Title

The effect of exercise intensity on subsequent gastric emptying rate in humans

Authors

Gethin H. Evans[a], Phillip Watson[b], Susan M. Shirreffs and Ronald J. Maughan[c]

Affiliation

[a]School of Healthcare Science, Manchester Metropolitan University, Manchester, United Kingdom, M1 5GD
[b]Department of Human Physiology, Vrije Universiteit Brussel, Brussels B-1050, Belgium
[c]School of Sport, Exercise and Health Sciences, Loughborough University, Loughborough, Leicestershire, United Kingdom, LE11 3TU

Corresponding Author

Dr. Gethin H Evans
School of Healthcare Sciences
Manchester Metropolitan University
Manchester
M1 5GD
United Kingdom

Telephone: +44 161 2471208
Email: gethin.evans@mmu.ac.uk

Abstract

Previous investigations have suggested that exercise at intensities greater than 70% VO_{2max} reduces gastric emptying rate during exercise, but little is known about the effect of exercise intensity on gastric emptying in the post-exercise period. To examine this, eight healthy subjects completed three experimental trials that included 30 minutes of rest (R), low intensity (L; 33% of peak power output) or high intensity (H; 10 x 1 min at peak power output followed by 2 min rest) exercise. 30 minutes after completion of exercise, participants ingested 595 mL of a 5% glucose solution and gastric emptying rate was assessed via the double sampling gastric aspiration method for 60 minutes. No differences ($P > 0.05$) were observed in emptying characteristics for total stomach volume or test meal volume between the trials and the quantity of glucose delivered to the intestine was not different between trials ($P > 0.05$). Half emptying times (T_{half}) were not different ($P = 0.902$) between trials and amounted to (mean ± SD) 22 ± 9, 22 ± 9 and 22 ± 7 minutes during trial R, L and H respectively. These results suggest that exercise has little effect on post-exercise gastric emptying rate of a glucose solution.

Key Words

Exercise Intensity; Gastric Emptying; Fluid delivery

Introduction

The overall rate of availability of ingested fluid and nutrients is determined by a combination of the rates of gastric emptying and intestinal absorption. The rate of gastric emptying of liquids is affected by stomach volume (Noakes et al. 1991), energy content of ingested solution (Vist and Maughan, 1994) and, to a lesser extent, solution osmolality (Vist and Maughan, 1995).

Previous investigations have observed that the gastric emptying rate of liquids is reduced during exercise at an intensity greater than 70% VO_2max. Costill and Saltin (1974) showed that the volume of a carbohydrate solution emptied from the stomach during exercise at up to 60% VO_2max was similar to that seen at rest, but was reduced during exercise of 70% VO_2max and above. Leiper et al. (2001a) observed that a greater volume of a 500 mL carbohydrate solution was emptied from the stomach during a period of walking than during a 5 a side soccer match of the same duration. Leiper et al. (2001b) compared gastric emptying rates at rest or during continuous cycling exercise at 66% of VO_2max with intermittent high intensity consisting of either a power output calculated to be equivalent to 60% of VO_2max interspersed at fixed intervals with 30 s sprints at 100% of VO_2max and with intermittent exercise at a power output equivalent to 70% of their VO_2max interspersed with the sprints. They observed that intermittent exercise at an intensity of 66% VO_2max resulted in a reduction in gastric emptying rate of a carbohydrate solution when compared to rest or continuous exercise at 66% VO_2max and the slowest rate of emptying occurred during intermittent exercise at an intensity of 75% VO_2max.

