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Accepted manuscript

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Short Title

Carbohydrate intake during indoor cycling

THE NUTRITION SOCIETY
Advancing Nutritional Science

This peer-reviewed article has been accepted for publication but not yet copyedited or typeset, and so may be subject to change during the production process. The article is considered published and may be cited using its DOI

10.1017/S0007114521001860

The British Journal of Nutrition is published by Cambridge University Press on behalf of The Nutrition Society

Abstract

Cycling is a sport characterised by high training load and adequate nutrition is essential for training and race performance. With increased popularity of indoor trainers, cyclists have a unique opportunity to practice and implement key nutritional strategies. This study aimed to assess carbohydrate intake and nutrition knowledge of cyclists training or racing in this unique scenario for optimising exercise nutrition. A mixed-methods approach consisting of a multiple-pass self-report food recall and questionnaire was used to determine total carbohydrate intake pre, during and post training or racing using a stationary trainer and compared to current guidelines for endurance exercise. Sub-analyses were also made for higher ability cyclists (>4.W.kg^{-1} functional threshold power), races *vs.* non-races and 'key' training sessions. Mean CHO intake pre and post ride was 0.7±0.6 and 1.0±0.8 g.kgBM^{-1} and 39.3±27.5 g.h^{-1} during. Carbohydrate intake was not different for races (pre/during/post, p=0.31, 0.23, 0.18 respectively), 'key sessions' (p=0.26, 0.89, 0.98), or higher ability cyclists (p=0.26, 0.76, 0.45). The total proportion of cyclists who failed to meet CHO recommendations was higher than those who met guidelines (pre=79%, during=86%, post=89%). Cyclists training or racing indoors do not meet current CHO recommendations for cycling performance. Due to the short and frequently high-intensity nature of some sessions, opportunity for during exercise feeding may be limited or unnecessary.

Keywords: Exercise, food, diet, metabolism, stationary cycling, cycling

Background

Endurance cycling (road, mountain, gravel) is a sport characterised by prolonged periods of steady-state power output with stochastic efforts in the heavy and severe intensity domains [1], requiring adequate CHO consumption from exogenous and endogenous (liver and muscle glycogen) sources. Recent evidence for withholding CHO from certain sessions, i.e. periodised nutrition for endurance adaptations shows promise [2], but athletes have historically recognised the value of 'key' sessions within the training cycle, where high intensity performance and/or practice of race intensities are needed. Therefore adequate CHO consumption is suggested [3, 4] signifying the important role of sports nutrition. In recent years, rapid improvement in 'turbo-trainer' technology and increased popularity in amateur cycling has led to the advent of online racing and training platforms, such as 'Zwift', 'Sufferfest' and 'TrainerRoad', gaining substantial subscribers in the previous 2-3 years [5]. On-bike nutrition can be challenging due to tactical and bike-handling requirements of racing not allowing suitable feeding opportunity, and long training rides limiting the ability to carry sufficient fuel. CHO consumption during training can also enhance gut tolerance and intestinal absorption capacity [6, 7].

In order to maximise performance and mitigate exercise induced disturbances to energy balance, current nutrition guidelines [16] for endurance exercise recommend athletes consume 1-4 g of CHO per kilogram of body mass (referred to as $g.kg^{-1}$ from hereon) between 1 and 4 hours prior to exercise. For rides lasting between one and two hours, it is recommended athletes consume up to 60 $g.h^{-1}$ CHO during exercise [17], but up to 90 $g.h^{-1}$, consisting of multiple transportable CHO is advised for longer duration exercise [18] where optimal performance is desired, rather than training where duration (<1 hour) and intensity are low, or where metabolic fat adaptation is specifically sought. For optimal recovery, CHO recommendations are to aim for 1.0-1.2 $g.kg^{-1}$ CHO within the hour following exercise, with repetition of this every hour for the first 4 hours in the instance of a second key session or race <8 hours [8]. However, amateur athletes training in their usual environments do not meet nutrition recommendations pre or post-exercise [19], and the discrepancy between recommendations and actual CHO intake during exercise is apparent in both elite and sub-elite athletes [9]. The unique environment created by indoor cycling presents an opportunity for athletes to successfully meet nutritional requirements due to the ability to source food and fluid at home.

The aim of this study was to determine if athletes racing and training indoors with online platforms meet current CHO recommendations for exercise performance. It was hypothesised that cyclists would not meet overall current CHO recommendations but would meet during exercise targets, planned session intensity would relate to higher CHO intake, cyclists of higher ability would achieve better pre, during and post-ride CHO intake, and cyclists identifying as well-trained and identifying the session as a ‘key’ session or race would be more likely to meet CHO recommendations.

Methods

Participants and Study Design

This cross-sectional, observational study assessed food intake pre, during and post a cycling based training session conducted using an indoor trainer by using a mixed-methods (qualitative and quantitative) questionnaire. The study was available to cyclists of any ability who had completed an indoor training ride or online race in the preceding 24 hours (to reduce recall bias). Study recruitment was through professional networks, word-of-mouth, and social media platforms (Twitter/Facebook). The study was conducted in accordance with the Declaration of Helsinki and approved by the Australian Catholic University Human Research Ethics Committee (HREC-2020-125E). Participants provided informed consent, their main cycling discipline, typical duration of indoor training sessions, if they considered themselves competitive (defined by either online or traditional races), highest level of competition, and years of competitive experience. Session specific information included self-reported current body mass, functional threshold power (FTP), if the session was a race, perceived session intensity (‘moderate’, ‘high’ or ‘very high’), session duration and average power output (if using a smart trainer or power meter), and if the session was considered a ‘key’ session, defined as where training quality, high-intensity performance, and/or practice of race conditions is required [4]. FTP was provided by participants from a known 20-minute time trial test or calculated by a cycling software program if it had been conducted within the previous 2 weeks.

Online Questionnaire Design

The questionnaire was in English and consisted of 81 questions encompassing demographics, ride details, food recall, fluid and supplements consumed in 3 distinct time periods around the session; hours prior (pre), during and following (post). The questionnaire was built and run using specialised software (REDCap, Tennessee, USA). Detailed instructions were provided at the start of each sub-section to reiterate the detail required; quantities in known units, brands and specified food types to be provided. The multi-pass method for food recall [8] was used, with focused, prompting questions to enhance diet recall. Questions were also included to determine the time of the session and food and drink intake, including what meal (including 'snack') participants considered pre and post-ride intake. Qualitative, open-ended questions were used to allow participants to expand on 'anything missed' for each period of food intake as well as to qualify their decisions around food timing and composition. Also to ask if time of day affected food choice.

