1.1 The gut is trainable

1.1.1 Studies and the real world

Although recommendations are relatively clear, football players cannot or do not follow them. So there seems to be a disconnect between the outcome of controlled laboratory and field studies in moderately trained men and the actual situation of match day. This does not mean that the results of the studies are not valid, it just means that we need to find better ways to implement them in real life situations.

The importance of the gastro-intestinal tract is often underestimated by athletes. Especially during prolonged exercise, the supply of exogenous fluid and carbohydrates sources can be critical to performance (Jeukendrup, 2011a).

In football, it has been shown that carbohydrate intake should be around 75g during matches and fluid intake should be sufficient to minimise fluid losses to 2% body weight. In reality, football players do not reach these targets (Anderson et al., 2017). Carbohydrate intake during match play was around 30 g/h in the majority of players at Liverpool FC and four players consumed less than 30 g/h). The most common reason that is used are gastro-intestinal symptoms such as bloating and sometimes cramping and vomiting. In sports these are indeed common symptoms (de Oliveira, Burini, & Jeukendrup, 2014). During high intensity intermittent exercise gastric emptying may be inhibited (Leiper, Prentice, Wrightson, & Maughan, 2001) and blood flow may be diverted away from the gastro-intestinal tract and this may in turn impair the function of the gastro-intestinal tract. As a result, a range of gastro-intestinal symptoms may develop but also the delivery of nutrients will be impaired. Studies often observe certain aspects of sports nutrition in isolation. For example, for many years, the optimal composition of a sports drink was studied by looking at markers of hydration. It was established that a drink with a low level of carbohydrate and some sodium was required to optimise fluid delivery. Based on these results, sports drinks were developed that were isotonic, 6-7% carbohydrate solutions, and contained about 20 mmol/L of sodium (studies showed more would be better, but this reduced palatability too much). Other studies investigated carbohydrate delivery and the outcome measure here was exogenous carbohydrate oxidation. These studies generally found that higher intake rates of carbohydrate resulted in greater exogenous carbohydrate oxidation rates, but because the amount of fluid that could comfortably be consumed was relatively small the carbohydrate concentrations of the solution were much higher than the rehydration drinks (10-18% on average). Of course, in a real-world setting both fluid and carbohydrate requirements must be considered and not just the results of hydration studies or just the results of carbohydrate oxidation studies. It must be decided what is more important: fluid delivery or carbohydrate delivery. For football, this is probably an easy question to answer: there are studies that show that players lose relatively small amounts of fluids during matches (<2-3% in moderate to warm conditions), but carbohydrate needs are relatively high (studies suggest that at least 60 g needs to be ingested to see performance benefits. Thus, providing carbohydrate may be more important than providing fluids. When conditions get warmer and fluid losses increase, the need for carbohydrate will remain the same (or increase slightly) and the need for fluids increases. The ingestion of carbohydrate at the recommended rate is already challenging for players (as evidenced by the lower intake that is normally observed) and adding fluids will only make it more difficult to execute.

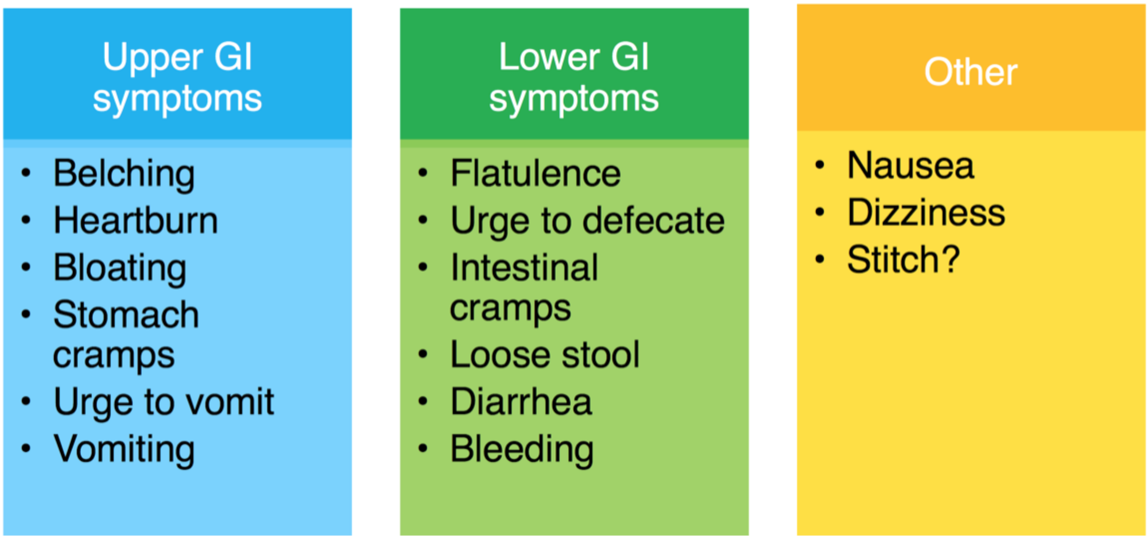
However, it is clear that the intestinal tract is highly adaptable, and it has been suggested that targeted training of the intestinal tract may improve the delivery of nutrients during exercise whilst at the same time alleviating some (or all) of the symptoms (Jeukendrup, 2011b). This training sometimes referred to as "training the gut" has received relatively little attention in the literature but was recently reviewed (Jeukendrup, 2011b) and is now becoming part of the daily training routine of many athletes. This could be an important aspect of delivering carbohydrate and fluids especially before and during the match so that players can follow recommendations without any negative effects of carbohydrate and fluid intake.