The regulation of gastric emptying is a complex process involving changes in intragastric pressure that promote movement of food or fluid from the stomach into the duodenum. The reduction in gastric emptying rate that has been observed during exercise exceeding 70% VO_2max has been attributed to a reduction in splanchnic blood flow. The role of gut derived hormones in the regulation of gastric empting has received significant attention. Levin et al. (2006) observed that infusion of ghrelin accelerated gastric emptying rate of an omelette in comparison to saline. Wishart et al. (1998) reported that higher plasma concentrations of glucagon like peptide 1 (GLP-1) resulted in slower gastric emptying rates. Similarly, animal studies have suggested that infusion of Peptide YY (PYY) results in a reduction in gastric emptying rate (Chen et al. 1996). Exercise has been shown to result in reductions in ghrelin (Broom et al. 2007) and increases in circulating concentrations of GLP-1 and PYY (Martins et al. 2007). Ueda et al. (2009) observed that a period of high intensity exercise resulted in significantly greater secretion of PYY than moderate intensity exercise or rest. Similarly, Deighton et al. (2013) reported that circulating concentrations of PYY were greater following a high intensity intermittent exercise protocol in comparison to a steady state exercise protocol. These observations suggest that the secretion of some gut hormones, that have been implicated in the regulation of gastric emptying rate, may be influenced by the intensity of exercise undertaken.

Recently, much attention has been given to the area of post-exercise recovery with the main aims being to restore water and nutrient loss and to maximise the adaptive process after completion of exercise (Burke and Mujika, 2014). In particular, strategies to maximise post-exercise glycogen resynthesis, protein synthesis and recovery of water loss have received significant attention. Advice for post-exercise recovery includes ingestion of water, carbohydrate and protein soon after the completion of exercise (Burke et al. 2004; Burke and Mujika, 2014).

While evidence suggests that the gastric emptying rate of carbohydrate solutions is reduced at relatively high exercise intensities, there is currently no data on the effects of exercise intensity on gastric emptying rate after the completion of exercise. The aim of this investigation was to determine whether exercise affects the rate of gastric emptying of a carbohydrate solution after exercise.

Methods

Five males and three females ((Mean ± SD) age 22 ± 3 y, height 175 ± 8 cm, body mass 69 ± 9 kg, VO_{2peak} 53 ± 9 ml kg^{-1} min^{-1}) volunteered to take part in this investigation. Gill et al (1987) reported that gastric emptying of liquids did not change across the menstrual cycle though they did find slowing of the emptying of a solid phase marker during the luteal phase. A later study by Horowitz et al (1985) found that the normal female menstrual cycle has no effect on the rate of gastric emptying of solids or liquids so there is no obvious reason not to include both men and women in the present study. Ethical approval was provided prior to the start of the investigation by Loughborough University Ethical Advisory Committee. Written informed consent was obtained from each participant prior to the completion of a medical screening questionnaire.

Each participant completed two preliminary trials prior to undertaking experimental trials. During the first preliminary trial, a discontinuous, incremental cycle ergometer test was completed for measurement of peak oxygen uptake (VO_{2peak}) and peak power output. Exercise intensities used during the experimental trials were calculated from the peak power output measured during this test. During the second preliminary trial, participants completed the high intensity exercise experimental protocol, described in detail below, before positioning a nasogastric tube at the base of the stomach.

Each participant completed three experimental trials that involved either a period of rest, low intensity (L) or high intensity (H) exercise prior to ingestion of a 5% glucose solution. Trials were randomly assigned, separated by a period of at least 7 days and began at the same time of day. Participants were fasted on arrival at the laboratory having undertaken similar physical activity and dietary patterns in the 24 h prior to the beginning of the trial. Participants were asked to ingest 500 mL of water approximately 90 minutes before the start of the experimental trial in an attempt to ensure an adequate and consistent level of hydration at the start of all experimental trials.

Following arrival at the laboratory, participants provided a urine sample before a measurement of body mass was made to the nearest 10 g (Adam Equipment, Milton Keynes, United Kingdom). A blood sample was collected via puncture of an antecubital vein before a 30 minute period of rest, L or H intensity exercise. During the resting trial, participants sat quietly in a comfortable environment and heart rate (Polar, USA) was recorded at 3 minute intervals throughout. Expired air samples were collected between 3-6, 9-12, 15-18, 21-24 and 27-28 minutes. During the L exercise trial, participants completed 30 minutes of continuous exercise at an intensity equivalent to 33% of their peak power output. Heart rate and rating of perceived exertion (RPE) were recorded at 3 minute intervals throughout. Expired air samples were collected between 3-6, 9-12, 15-18, 21-24 and 27-28 minutes. During the H exercise trial, participants completed 1 minute of exercise at their peak power output before 2 minutes of rest. This exercise/rest cycle was completed 10 times. Heart rate and RPE were recorded at the end of each period of exercise. Following this 30 minute period, a blood sample was collected before participants were given 10 minutes to shower.