Data Analysis and Statistics

Demographic and ride detail data were checked for completeness and relative FTP calculated [reported FTP (W) / body mass (kg)]. Analyses performed to differentiate effects of 'trained cyclists' were made using an FTP >4.0 $W.kg^{-1}$. Diet recall data was quantified by an Accredited Practising Dietitian using FoodWorks-10 (Xyris, Australia). Quantified data were then compared to CHO guidelines for cycling in the context of ride intensity and duration [3, 9]. If a diet recall for pre, during or post was provided without specified quantity or detail, that record was excluded from analysis for the given intake period. Responses were labelled to note food composition, fluid and supplement choices including 'CHO', 'protein', 'high fat', 'supplements', 'sports foods' and 'caffeine'. Open-ended questions were analysed using thematic analysis, with coded responses combined after independent analysis by two researchers. Where applicable, responses and themes were tallied to allow both a quantitative and qualitative representation of responses.

Responses were counted for the number of participants who met pre, during or post-exercise CHO intake recommendations and are presented as a total number and percentage of the total number of responses for each subsection. Comparisons for CHO intake between 'key sessions', 'trained cyclists' and all sessions were conducted by one-way ANOVA with Tukey *post hoc* adjustment where applicable (alpha level: 5%). Cohen's D effect sizes were calculated for comparisons where relevant. Box and whisker plots are presented for pre, during and post-exercise CHO intake.

Results

A total of 106 responses were collated between 26/06/2020 and 19/08/2020. *Figure 1* outlines where sufficient data was present to report nutritional intake for each stage of the sessions, i.e. pre-ride, during and post-ride. 76 responses were identified as providing detailed information about of at least pre-ride, during or post-ride session nutritional intake. Breakdown of participant information is contained in table 1.

Training Sessions

Forty sessions were reported as 'key' and 21 as races. Of these, 15 were identified as both 'key' and race, with 31 neither of these. Nutrition data are reported for all sessions, and subgroup analyses reported with sessions removed meeting the following criteria for not being a 'key session'. Relative session intensity was reported by 57 participants and were (%FTP): >100%=6, 90-100%=11, 80-90%=20, 70-80%=8, 60-70%=8, 50-60%=3 and 40-50%=1. Qualitative self-reported intensity was given by 74 participants and included: 'very high'=12, 'high'=25 and 'moderate'=37. Session duration was predominantly between 45 and 120 minutes (45-60 minute=32 and 60-120 minutes=27), with 8 sessions reported as being >120 minutes, and 7 sessions <45 minutes. 2 were not reported. The time of day sessions were completed was 0000-0600=5, 0600-1200=30, 1200-1800=22, 1800-2359=19.

Pre-ride Nutrition

To the question "did you eat or drink anything in the 4 hours before this ride or race (a meal and or a snack or something to drink)?", 89% of participants responded that they consumed something prior to their session, of which 9% did not consume any CHO. For sessions of all duration, 73% of all participants consumed <1 $g.kg^{-1}$ of CHO in the 4 hours pre-ride (*Table 2*), with 20% of these consuming zero CHO. Data for each session duration are presented in *Table 2*, with the highest proportion of participants meeting pre-exercise CHO intake recommendations for sessions lasting 60-120 minutes and sessions >120 minutes. Overall, 26% of participants consumed 1-4 $g.kg^{-1}$ of CHO, which was higher among 'trained' cyclists (39%) and for 'key sessions' (35% of all 'key sessions'). *Figure 2* shows the distribution of intakes for all sessions, however, mean intake did not differ between all sessions, 'key sessions' and 'trained cyclists' (0.7±0.6 *vs.* 0.8±0.6 *vs.* 0.9±0.8 $g.kg^{-1}$, p=0.26). However, average CHO intake for participants that consumed some pre-exercise CHO was slightly higher in 'trained' cyclists at 1.2±0.7 $g.kg^{-1}$ (ES=0.33, p=0.06). Average CHO intakes for each session duration are in *Table 2*, being highest for sessions lasting >120 minutes. Total pre-ride CHO intake did not differ between sessions identified as races or non-races for total CHO (55.9±40.5 *vs.* 45.337.4 g; ES=0.27, p=0.31) or relative CHO intake (0.68±0.61 *vs.* 0.81±0.62 $g.kg^{-1}$, ES=0.29, p=0.42).

Data relating to timing and type of food intake pre-ride is presented in *Figure 4*. 89% of participants reported eating pre-ride food as either part of a regular meal, most commonly breakfast, or a snack. The time prior to exercise that participants consumed food or drink was between 0 (n=4) and 4 hours (7, 9.2%), with 28% of participants consuming food or drink <1 hour pre-ride, and 34% between 1-3 hours prior. The distribution of eating time prior to exercise was similar for all ride durations (p = 0.07). 53% of participants stated that the time of day they ate affected the quantity of food/drink they consumed. This was qualified by asking "If yes, then how did it affect how much you ate?". Accordingly, 11 participants reported eating less than usual, 2 reported eating more, and 1 the same amount. Seven participants deliberately ate nothing due to the time of day, 1 person reported eating an "additional snack" and 2 people "ate enough to feel full but avoid GI issues". However, 13 participants also reported food timing as a consideration; 9 stating the session was too early to eat, and 3 adjusted food timing to account for an early training session. Two participants noted the session intensity being "hard" influenced their food intake. Considering types of food and drink consumed pre-ride, 70% of participants specifically listed fluid intake , 75% consumed some CHO, 45% used caffeine containing foods/drinks, 5% took supplements (5%), 11% ate high fat foods, 5% used sports specific foods/products, and 2.5% chose gluten free foods.