1.1.2 Gastrointestinal problems

Gastro-intestinal problems are very common amongst athletes and 30-50% of all athletes experience such problems regularly (de Oliveira et al., 2014). Football players suffer less from these problems than, for example, runners or triathletes but it is still a commonly reported problem.

> The most common complaints in football players include ructation (belching), abdominal pain, gastroesophageal reflux (or heartburn) and bloating (symptoms of the upper gastro-intestinal tract) (Figure 1). Slightly less common are abdominal cramping, increased flatulence, loose stool, diarrhea or even bloody diarrhea, and vomiting (symptoms of the lower gastro-intestinal tract). There is a third category of symptoms that cannot be classified as upper or lower gastro-intestinal problems but might be related to the gastro-intestinal tract (for example stitch, nausea, dizziness). (Jeukendrup, 2016, https://bit.ly/2gfipb2)

Figure 1: Gastro-intestinal symptoms can be divided into three categories

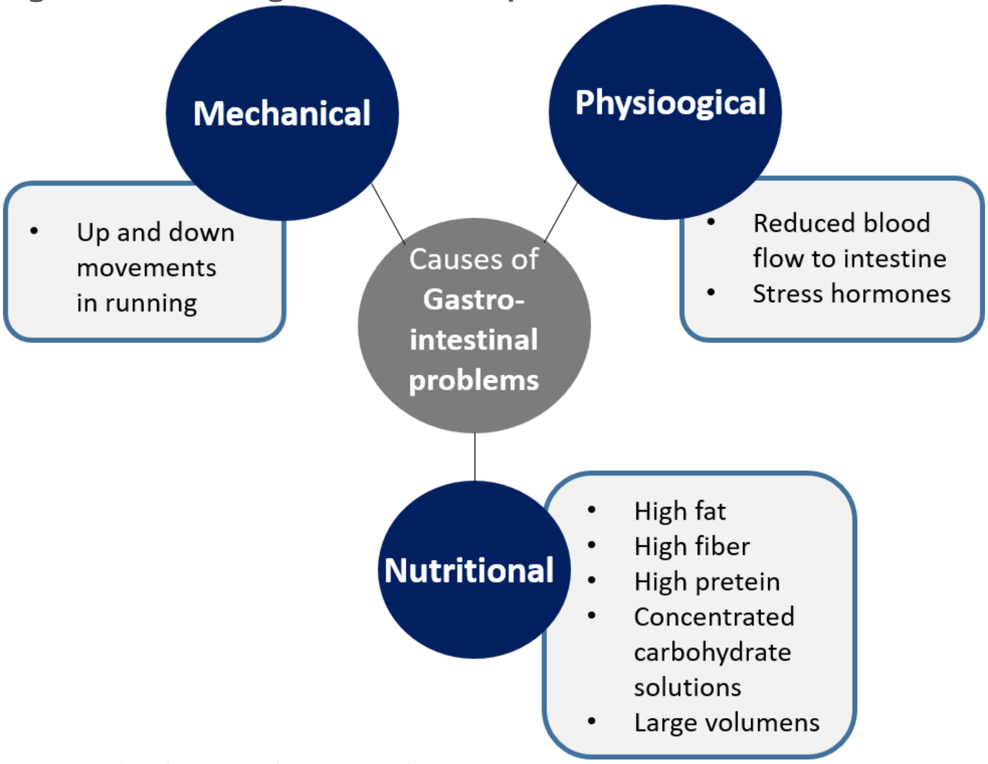


Source: Jeukendrup, 2016, https://bit.ly/2gfipb2

The causes are still largely unknown but appear to be partly genetically determined and highly individual (de Oliveira et al., 2014). The mechanisms are likely to be different for upper and lower gastro-intestinal problems. The symptoms are more likely to occur and are exacerbated by hot weather conditions and dehydration (de Oliveira et al., 2014). Although a link with nutrition intake is not always found, certain practices have been found to correlate with the incidence of gastro-intestinal problems: fibre intake, fat intake and highly concentrated carbohydrate solutions seem to increase the prevalence of GI problems. (Jeukendrup, 2017, https://bit.ly/2soS2oQ)

At present, the causes of gastrointestinal symptoms are not completely understood. The symptoms are difficult to investigate because they are sometimes unpredictable and are very difficult to reproduce or simulate in a laboratory. Nevertheless, some laboratory studies have been performed, and field studies have correlated the symptoms with nutritional intake and other factors. From these studies a number of potential causes and contributors have been identified and they can be divided into 3 general categories (Figure 2):
(1) physiological
(2) mechanical, and
(3) nutritional.

Figure 2: Causes of gastro-intestinal problems



Source: Jeukendrup, 2016, https://goo.gl/AYHoQD

Physiological causes