Participants inserted a nasogastric tube before the stomach was emptied, washed and a recovery test performed as described by Hassan and Hobsley (1970). Briefly, this involves instilling 100 mL of distilled water into the stomach before mixing by aspirating and immediately re-injecting between 30 and 50 mL on 10 occasions. The contents of the stomach are then removed as completely as possible. If between 80 and 110 mL are removed, the tube is considered to be correctly inserted at the base of the stomach. Following this, a 21 g cannula was inserted into a surface forearm vein. This remained in position for the rest of the trial and was kept patent between sample collection by flushing with heparinized isotonic saline. 28 minutes after the end of the rest, low intensity or high intensity exercise period, the stomach was emptied and a blood sample collected. 595 mL of a 5% glucose solution with an osmolality of (Mean ± SD) 287 ± 6 mosm kg^{-1} was then ingested over a period of 1 minute. Gastric volumes were then measured at 10 minute intervals for one hour. Blood samples were collected 10, 20, 30, 45 and 60 minutes after ingestion of the test drink. One hour after ingestion, the stomach was emptied before the gastric tube and cannula were removed and participants provided a urine sample before they were free to leave the laboratory.

Gastric volumes were measured using the double sampling technique of George (1964) as modified by Beckers *et al*. (1988). Residual stomach volume was calculated from the change in phenol red concentration of the test drink consumed and the phenol red concentration of the stomach contents obtained immediately after ingestion. At each sampling point, gastric aspirate samples were collected before and after addition of a known volume of a standard phenol red solution. Stomach contents were mixed thoroughly prior to sample collection. The concentration of phenol red solution added to the stomach was increased throughout the trial: 5 mL of 0.25 g/L phenol red was added at time points 10 and 20 minutes. 5 mL of 0.5 g/L phenol red was added at time points 30 and 40 minutes. 5 mL of 1.0 g/L phenol red was added at time points 50 and 60 minutes. From the change in concentration of phenol red at each of the time points, total stomach volume and test solution volume was calculated as described by Beckers *et al.* (1988). The volume of gastric secretions at each time point was estimated by subtracting the test meal volume from total stomach volume.

Sample analysis

The volume of urine produced was recorded and a sample retained for analysis of osmolality by freezing point depression (Gonotec Osmomat 030, Gonotec, Berlin, Germany). Drink osmolality was also measured in this manner.

Drink and gastric aspirate samples were analysed for phenol red concentration by spectroscopy following dilution (1:20) with NaOH-$NaCO_3$ (200:500 mmol L^{-1}) buffer.

Blood samples were analysed for glucose concentration using the glucose oxidase peroxidase amino-antipyrine phenol method (Randox, Crumlin, UK).

All analyses were performed in dulplicate.

Statistical analysis

All data were found to be normally distributed using the Kolmogorov-Smirnov test and are, therefore, presented as Mean ± SD.

Two factor repeated measures ANOVA was used to determine main effects of trial, time and interaction. To determine differences between trials and from baseline over time, one factor repeated measures ANOVA followed by paired t-tests were used. Bonferroni corrections for multiple comparisons were employed. $P < 0.05$ was considered significant.

All analysis was performed using IBM SPSS 21.0 (SPSS Inc., Chicago, USA) for Windows.

Results

Body mass at the start of each trial was the same ($P = 0.552$) and amounted to 68.9 ± 9.0, 68.6 ± 9.2 and 68.6 ± 9.1 kg on the R, L and H trials respectively. Pre-trial urine osmolality was similar between trials ($P = 0.290$) and amounted to 360 ± 192, 385 ± 211 and 302 ± 203 mosm kg^{-1} during the R, L and H trials respectively suggesting that participants were adequately and consistently hydrated at the start of the trials.