During Ride Nutrition

A total of 78% of participants reported consuming some food or drink during their ride. However, of these, 54% did not consume any food/drink with energy content, recording water, zero-calorie electrolyte drinks or coffee/caffeine supplements as 'fuel'. Together with participants who reported not fuelling during their ride, 74% did not consume any CHO during exercise. The number of participants who fuelled during 'key' sessions did not differ for all sessions types; 78% of participants reported food/drink intake but 50% did not consume any CHO. Mean CHO intake was 9.4±21.3 $g.h^{-1}$ for all sessions and was not different between non-races and races (6.5±16.5 $g.h^{-1}$ *vs.* 13.6±23.2 $g.h^{-1}$, ES=0.35, p=0.23) or to 'key sessions' (10.2±20.9 $g.h^{-1}$, p=0.84) or 'trained cyclists' (9.5±20.9 $g.h^{-1}$, p=1.00). Where participants did consume CHO during-ride, the average intake was 39.3±27.5 $g.h^{-1}$

and not significantly different for 'key sessions' (36.9±26.3 g.h^{-1}, ES=0.08, p=0.89) or 'trained cyclists' (43.6±27.7 g.h^{-1}, ES=0.15, p=0.76). Intakes were identical between races and non-races (p=0.95). Data for each duration are presented in *Table 3* and with no differences for session time. Sources of during-ride food and drink are shown in *Figure 3*, largely being comprised of commercially available drinks, gels and solid foods. Responses to the question "If no, please state why you did not consume or drink anything during your recent ride?", are also presented in *Figure 3*.

Post-ride Nutrition

For all sessions 49% of participants consumed <1 g.kg^{-1} of CHO post-ride (*Table 4*), with 13% of these consuming no food/drink and 7% consuming food/drink containing no CHO. In total 70% of participants consumed <1.0 g.kg^{-1}, 13% consumed 1-1.2 g.kg^{-1}, 11% consumed 1.2-2.0 g.kg^{-1} and 6% consumed >2 g.kg^{-1} (*Figure 2*). For long sessions (60-240 minutes) 12% consumed 1-1.2 g.kg^{-1} post-ride, 25% consumed between 1.2-2.0 g.kg^{-1} and 4% consumed 2.0-4.0 g.kg^{-1}. For sessions <1 hour, 66% of participants consumed <1.0 g.kg^{-1}, 19% participants consumed 1-1.2 g.kg^{-1}, 6% consumed 1.2-2.0 g.kg^{-1} and 9% consumed >2.0 g.kg^{-1}. For 'key sessions' 50% of participants consumed <1 g.kg^{-1}, including 23% of participants who ate no CHO. Of the 'trained cyclists' none reported eating zero CHO, but the 58% consumed <1.0 g.kg^{-1} 8% consuming 1.2-2.0 g.kg^{-1}.

Mean CHO consumption post-ride was 55.9±42.8 g across all sessions. Mean CHO intakes for each session duration are in *Table 4* and were highest for sessions lasting <45 minutes, but similar to pre-ride, the smaller sample is noted. Total post-ride CHO intake did not differ between sessions identified as races or non-races for total (76.5±64.3 *vs.* 55.9±42.8 g; ES=0.29, p=0.22) or relative CHO (0.9±0.7 *vs.* 1.1±1.0 g.kg^{-1}, ES=0.18, p=0.55, *Table 4*). Mean post-ride intake in 'trained cyclists' was not different compared to all participants (1.0±0.8 g.kg^{-1}, ES=0.20, p=0.45).

Seventy-five percent of participants reported post-exercise food intake was part of a meal; dinner (36%), breakfast (20%) and 25% reported post-ride intake as a snack (*Figure 4*). Post-ride intake occurred <10 minutes for 2 participants, however the majority (32, 46%) consumed their post-ride intake within the recommended one hour, with 17 (25%) eating 1-2 hours post-exercise. Ten participants consumed some food or drink in multiple sittings in the

4 hours post-ride. The mean intake time in minutes post-ride for each ride duration was: <45 minutes; 78±70, 45-60 minutes; 31±15, 60-120 minutes; 52±32, 120-240 minutes; 32±30.

The number of participants that stated the time of day they ate affected the quantity of food/drink they consumed was similar (45% "yes"/55% "no"). As for pre-ride this was qualitatively assessed. Responses from the 4 participants who did not eat anything in the 4 hours post-ride included "I went to bed", "waited for dinner/was an intense session" and "didn't need to". Three participants reported eating less than usual, one stating "ate enough to fuel but not puke", a participant who consumed their post-ride intake within 40 minutes and one who "didn't want to overeat before going to bed". Two participants specifically noted eating the same, based on the usual meal at that time of day, but six participants reported eating more than usual due to the session. Three of these noted "hunger" driving this decision. Nine responses noted food timing was affected by the ride, the time to bedtime was noted on two occasions, and the timing of the session in relation to usual meal patterns was noted by 5 participants. Eight participants also responded with statements to the effect of "watching food intake". For example, "I ate because I was hungry and to refuel after the session", "having milk-based snack to aid sleep", "I felt like I ate a fair bit before ride so didn't feel like I needed a huge amount after ride", "I am not hungry after training and it's difficult to eat because I am working" and "ate a lot of carbs and some protein immediately after for recovery" highlight sports nutrition considerations by participants. Of food/drink types consumed post-ride, 64% specifically listed fluid intake, 80% consumed some CHO, 23% used caffeine, 65% consumed some protein, 7% took supplements and 7% drank alcohol.

Discussion

This is the first study to investigate the nutrition practice of cyclists undertaking indoor, stationary training or competition. The primary outcome of this cross-sectional analysis of athletes' food intake is that cyclists do not implement CHO recommendations for endurance performance despite the ideal environment of riding indoors. Data for pre, during and post-ride indicate significantly suboptimal CHO intake for 'key' training sessions or races at all three important time points for exercise nutrition, meaning cyclists are not adequately fuelling sessions leading to likely under performance [10, 11]. A significant proportion (75%) of cyclists also consumed no CHO during sessions where CHO fuelling is known to be beneficial, which was not hypothesised given the advantageous scenario of practicing optimal race day nutrition compared to outdoor cycling. This study also demonstrates that although CHO intake was suboptimal, cyclists training or competing indoors have adequate nutrition knowledge relating to exercise CHO intake. Despite being seemingly well aware of the requirements of appropriate fuelling, this has not translated to practice and was unaffected by session duration, intensity, or training status.