Physiological causes of gastrointestinal symptoms include reduced blood flow and increased anxiety (especially before matches). With exercise, blood flow is preferentially redirected to the working muscles and blood flow to the gut can be reduced by as much as 80%. Such low blood supply can compromise gut function to varying degrees and can result in commonly experienced gastrointestinal symptoms such as cramping. In severe cases it can even result in injury of the large intestine as a result of inadequate blood supply (ischemic colitis). Although, with training, this decrease in blood flow becomes less pronounced, there is no clear evidence that less fit individuals are more prone to developing symptoms as a results of reduced blood flow to the gut. Anxiety has an effect on hormone secretion which in turn can affect gut movement, resulting in incomplete absorption and loose stool.

Mechanical causes

The mechanical causes of GI-problems are either impact-related or are related to posture. This is thought to be a result of the repetitive high-impact mechanics of running and subsequent damage to the intestinal walls.

Nutritional causes

Finally, nutrition can have a strong influence on gastro-intestinal distress. Fibre, fat, protein, and fructose have all been associated with a greater risk to develop GI-symptoms. Dehydration, possibly as a result of inadequate fluid intake, may also exacerbate the symptoms. Hypertonic beverages with high density (osmolarities >500 mOsm/L) seem especially likely to cause complaints. Although some risk factors have been identified it is still unclear why some individuals seem to be more prone to develop gastrointestinal problems than others.

To minimize gastrointestinal distress, all these risk factors must be taken into account, and a number of guidelines should be followed:

Avoid high fibre foods

Avoid high fibre foods in the day of the match, possibly also the day before the match. For the athlete in training, a diet with adequate fibre will help to keep the bowel regular. However, because fibre is not digestible, any fibre that is eaten essentially passes through the intestinal tract. Increased bowel movements during exercise are not desirable and may also accelerate fluid loss. The extra fibre can also result in unnecessary gas production which in turn can cause cramping and gastro-intestinal discomfort. Especially for those individuals who are prone to develop gastro-intestinal symptoms, a low fibre intake on match days, or in extreme cases a day or even two days before a match, is recommended. This essentially means selecting processed white foods, like regular pasta, white rice, and plain bagels instead of whole grain bread, high fibre cereals, oats and brown rice. Keep an eye on food labels for fibre content. Most fruits and vegetables are high in fibre but there are a few exceptions: zucchini, tomatoes, olives, grapes, and grapefruit all have less than one gram of fibre per serving.

Avoid aspirin and non-steroidal anti-inflammatory drugs (NSAIDs)

Avoid aspirin and non-steroidal anti-inflammatory drugs (NSAIDs) such as ibuprofen. Both aspirin and NSAIDs have been shown to increase intestinal permeability and may increase the incidence of GI complaints. The use of NSAIDs in the pre-race period should be discouraged.

