M30-39	85--90	1	1
709	3959	1:25:36	2211	M	M40-49	85--90	1	1
710	5124	1:25:36	2212	M	M30-39	85--90		1
711	5056	1:25:37	2213	F	F20-29	85--90		
712	8335	1:25:38	2214	F	F20-29	85--90		
713	6982	1:25:39	2215	M	M40-49	85--90		1
714	4080	1:25:39	2216	M	M60-69	85--90	1	1
715	5699	1:25:40	2217	F	F50-59	85--90	1	1
716	10128	1:25:41	2218	F	F40-49	85--90	1	1
717	7357	1:25:41	2219	F	F30-39	85--90	1	1
718	6731	1:25:41	2220	F	F20-29	85--90	1	1
719	8001	1:25:42	2221	M	M20-29	85--90		1
720	5057	1:30:00	2706	F	F40-49	90--95	1	1
721	8283	1:30:02	2707	F	F20-29	90--95		1
722	10690	1:30:02	2708	M	M30-39	90--95	1	1
723	10066	1:30:02	2709	M	M30-39	90--95	1	1
724	6100	1:30:04	2710	M	M60-69	90--95	1	1
725	7010	1:30:05	2711	F	F40-49	90--95		1
726	8273	1:30:05	2712	F	F20-29	90--95		1
727	3760	1:30:05	2713	F	F20-29	90--95	1	1
728	10411	1:30:05	2714	M	M40-49	90--95		

729	5290	1:30:06	2715	F	F40-49	90--95		1
730	7655	1:30:06	2716	F	F20-29	90--95	1	1
731	4166	1:30:07	2717	F	F40-49	90--95	1	1
732	3962	1:30:08	2718	M	M40-49	90--95		1
733	3794	1:30:08	2719	F	F30-39	90--95	1	1
734	6543	1:30:08	2720	M	M30-39	90--95		1
735	3894	1:30:08	2721	M	M40-49	90--95	1	1
736	5802	1:30:08	2722	M	M16-19	90--95		1
737	8248	1:30:09	2723	F	F20-29	90--95	1	0
738	6406	1:30:10	2724	F	F30-39	90--95		1
739	7639	1:30:10	2725	M	M30-39	90--95		1
740	7506	1:30:10	2726	F	F20-29	90--95	1	1
741	3564	1:30:11	2727	M	M60-69	90--95	1	1
742	6229	1:30:11	2728	F	F30-39	90--95		1
743	3995	1:30:12	2729	F	F40-49	90--95	1	1
744	5579	1:30:12	2730	F	F20-29	90--95	1	1
745	5645	1:30:12	2731	F	F20-29	90--95		
746	6034	1:30:14	2732	M	M20-29	90--95	1	1
747	7956	1:30:14	2733	M	M50-59	90--95		
748	7589	1:30:15	2734	F	F40-49	90--95	1	
749	7842	1:30:15	2735	M	M00-12	90--95		1
750	3940	1:30:15	2736	M	M40-49	90--95	0	0
751	7841	1:30:17	2737	M	M40-49	90--95		1
752	6612	1:30:17	2738	M	M50-59	90--95	1	1
753	3949	1:30:18	2739	F	F40-49	90--95	0	0
754	7508	1:30:19	2740	F	F20-29	90--95	1	1
755	7444	1:30:19	2741	F	F20-29	90--95	1	1
756	8311	1:30:19	2742	M	M40-49	90--95		1
757	7170	1:30:20	2743	F	F50-59	90--95	1	1
758	3578	1:30:23	2744	F	F30-39	90--95	1	1
759	4176	1:30:23	2745	F	F40-49	90--95		1
760	7586	1:30:25	2746	M	M30-39	90--95		3
761	7204	1:30:26	2747	F	F40-49	90--95		1
762	6338	1:30:26	2748	F	F40-49	90--95		0
763	7072	1:30:32	2749	M	M70-79	90--95	1	1
764	6098	1:30:33	2750	M	M30-39	90--95	1	1
765	3015	1:30:33	2751	M	M20-29	90--95		
766	5305	1:30:34	2752	M	M40-49	90--95		1
767	10903	1:30:37	2753	F	F20-29	90--95	1	1
768	5876	1:30:37	2754	F	F20-29	90--95		
769	5737	1:30:37	2755	M	M20-29	90--95		1
770	5738	1:30:37	2756	F	F20-29	90--95	1	1
771	7074	1:30:38	2757	F	F20-29	90--95		1