Cyclists undertaking ‘key’ training sessions should consume adequate CHO around the session, in order to provide optimal fuel for exercise power output and to support recovery and glycogen resynthesis [12]. Here cyclists did not consume sufficient CHO as measured by either the number meeting recommendations or mean intake. Critically we observed that a high proportion of cyclists do not consume any CHO during indoor sessions, and this is not differentiated during ‘key’ sessions or races. The term fuelling is currently used in sports nutrition to refer to a food or fluid option that contributes energy to intake. Interestingly there were a number of individuals (38) in this study who answered “yes” to fuelling during their ride but subsequently only reported non-calorie or very low-calorie beverage consumption. The wording of the question could perhaps have been improved with a definition of fuelling, but the number of similar responses suggest this term is not well understood or appropriate when used in isolation. Due to the combination of high intensity and duration often present in ‘key’ sessions CHO intake supports sustained power output where sessions are longer than ~45 minutes [13]. Where cyclists did consume CHO during exercise, mean intakes were ~35-40 $g.h^{-1}$ which although conferring some metabolic and performance advantage over zero CHO consumption [14, 15], also suggests reasons exist preventing higher consumption. CHO intakes of 80-90$g.h^{-1}$ may be beneficial for longer sessions with combined glucose:fructose composition [10, 16-18].

Consuming CHO during training can enhance gut tolerance and intestinal absorption capacity [19]. Although mechanisms to this effect are not fully determined [20], the unique indoor environment allows athletes to have sufficient CHO within reach to achieve higher intake without the demands of carrying it on the bike. Indoor training also allows athletes to practice on-bike feeding within the relative comfort of their own home or gym, whereby immediately terminating training due to GI distress is possible. Therefore, we hypothesised that cyclists training indoors would consume CHO during exercise in sufficient quantity to meet recommendations, which was not observed. Unfortunately, too few participants reported qualitative data on their decision making for during exercise CHO intake and firm explanations for this under fuelling are therefore not possible. However, the responses received noted the lack of need to fuel due to perceived session demands. This is despite only 8 of the 76 total responses in the study dealing with sessions <45 minutes, where CHO intake is not required [21], or mouth-rinse strategies can provide ergogenic benefits during race conditions [22], especially if fasted [23]. On-bike nutrition can be met through the use of homemade solutions, or commercially available products, including hydrogels, which have anecdotal support to mitigate GI issues [24]. In light of this finding, it is suggested that cyclists consider the role of indoor training to practice and optimise individual CHO intake while heeding nutrition recommendations, with the understanding that self-made CHO supplementation is a suitable strategy if required [21, 25]. Where cyclists consumed some CHO during exercise, consumption in the present study is in line with professional cyclists' intake during a stage of the Vuelta A Espana [26], that is, notably lower than current guidelines. However, data from the 1989 Tour de France indicate professional cyclists can and do meet 90 $g.h^{-1}$ targets if required to [27]. However, comparisons to elite bike racing are made with caution due to anticipated differences in habitual practice and CHO consumption knowledge to the current cohort, as well as the fact the current study assessed CHO intake in a novel environment. As such future research is required to fully elucidate if CHO intake differs between indoor racing and training and outdoor cycling.

Pre and post-ride CHO intake were also substantially below suggested ranges, further compromising performance during races or 'key' sessions. Whilst shorter sessions may not benefit from pre-exercise CHO, sessions lasting >/=60 minutes benefit from replenishing liver glycogen stores following overnight fasts or periods between meals [28, 29]. Therefore, the target of consuming 1-4 $g.kg^{-1}$ in the 1-4 hours prior to exercise is broad, and we speculate this may cause some confusion as to specific, individualised approaches needed for different athletes and sessions. However, this was not highlighted by participants, but due to constraints of questionnaire length this could be further investigated in future. Post-ride CHO intake was similarly under consumed, meaning participants were likely compromising recovery energy intake as CHO plays a significant role in exercise adaptation [30, 31] and immune system health [32]. Mean CHO intake post-ride was 0.84 $g.kg^{-1}$, but was higher following sessions lasting 60-120 minutes (1.13 $g.kg^{-1}$) indicating the possibility that participants were either aware of the need to replenish CHO stores, or appetite was sufficiently stimulated, leading to increased CHO consumption. We were unable to directly test these effects. Despite this, CHO intake was substantially below requirements and is in agreement with season long data from Viner et al. [33]. The data for sessions lasting >120 minutes in the current study are reported with the caveat that several of the food records were insufficiently complete to determine accurate CHO intake. Similarly, memory-based food recall methods have limitations to their accuracy of actual food intake [34], although the multiple-pass method mitigates some reporting error [8]. Despite a higher prevalence of insufficient food intake data in the post-ride period, the majority of participants under consumed CHO, reflecting a possible limitation in the length of the questionnaire. Furthermore, due to the much narrower CHO intake target for immediate post-exercise intake (1-1.2 $g.kg^{-1}$), mean intakes post-ride are less likely to be 'on target' despite the fact that small deviations either way, particularly with higher intakes in this cohort, are unlikely to be harmful. Considering the context of a single session in an athlete's training program is essential, but despite this, few athletes reported the need to recover or prepare for their next session when reflecting on their post-session food intake.

An important facet of sports nutrition is understanding athlete behaviour, beliefs and diet education [35]. We attempted to qualify cyclists' practice by including open questions to determine if, and how, any factors influenced the time of day and type of food that was consumed pre and post-ride. Despite choosing to compare to the gold standard of nutrition recommendations for elite cyclists, all sports nutrition advice should, and is typically, individualised to the athlete and further periodised to their training goals. We acknowledge limitations in the study design not allowing thorough and in depth interrogation of all elements of food intake around the sessions or the days prior and following, but the constraints of time for the quantitative element of the study questionnaire did not allow such investigation. However, cyclists reported the time of day and/or session timing significantly influenced their pre-ride food intake (timing and quantity), especially where sessions were in the early morning. Given that participants significantly under consumed CHO prior to their session, consuming on average only 0.67 $g.kgBM^{-1}$, it would be interesting to know with those who opted for a snack whether this was additional to normal intake or a regular snack incorporated in daily meal pattern irrespective of training. In this way, snacking or consuming extra meals would present an immediate solution to increasing CHO intake, especially given only 30% of elite endurance athletes consume CHO based foods, gels or drinks prior to 'key sessions' [4]. Future research may wish to focus on athletes' awareness and practitioner measurement of [low] energy availability (LEA) which is widely recognised to impair numerous physiological functions critical to exercise performance and adaptation

[36]. However, assessment of LEA requires access to the athlete and a laboratory, which was beyond the remit of this study. Future research would ideally explore the reasons behind this observed sub-optimal fuelling and closely examine the prospect of poor within-day energy availability.