Avoid milk products

Some players may have a mild lactose intolerance that does not affect them during normal life but on match days with match day anxiety in combination with exercise, the mild lactose intolerance may become symptomatic. Avoid milk products that contain lactose by avoiding milk completely or by replacing it with lactose free milk. Soy, rice, and almond milks generally don't contain lactose (although many of such drinks also do not contain protein).

Avoid fructose-only foods

Avoid high fructose foods (in particular drinks that have exclusively fructose). Fructose is not only found in fruit, but also in most processed sweets; candy, cookies etc., in the form of high fructose corn syrup. Some fruit juices are almost exclusively fructose. Fructose is absorbed by the intestines more slowly the tolerance of fructose is much less than glucose (may lead to cramping, loose stool and diarrhea). If fructose is ingested in combination with glucose, this is unlikely to cause problems and may even be better tolerated.

Avoid dehydration

Since dehydration can exacerbate GI-symptoms it is important to avoid dehydration. Start the race well hydrated.

Train your gut

Training the gut is another practice that can help to prevent gastro-intestinal problems. If a player's gut is adapted to the foods consumed during a match, he or she is less likely to get stomach problems. (Jeukendrup, 2016, https://bit.ly/2gfipb2)

"It is thought that training the gut may alleviate some of these symptoms, perhaps by improving gastric emptying, the perception of fullness (reduced bloating), improved tolerance of larger volumes and more rapid absorption causing less residual volume and smaller osmotic shifts (de Oliveira et al., 2014)". (Jeukendrup, 2017, https://bit.ly/2soS2oQ)

1.1.3 Gastric emptying

Gastric emptying is an important step towards delivering exogenous carbohydrate and fluids to the working muscle. Anecdotally athletes complain about drinks accumulating

> in the stomach and feeling bloated, especially during high intensity (Neufer, Young, & Sawka, 1989) or very prolonged exercise in hot conditions. Dehydration can contribute to this phenomenon and make complaints worse (Neufer et al., 1989; Rehrer, Beckers, Brouns, ten Hoor, & Saris, 1990). (Jeukendrup, 2017, https://bit.ly/2soS2oQ)

In football players often complain about bloatedness, especially if they have just consumed a meal or sports foods before a match or hard training.

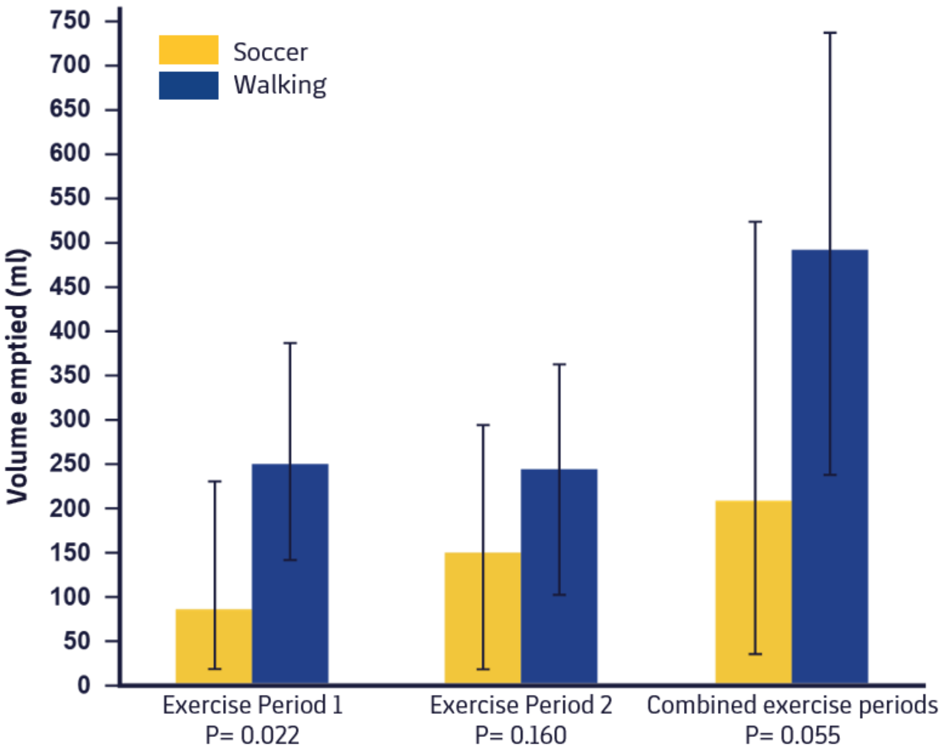
> After ingestion, it usually takes 1 to 4 hours for food to leave the stomach. The speed depends on the content and volume of the meal. Gastric motility and secretion are to some extent automatic. Contraction of the stomach increases the intragastric pressure to push the food (now called chyme) through the pyloric sphincter. Such contractions are initiated by pacemaker cells in the stomach wall. Gastric emptying is further controlled by a variety of signals (either nervous or hormonal signals) directly from the stomach or the duodenum. An increased amount of food relaxes the pyloric sphincter and increases gastric emptying. Signals from the first part of the intestine (duodenum) provide negative feedback and will inhibit gastric emptying. The duodenum contains receptors that can detect acidity, distension of the duodenum, osmolarity, and possibly carbohydrate, fat, and protein. When these receptors are stimulated, the enterogastric reflex is initiated, which increases the contraction of the pylorus. This mechanism prevents dumping of an excessive amount of chyme into the small intestine. Too rapid delivery of the chyme into the intestine could mean insufficient time for digestion and absorption to take place, and some nutrients would be lost in the feces. There are considerable differences in the rate of gastric emptying between individuals. Some people may empty 70% to 80% of a solution in 15 minutes, whereas others empty only 20% to 30% of that same solution in 15 minutes. The reasons for these individual differences are not known, but diet has been suggested as an important factor. The gastrointestinal tract possibly adapts to the intake of certain nutrients, and a high habitual fat intake may result in a high gastric-emptying rate of fat. Whatever the mechanisms, they highlight the importance of individual fluid intake recommendations.
>
> Factors that have been suggested to affect gastric emptying include:

- smell and sight of food,
- thought of food,
- volume of a drink,
- energy density of a drink,
- temperature of a drink,
- osmolarity of a drink,
- body temperature and dehydration,
- type of exercise,
- exercise intensity,
- gender, and
- psychological stress and anxiety (Jeukendrup & Gleeson 2018, https://bit.ly/2LC9XB7)

During exercise the rate of gastric emptying can slow down, although this may only happen during very high intensity exercise. Below 80% of VO_2max, the rate of gastric emptying does not seem to be affected by exercise intensity. With an intensity above 80% of VO_2max, a reduction may occur in fluid and nutrient delivery to the small intestine (Costill & Saltin, 1974; Sole & Noakes, 1989). From a practical point of view, however, this reduction may not be important because exercise intensities greater than 80%VO_2max are generally of shorter duration and therefore the supply of carbohydrate and fluid during exercise is not important. Eating and drinking would be difficult anyway at these intensities because of exercise-induced hyperventilation.

> Gastric emptying of liquids is slowed during brief intermittent high-intensity exercise compared with rest or steady-state moderate exercise (Leiper, Broad, & Maughan, 2001). Gastric emptying measured after a five-a-side indoor soccer match decreased even though the average intensity of the activity was only 54% to 63% VO_2max (Leiper, Prentice et al., 2001) (Figure 3). The relatively short bouts of very high-intensity exercise were clearly enough to reduce gastric emptying. (Jeukendrup & Gleeson 2018, https://bit.ly/2LC9XB7)

Figure 3: Gastric emptying during football (soccer) and walking. There is a clear reduction in the volume emptied during football



Probability values between trials
Probability values between time periods: Soccer trial P= 0.41: Walking trial P= 1.00

Source: Leiper, Prentice et al., 2001. https://bit.ly/2AIT17K

There is a lot of talk about isotonic drinks and osmolality has always been considered an important factor in controlling the rate of gastric emptying. A high beverage osmolality will increase gastric secretions but also secretions in the intestine and this will counteract fluid delivery. Osmolarity is therefore an important factor to consider when selecting a beverage for ingestion during exercise. Higher osmolarity may reduce gastric emptying and decrease water absorption.