772	4036	1:30:38	2758	F	F40-49	90--95	1	1
773	5375	1:30:38	2759	F	F20-29	90--95		1
774	7770	1:30:38	2760	F	F20-29	90--95		1
775	10710	1:30:39	2761	M	M30-39	90--95	1	1
776	7558	1:30:39	2762	F	F30-39	90--95	1	1
777	3778	1:30:41	2763	M	M30-39	90--95	1	1
778	8258	1:30:41	2764	M	M30-39	90--95		1
779	5265	1:30:41	2765	M	M40-49	90--95		
780	4157	1:30:42	2766	F	F30-39	90--95	1	1
781	5075	1:30:42	2767	M	M40-49	90--95		
782	5211	1:30:42	2768	M	M40-49	90--95	1	1
783	7521	1:30:43	2769	F	F20-29	90--95	1	1
784	7696	1:30:43	2770	M	M40-49	90--95		1
785	3933	1:30:43	2771	M	M40-49	90--95	1	
786	4215	1:30:43	2772	F	F30-39	90--95	1	1
787	6036	1:30:43	2773	F	F30-39	90--95	1	1
788	4029	1:30:44	2774	F	F20-29	90--95	1	1
789	4261	1:30:44	2775	F	F40-49	90--95	1	
790	8109	1:30:48	2776	F	F40-49	90--95		
791	7535	1:30:48	2777	F	F40-49	90--95	0	1
792	652	1:30:48	2778	M	M40-49	90--95	1	1
793	2039	1:30:50	2779	F	F20-29	90--95		
794	7102	1:30:52	2780	M	M30-39	90--95	1	1
795	5467	1:30:52	2781	M	M40-49	90--95	1	1
796	10366	1:30:54	2782	M	M16-19	90--95	1	1
797	4262	1:30:55	2783	F	F30-39	90--95	1	1
798	5826	1:30:56	2784	F	F30-39	90--95		1
799	5963	1:30:58	2785	F	F50-59	90--95		1
800	5896	1:30:58	2786	F	F20-29	90--95		1
801	5897	1:30:58	2787	M	M20-29	90--95		1
802	6552	1:30:59	2788	F	F30-39	90--95		1
803	10472	1:31:00	2789	M	M20-29	90--95	0	0
804	10471	1:31:00	2790	M	M20-29	90--95	1	1
805	7374	1:31:04	2791	F	F40-49	90--95	1	1
806	6831	1:31:04	2792	F	F20-29	90--95	1	1
807	6936	1:31:04	2793	F	F30-39	90--95		1
808	6935	1:31:05	2794	M	M30-39	90--95		1
809	5368	1:31:06	2795	M	M30-39	90--95	1	1
810	8123	1:31:06	2796	M	M30-39	90--95	1	
811	6497	1:31:06	2797	F	F30-39	90--95	1	1
812	6692	1:31:07	2798	F	F30-39	90--95		1
813	6138	1:31:07	2799	F	F30-39	90--95		1
814	5849	1:31:08	2800	F	F20-29	90--95		1

815	10590	1:31:09	2801	M	M50-59	90--95		1
816	7283	1:31:09	2802	F	F20-29	90--95		1
817	10902	1:31:09	2803	M	M50-59	90--95		1
818	5050	1:31:10	2804	M	M50-59	90--95	0	1
819	7996	1:31:10	2805	F	F40-49	90--95		1
820	7011	1:31:10	2806	F	F40-49	90--95	1	1

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