This study has limitations, including the cross-sectional study design. However, the opportunity to capture nutritional practice of cyclists engaging in this type of training was unique during 2020. Due to this being the first study to investigate sports nutrition practice in this environment, the design provides novel and applicable data to the field in a timely manner. A prospective study in a similar cohort would allow further depth regarding precise food intake on a training day, but also capture the nutritional context of food intake and training. It would also be interesting to investigate and qualify the behavioural and habitual practice of cyclists racing and training indoors, but this was beyond the remit of the current study. Due to the intensive nature of capturing accurate food intake, our goal was to maximise recruitment and engagement to provide a preliminary report without overly compromising session related food intake data, where the multi-pass method used increases food recall. The mixed-methods design provides a useful perspective of some of the decision making around CHO intake but due to concerns of questionnaire length, the study was not able to fully elucidate participant behaviour or context in relation to food intake. In terms of the qualitative component of the study, this could be enhanced and further investigated in future work, and some concerns exist as to the inferential power of the current design for the qualitative component [37]. Comparisons to previous studies are also difficult as no investigations of athletes training in this environment have been conducted. However, understanding practice of athletes in their usual training environments is crucial and can be overlooked in sports nutrition, as food intake and the relation to energy expenditure are complex bio-psycho-social structures [35, 38, 39]. Limitations also exist around the self-report nature of key physiological variables such as FTP and body mass, as well as food recall. ‘Digital doping’ is prevalent in online racing, whereby athletes under report body mass or modify equipment to provide higher power output values. We anticipate such effects were small, if not entirely absent due to research being anonymous and with little or no extrinsic, competitive element. However, this cannot be entirely ruled out.

Conclusion

In conclusion, cyclists conducting training sessions using indoor means, do not meet sports nutrition guidelines for CHO intake pre, during or post-ride. Therefore cyclists using indoor training to achieve training targets should be mindful of appropriately fuelling these sessions. Coaches and practitioners should also be aware that athletes may not achieve suggested CHO intakes around ‘key’ training sessions requiring high CHO availability despite good knowledge of session demands. Athletes should focus on consuming sufficient CHO before & during sessions to increase glycogen storage and exercising CHO oxidation where maximum performance outcomes involving prolonged high intensity or high quality outputs are required.

List of Abbreviations

CHO – carbohydrate

ES – effect size

FTP – functional threshold power

LEA – low energy availability

SD – standard deviation

References

1. Faria, E. W.; Parker, D. L.; Faria, I. E., The science of cycling: physiology and training - part 1. *Sports Med* **2005,** *35* (4), 285-312. 10.2165/00007256-200535040-00002
2. Impey, S. G.; Hearris, M. A.; Hammond, K. M.; Bartlett, J. D.; Louis, J.; Close, G. L.; Morton, J. P., Fuel for the Work Required: A Theoretical Framework for Carbohydrate Periodization and the Glycogen Threshold Hypothesis. *Sports Med* **2018,** *48* (5), 1031-1048. 10.1007/s40279-018-0867-7
3. Burke, L. M.; Hawley, J. A.; Wong, S. H.; Jeukendrup, A. E., Carbohydrates for training and competition. *J Sports Sci* **2011,** *29 Suppl 1*, S17-27. 10.1080/02640414.2011.585473
4. Heikura, I. A.; Stellingwerff, T.; Mero, A. A.; Uusitalo, A. L. T.; Burke, L. M., A Mismatch Between Athlete Practice and Current Sports Nutrition Guidelines Among Elite Female and Male Middle- and Long-Distance Athletes. *Int J Sport Nutr Exerc Metab* **2017,** *27* (4), 351-360. 10.1123/ijsnem.2016-0316
5. Heil, N. Zwift Already Transformed Indoor Training. What's Next? https://www.outsideonline.com/2393635/zwift-virtual-training (accessed 19th November).
6. Cox, G. R.; Clark, S. A.; Cox, A. J.; Halson, S. L.; Hargreaves, M.; Hawley, J. A.; Jeacocke, N.; Snow, R. J.; Yeo, W. K.; Burke, L. M., Daily training with high carbohydrate availability increases exogenous carbohydrate oxidation during endurance cycling. *J Appl Physiol (1985)* **2010,** *109* (1), 126-34. 10.1152/japplphysiol.00950.2009
7. Costa, R. J. S.; Miall, A.; Khoo, A.; Rauch, C.; Snipe, R.; Camoes-Costa, V.; Gibson, P., Gut-training: the impact of two weeks repetitive gut-challenge during exercise on gastrointestinal status, glucose availability, fuel kinetics, and running performance. *Appl Physiol Nutr Metab* **2017,** *42* (5), 547-557. 10.1139/apnm-2016-0453
8. Steinfeldt, L.; Anand, J.; Murayi, T., Food Reporting Patterns in the USDA Automated Multiple-Pass Method. *Procedia Food Sci* **2013,** *2*, 145-156.
9. Jeukendrup, A. E., Nutrition for endurance sports: marathon, triathlon, and road cycling. *J Sports Sci* **2011,** *29 Suppl 1*, S91-9. 10.1080/02640414.2011.610348

10. King, A. J.; O'Hara, J. P.; Morrison, D. J.; Preston, T.; King, R., Carbohydrate dose influences liver and muscle glycogen oxidation and performance during prolonged exercise. *Physiol Rep* **2018,** *6* (1). 10.14814/phy2.13555

11. Mata, F.; Valenzuela, P. L.; Gimenez, J.; Tur, C.; Ferreria, D.; Dominguez, R.; Sanchez-Oliver, A. J.; Martinez Sanz, J. M., Carbohydrate Availability and Physical Performance: Physiological Overview and Practical Recommendations. *Nutrients* **2019,** *11* (5). 10.3390/nu11051084