But osmolarity and the concentration of simple carbohydrates are related, and it is sometimes difficult to separate the effects of osmolality from those of the carbohydrate content. A high-energy or high-carbohydrate content is usually related to high osmolarity, and the effects of concentration and osmolarity are therefore difficult to distinguish. Studies, however, suggest that although osmolarity reduces the rate of gastric emptying, this factor is not important in beverages with osmolarities in the range of 200 to 400 mOsm/L (Brouns, Senden, Beckers, & Saris, 1995), this includes most of the common sports drinks. Osmolarity possibly becomes more important in beverages with extremely high osmolarities (>500 mOsm/L).

There are a number of factors that can really slow down gastric emptying. Energy density is one of them. The greater the energy density the slower the gastric emptying. Whether this effect is an effect of energy density per se or of specific nutrients is not clear. Several nutrients exert a strong inhibitory effect on gastric emptying. For example, fat is a strong inhibitor of gastric emptying. Increasing the carbohydrate or protein content of a beverage, however, also slows gastric emptying. Carbohydrate-electrolyte solutions with 2% carbohydrate already show a tendency to empty slower than water does (Vist & Maughan, 1994), but solutions of 8% or more significantly inhibit gastric emptying. The energy content of the solution is a more important factor than the osmolarity (Vist & Maughan, 1995). The effect of meal or beverage temperature is probably not important physiologically. Lambert, Ball, Leiper, and Maughan (1999) showed that after ingestion of a $^{2}H_2O$-containing beverage, deuterium (^{2}H) accumulation in plasma was similar in drinks at varying temperatures. Gastric emptying was not different despite the differences in beverage temperature. This study reflects the findings in the literature that, generally, no effects of meal temperature have been found on the rate of gastric emptying unless extremely cold or extremely hot drinks are used.

Stress and anxiety can reduce gastrointestinal motility and the rate of gastric emptying. This reduction in the rate of gastric emptying is usually related to changes in circulating hormone concentrations because of stress. Some of these hormones (e.g., epinephrine) also reduce blood flow to the gastrointestinal tract.

Besides the factors mentioned earlier, other factors may affect gastric emptying. Studies in hot conditions have shown that dehydration and hyperthermia can cause a slowing of gastric emptying (Neufer et al., 1989; Rehrer et all., 1990). Because subjects in these studies became dehydrated and hyperthermic at the same time, determining what the mechanisms were and whether dehydration, hyperthermia, or a combination of the two was responsible for the reduced gastric emptying rate is not possible. (Jeukendrup & Gleeson 2018, https://bit.ly/2LC9XB7)

Women have slightly slower gastric emptying rates than men, although gastric emptying rates seemed to increase somewhat during ovulation. Interestingly, women are reported to be more prone to gastrointestinal complaints after prolonged endurance exercise. This finding could be related to a slower rate of gastric emptying.

It is possible that inter individual variation in gastric emptying is related to diet and "stomach training". The next section will discuss the "trainability" of the stomach.

1.1.4 "Stomach Training"

There is, however, anecdotal evidence that the stomach can adapt to ingesting large volumes of fluid, solids or combinations (Jeukendrup, 2017). For example, serious contestants in eating competitions are known to "train" their stomach to hold larger volumes of food with less discomfort and through regular training they are able to eat volumes of food within 10 min. that are unthinkable for the average and untrained person. The current all-time record is 69 hot dogs (with bun) in 10 min. In order to achieve this, competitive eaters train using a variety of methods: chewing large pieces of chewing gum for longer periods of time, stomach extension by drinking fluids or by eating the competition foods (Jeukendrup, 2017). Volumes are progressively increased, and it takes many weeks to reach a level where these eaters can be competitive. This demonstrates the adaptability of the stomach. Conducting this "stomach training" has two main effects: 1. The stomach can extend and contain more food and 2. A full stomach can be tolerated better and is not perceived so full. Both aspects could be advantageous in an exercise situation.

Current guidelines recommend fluid intakes during exercise that prevent 2% dehydration (2% of body weight). Especially in trained athletes and hot conditions, when sweat rates are high, recommended fluid intake can be substantial. Such high intakes can cause discomfort and in some cases gastro-intestinal problems. So, athletes are generally managing gastro-intestinal comfort on the one hand and hydration as well as carbohydrate delivery on the other hand. It is recommended to train these higher intakes so there is less discomfort and the chances of gastro-intestinal distress are reduced (Jeukendrup, 2013, 2014; Jeukendrup, 2011b). Unfortunately, we have very few studies that have directly investigated such effects of "nutritional training of the stomach".