12. Burke, L. M.; van Loon, L. J. C.; Hawley, J. A., Postexercise muscle glycogen resynthesis in humans. *J Appl Physiol (1985)* **2017,** *122* (5), 1055-1067. 10.1152/japplphysiol.00860.2016

13. Jeukendrup, A. E., A step towards personalized sports nutrition: carbohydrate intake during exercise. *Sports Med* **2014,** *44 Suppl 1*, S25-33. 10.1007/s40279-014-0148-z

14. Newell, M. L.; Wallis, G. A.; Hunter, A. M.; Tipton, K. D.; Galloway, S. D. R., Metabolic Responses to Carbohydrate Ingestion during Exercise: Associations between Carbohydrate Dose and Endurance Performance. *Nutrients* **2018,** *10* (1), 37. 10.3390/nu10010037

15. Smith, J. W.; Zachwieja, J. J.; Peronnet, F.; Passe, D. H.; Massicotte, D.; Lavoie, C.; Pascoe, D. D., Fuel selection and cycling endurance performance with ingestion of [13C]glucose: evidence for a carbohydrate dose response. *J Appl Physiol* **2010,** *108* (6), 1520-29. 10.1152/japplphysiol.91394.2008

16. King, A. J.; O'Hara, J. P.; Arjomandkhah, N. C.; Rowe, J.; Morrison, D. J.; Preston, T.; King, R., Liver and muscle glycogen oxidation and performance with dose variation of glucose-fructose ingestion during prolonged (3 h) exercise. *Eur J Appl Physiol* **2019,** *119* (5), 1157-1169. 10.1007/s00421-019-04106-9

17. Rowlands, D. S.; Thorburn, M. S.; Thorp, R. M.; Broadbent, S.; Shi, X., Effect of graded fructose coingestion with maltodextrin on exogenous 14C-fructose and 13C-glucose oxidation efficiency and high-intensity cycling performance. *J Appl Physiol (1985)* **2008,** *104* (6), 1709-19. 10.1152/japplphysiol.00878.2007

18. Smith, J. W.; Pascoe, D. D.; Passe, D. H.; Ruby, B. C.; Stewart, L. K.; Baker, L. B.; Zachwieja, J. J., Curvilinear dose-response relationship of carbohydrate (0-120 g.h(-1)) and performance. *Med Sci Sports Exerc* **2013,** *45* (2), 336-41. 10.1249/MSS.0b013e31827205d1

19. Costa, R. J. S.; Snipe, R. M. J.; Kitic, C. M.; Gibson, P. R., Systematic review: exercise-induced gastrointestinal syndrome-implications for health and intestinal disease. *Aliment Pharmacol Ther* **2017,** *46* (3), 246-265. 10.1111/apt.14157

20. Jeukendrup, A. E., Training the Gut for Athletes. *Sports Med* **2017,** *47* (Suppl 1), 101-110. 10.1007/s40279-017-0690-6

21. Thomas, D. T.; Erdman, K. A.; Burke, L. M., American College of Sports Medicine Joint Position Statement. Nutrition and Athletic Performance. *Med Sci Sports Exerc* **2016,** *48* (3), 543-68. 10.1249/MSS.0000000000000852

22. Brietzke, C.; Franco-Alvarenga, P. E.; Coelho-Junior, H. J.; Silveira, R.; Asano, R. Y.; Pires, F. O., Effects of Carbohydrate Mouth Rinse on Cycling Time Trial Performance: A Systematic Review and Meta-Analysis. *Sports Med* **2019,** *49* (1), 57-66. 10.1007/s40279-018-1029-7

23. Li, S.; Wu, Y.; Cao, Y., Comment on: "Effects of Carbohydrate Mouth Rinse on Cycling Time Trial Performance: A Systematic Review and Meta-Analysis". *Sports Med* **2019,** *49* (5), 819-821. 10.1007/s40279-019-01076-y

24. King, A. J.; Rowe, J. T.; Burke, L. M., Carbohydrate Hydrogel Products Do Not Improve Performance or Gastrointestinal Distress During Moderate Intensity Endurance Exercise: A Review. *Int J Sport Nutr Exerc Metab* **2020,** *30* (5), 576-582. 10.1123/ijsnem.2020-0102

25. Rowlands, D. S.; Houltham, S.; Musa-Veloso, K.; Brown, F.; Paulionis, L.; Bailey, D., Fructose-Glucose Composite Carbohydrates and Endurance Performance: Critical Review and Future Perspectives. *Sports Med* **2015,** *45* (11), 1561-76. 10.1007/s40279-015-0381-0

26. Garcia-Roves, P. M.; Terrados, N.; Fernandez, S. F.; Patterson, A. M., Macronutrients intake of top level cyclists during continuous competition--change in the feeding pattern. *Int J Sports Med* **1998,** *19* (1), 61-67. 10.1055/s-2007-971882

27. Saris, W. H.; van Erp-Baart, M. A.; Brouns, F.; Westerterp, K. R.; ten Hoor, F., Study on food intake and energy expenditure during extreme sustained exercise: the Tour de France. *Int J Sports Med* **1989,** *10 Suppl 1*, S26-31. 10.1055/s-2007-1024951

28. Burke, L. M.; Jeukendrup, A. E.; Jones, A. M.; Mooses, M., Contemporary Nutrition Strategies to Optimize Performance in Distance Runners and Race Walkers. *Int J Sport Nutr Exerc Metab* **2019,** *29* (2), 117-129. 10.1123/ijsnem.2019-0004