Lambert et al. (2008) showed that trained runners were able to comfortably tolerate carbohydrate-electrolyte solution ingested at a rate approximately equal to their sweat rates during 90 min of running at 65 % VO_2max (maximum oxygen uptake) in a ~ 25ºC, 30% relative humidity (RH) environment. When these runners ingested this volume of fluid for the first time it caused a lot of discomfort. Interestingly, the researchers observed that stomach comfort significantly improved over time by practicing these high intakes. It must be noted that this improved comfort occurred without measurable changes in the rate of gastric emptying (Lambert et al., 2008). Perhaps the stomach adapted by extending the stomach walls allowing greater space for fluid. This would likely reduce feelings of stomach discomfort and reduce the stimulus for faster gastric emptying. Especially for those athletes who experience gastro-intestinal discomfort even when ingesting relatively small volumes, training the intake of larger volumes could be an effective strategy to avoid these problems in races.

Studies have also demonstrated that gastric emptying of carbohydrate can be accelerated by increasing dietary intake of that carbohydrate (Jeukendrup, 2017). Cunningham, Horowitz, & Read (1991) supplemented the diet of two groups of volunteers with 400 g glucose per day for 3 days. The half emptying time (t½) for the glucose test meal was significantly faster after the standard diet had been supplemented with glucose compared with the standard diet alone (median and range, 20.7 (4.6-36.8) v. 29.1 (19.8-38.4) min). Interestingly the gastric emptying of a protein drink was unchanged (median and range, 18.0 (12.5-23.6) v. 16.1 (9.6-22.7) min). The authors concluded that specific adaptation of the small intestinal regulatory mechanisms for gastric emptying of nutrient solutions can occur in response to increases in dietary load. This change may occur extremely rapidly, in a matter of days. Another study showed that supplementing a standard diet with 440 g glucose per day for 4-7 days accelerated gastric emptying of both glucose and fructose (t ½ 82 ± 8 vs 106 ± 10 min for glucose and 73 ± 9 versus 106 ± 9 min for fructose) (Horowitz, Cunningham, Wishart, Jones, & Read, 1996). Plasma GIP concentrations were higher during the glucose supplemented diet and thus the authors concluded that the gastric emptying of both glucose and fructose was accelerated probably as a result of reduced feedback inhibition from intestinal luminal receptors (Horowitz et al., 1996).

Another study showed that daily ingestion of 120g of fructose for 3 days accelerated gastric emptying of fructose but not of glucose (Yau, McLaughlin, Maughan, Gilmore, & Evans, 2014). It appears that the relatively short duration of the dietary manipulation (3 days) was sufficient to cause adaptations in gastric emptying.

Such observations are not specific for carbohydrate. Studies have demonstrated that a higher fat diet stimulated gastric emptying. Cunningham, Daly, Horowitz, & Read (1991) demonstrated that gastric emptying of a test meal was accelerated after 7 days of a higher fat diet (258g/day). Reductions in t½ of a test meal in response to the intervention reached significance after 14 days. After 4 days, similar trends were observed, but these did not reach statistical significance. This suggests that the adaptations to fat in the diet may be slower than the responses to carbohydrate. Castiglione et al. (2002) demonstrated a similar adaptation after 14 days of a high-fat diet and reported that these effects were highly specific to fats and a carbohydrate meal was emptied at the same rate before and after a high-fat diet.

Adaptations are likely explained by desensitization of nutrient receptors and reduced feedback inhibition of gastric emptying. However, it is also possible that an increased absorption results in a reduced exposure of receptors to nutrients. As we will see in the following sections, there is also evidence of increased absorption of nutrients in response to changes in diet.

In summary, studies have clearly demonstrated that specific nutritional challenges result in specific adaptations of gastric emptying to that challenge. For example, an increased dietary glucose intake will increase the gastric emptying of glucose, but not protein and an increase in fat intake in the diet will result in faster gastric emptying of fats but not carbohydrate. Very few studies have specifically trained the gut to improve tolerance and gastric emptying during exercise but the results, generally, look promising. Effects have been observed after 3 days of dietary manipulations. (Jeukendrup, 2017, https://bit.ly/2soS2oQ)

In football, this type of “stomach” training may help the player who does not take in any carbohydrate or fluids before and during the match out of fear of gastro-intestinal discomfort.