29. Gonzalez, J. T.; Fuchs, C. J.; Betts, J. A.; van Loon, L. J., Liver glycogen metabolism during and after prolonged endurance-type exercise. *Am J Physiol Endocrinol Metab* **2016,** *311*, E543-553.
30. Hammond, K. M.; Sale, C.; Fraser, W.; Tang, J.; Shepherd, S. O.; Strauss, J. A.; Close, G. L.; Cocks, M.; Louis, J.; Pugh, J.; Stewart, C.; Sharples, A. P.; Morton, J. P., Post-exercise carbohydrate and energy availability induce independent effects on skeletal muscle cell signalling and bone turnover: implications for training adaptation. *J Physiol* **2019,** *597* (18), 4779-4796. 10.1113/JP278209
31. Gonzalez, J. T.; Fuchs, C. J.; Betts, J. A.; van Loon, L. J., Glucose Plus Fructose Ingestion for Post-Exercise Recovery-Greater than the Sum of Its Parts? *Nutrients* **2017,** *9* (4), 344. 10.3390/nu9040344
32. Peake, J. M.; Neubauer, O.; Walsh, N. P.; Simpson, R. J., Recovery of the immune system after exercise. *J Appl Physiol (1985)* **2017,** *122* (5), 1077-1087. 10.1152/japplphysiol.00622.2016
33. Viner, R. T.; Harris, M.; Berning, J. R.; Meyer, N. L., Energy Availability and Dietary Patterns of Adult Male and Female Competitive Cyclists With Lower Than Expected Bone Mineral Density. *Int J Sport Nutr Exerc Metab* **2015,** *25* (6), 594-602. 10.1123/ijsnem.2015-0073
34. Shim, J. S.; Oh, K.; Kim, H. C., Dietary assessment methods in epidemiologic studies. *Epidemiol Health* **2014,** *36*, e2014009. 10.4178/epih/e2014009
35. Bentley, M. R. N.; Mitchell, N.; Backhouse, S. H., Sports nutrition interventions: A systematic review of behavioural strategies used to promote dietary behaviour change in athletes. *Appetite* **2020,** *150*, 104645. 10.1016/j.appet.2020.104645
36. Mountjoy, M.; Sundgot-Borgen, J.; Burke, L.; Ackerman, K. E.; Blauwet, C.; Constantini, N.; Lebrun, C.; Lundy, B.; Melin, A.; Meyer, N.; Sherman, R.; Tenforde, A. S.; Torstveit, M. K.; Budgett, R., International Olympic Committee (IOC) Consensus Statement on Relative Energy Deficiency in Sport (RED-S): 2018 Update. *Int J Sport Nutr Exerc Metab* **2018,** *28* (4), 316-331. 10.1123/ijsnem.2018-0136
37. Price, J. H.; Murnan, J.; Dimmig, J.; Akpanudo, S., Power Analysis in Survey Research- Importance and Use for Health Educators. *Am J Health Educ* **2005,** *36* (4), 202-207.

38. Garthe, I.; Raastad, T.; Sundgot-Borgen, J., Long-term effect of nutritional counselling on desired gain in body mass and lean body mass in elite athletes. *Appl Physiol Nutr Metab* **2011,** *36* (4), 547-554. 10.1139/h11-051

39. Nascimento, M.; Silva, D.; Ribeiro, S.; Nunes, M.; Almeida, M.; Mendes-Netto, R., Effect of a Nutritional Intervention in Athlete's Body Composition, Eating Behaviour and Nutritional Knowledge: A Comparison between Adults and Adolescents. *Nutrients* **2016,** *8* (9), 535. 10.3390/nu8090535

Declarations

Ethics approval and consent to participate

This study was approved by the Australian Catholic University Human Research Ethics Committee (number; HREC-2020-125E) and were in agreement with the Declaration of Helsinki.

Financial Support

There are no funders to report for this submission

Consent for publication

n/a

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

Author AK declares to have no competing interests. RH works with VIS cycling, but no contribution was made by this body to the study.

Authors' contributions

AK & RH were responsible for study conception, data collection, analysis and preparing and reviewing the manuscript.

Acknowledgements

The authors thank each participant who took the time to complete the survey during a difficult year.

Table 1: Participant demographics

Body Mass (kg)*	71.3±14.3	
FTP (W)*	261.7 ± 71.9	
(W.kg^{-1})*	3.81 ± 0.83	
Age	<18	1
	18-24	8
	25-29	7
	30-34	12
	35-39	12
	40-44	11
	45-49	9
	50-54	9
	55-59	2
	60-64	1
	not reported	4
Sex	Male	34
	Female	23
	not reported	19
Country of residence	Australia	39
	UK	16
	South Africa	6
	Netherlands	3
	Canada	2
	New Zealand	2
	USA	1
	Spain	1
	Portugal	1
	Belgium	1
	not reported	4
Cycling Discipline[#]	Road	45
	Cyclocross	3
	Endurance/ultra	7
	MTB	6

	not reported	1
Education	High school	12
	(Advanced) diploma	2
	Bachelor’s degree	19
	Post grad cert/dip	7
	Master’s degree	21
	Doctorate	11
	not reported	4

*self-reported data

[#]participants could identify >1 category

Table 2: Carbohydrate consumption pre-ride

	Fuelled Pre-Ride? (n)			**CHO guidelines met?**			**CHO consumption**		
Session duration (min)	**YES**	**NO**	**'yes'***	**YES**	**NO**	**n/a**	**(g)**	**(g) [when CHO consumed]**	**(g.kgBM^{-1}) [when CHO consumed]**
ALL	61	8	7	16	45	15	48.1 ± 38.3	60.1 ± 33.3	0.92 ± 0.56
< 45	7	0	0	1	5	1	51.6 ± 22.4	51.6 ± 22.4	0.74 ± 0.42
45-60	26	4	2	3	20	9	43.8 ± 40.2	55.8 ± 38.7	0.84 ± 0.64
60-120	21	2	4	8	15	4	51.0 ± 38.9	66.2 ± 30.7	0.97 ± 0.49
>120	7	2	1	4	5	1	52.1 ± 48.3	74.4 ± 29.5	1.17 ± 0.56

Data are total number of participants (column 2-4) and mean ± sd consumption (column 5-7).

n/a indicates where insufficient dietary information reported to quantify CHO intake.

***** indicates participants answering YES to question "Did you eat or drink anything in the 4 hours before this ride or race (a meal and or a snack or something to drink)?" but who consumed zero carbohydrate.

Table 3: Carbohydrate consumption during-ride

	Fuelled During-Ride? (n)			**CHO consumption**	
Session duration	**YES**	**NO**	**YES (no CHO consumed)**	**(g)**	**(g/h) [when CHO consumed]**
ALL	18	15	41	62.0 ± 52.8	39.3 ± 27.5
< 45 min	3	1	3	37.3 ± 38.2	49.8 ± 51.0
45-60 min	3	8	20	36.7 ± 7.3	36.7 ± 7.6
60-120 min	6	5	15	56.4 ± 33.7	37.6 ± 22.5
>120 min	6	1	3	92.5 ± 76.3	37.0 ± 30.5

Data are total number of participants (column 2-4) and mean ± sd consumption (column 5-7)

Table 4: Carbohydrate consumption post-ride

	Ate/Drank Post-Ride? (n)			**CHO guidelines met?**			**CHO consumption**		
Session duration (min	**YES**	**NO**	**'yes'***	**YES**	**NO**	**n/a**	**(g)**	**(g) [when CHO consumed]**	**(g.kgBM^{-1})**
ALL	65	4	2	7	40	24	57.1 ± 42.4	67.3 ± 42.4	0.84 ± 0.73
< 45	5	0	0	1	1	3	83.8 ± 54.0	83.8 ± 54.0	1.73 ± 0.98
45-60	27	2	0	3	17	9	50.2 ± 37.0	59.0 ± 37.0	0.72 ± 0.55
60-120	23	2	1	3	17	6	62.4 ± 47.7	74.1 ± 47.7	1.13 ± 0.80
>120	10	0	1	0	5	6	46.5 ± 37.8	62.0 ± 37.8	0.85 ± 0.42

Data are total number of participants (column 2-4) and mean ± sd consumption (column 5-7).
n/a indicates where insufficient dietary information reported to quantify CHO intake.
***** indicates participants answering YES to question "Did you eat a meal or snack in the hours after this ride or race?" but who consumed zero carbohydrate.

Figure Titles

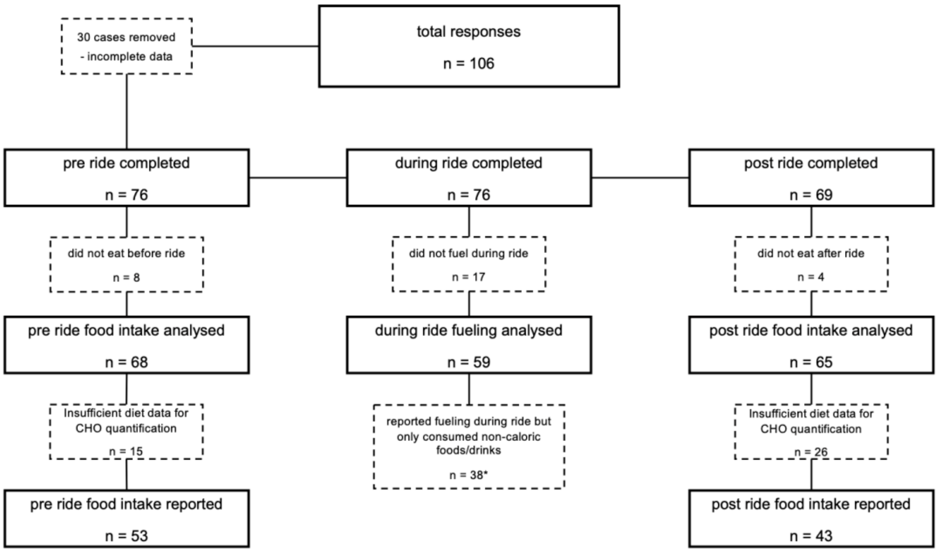

Figure 1: Flowchart of responses and data screening for pre, during and post session data

Figure Legend: NO LEGEND

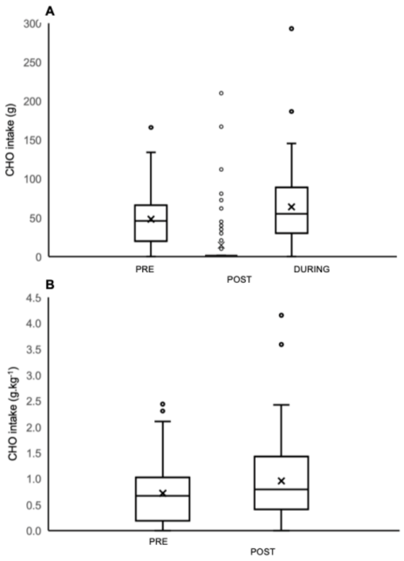

Figure 2: Total CHO intake pre, during and post ride and relative CHO intake

Figure Legend: post ride (panel A) and relative (per kg body mass) CHO intake (panel B). Boxes represents median with 1st and 3rd quartile range, and whiskers maximum and minimum values, excluding outliers (open circles; 1.5 x IQ range). X represents mean CHO intake.

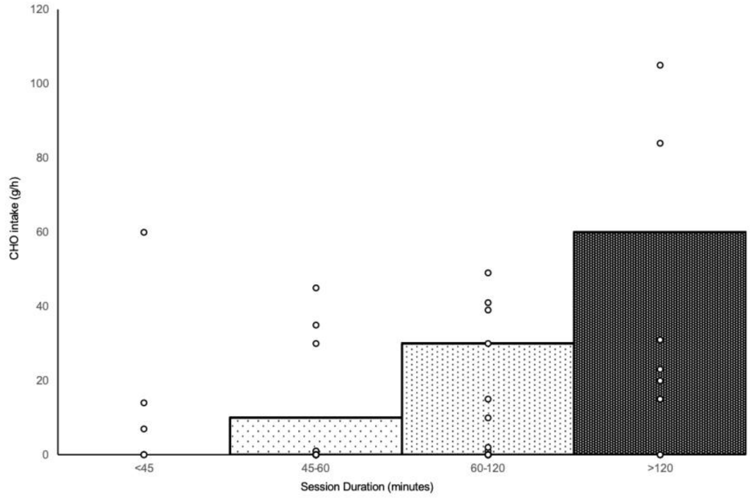

Figure 3: CHO intake during sessions of all durations

Figure Legends: Circles represent individual CHO intakes; bars represent recommended CHO targets for session duration.

Figure 4: Response breakdown to questions "did you fuel" pre, during and post session

Figure Legends: Qualitative responses are represented as total numbers of a response provided and grouped within themes. Qualitative responses are also presented as quotes from participants where these highlight specific individual considerations.