Exercise intensity amounted to 102 ± 23 and 303 ± 70 W during L and H respectively. As 1 Watt is equivalent to 1 joule per second, work done was approximately 184 ± 42 and 182 ± 42 kJ ($P = 0.387$) during the 30 minute exercise period for the L and H trials respectively. Heart rate was significantly ($P < 0.05$) higher during H than L and R at each time point and was significantly ($P < 0.05$) higher during L than R at each time point. RPE was significantly ($P < 0.05$) higher during H than L at each time point.

Gastric volumes: For total stomach volume (Fig. 1), two factor repeated measures ANOVA reported no main effect of trial ($P = 0.087$), a main effect of time ($P < 0.001$) and no interaction effect ($P = 0.255$). Total stomach volume was significantly reduced ($P < 0.05$) 10 minutes after ingestion of the solution trials R and H and from 20 minutes during trial L. The volume manually withdrawn from the stomach at the end of each trial was not different ($P > 0.05$) from that calculated from changes in phenol red concentration.

For test meal volume (Fig. 2), two factor repeated measures ANOVA reported no main effect of trial ($P = 0.183$), a main effect of time ($P < 0.001$) and no interaction effect ($P = 0.209$). The volume of the original test solution remaining in the stomach was significantly reduced ($P < 0.05$) from 10 minutes after ingestion during all trials. The amount of time taken for half of the original test meal volume to empty from the stomach (T_{half}; Fig. 3a and b) amounted to 22 ± 9, 22 ± 9 and 22 ± 7 minutes during trial R, L and H respectively and was not different between trials ($P = 0.902$). The total volume of gastric secretions amounted to 456 ± 164, 385 ± 105 and 392 ± 160 ($P = 0.113$) during the R, L and H trials respectively.

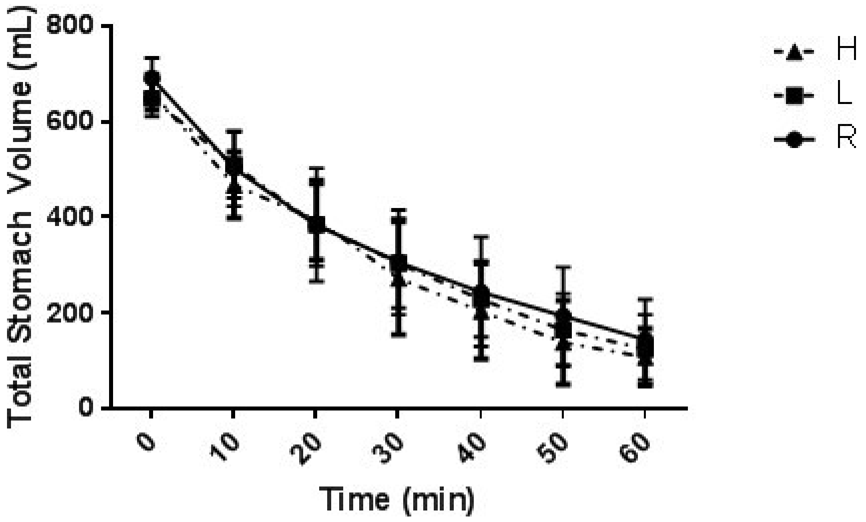
The total quantity of glucose emptied from the stomach over the one hour period amounted to 26 ± 2, 26 ± 3 and 27 ± 2 g during the R, L and H trials respectively and was not different ($P = 0.172$) between trials.

Blood glucose concentration: Two factor repeated measures ANOVA reported no main effect of trial ($P = 0.802$), a main effect of time ($P < 0.001$) and an interaction effect ($P = 0.001$). During R, blood glucose concentration was increased ($P < 0.05$) from pre-exercise levels prior to ingestion of the solution and increased ($P < 0.05$) from pre-ingestion levels 20 minutes after ingestion of the solution. During L and H, blood glucose concentration was increased ($P > 0.05$) from pre-ingestion levels 20 and 30 minutes after ingestion of the solution.

Discussion

The main finding of this study is that gastric emptying rate of a 5% glucose solution was not affected by prior exercise at different intensities. Half emptying time for the solution was similar during the rest, L and H trials and the pattern of emptying was similar during all trials. Consequently, carbohydrate delivery to the intestine was similar between the exercise intensities.

Previous research has observed that gastric emptying rate is reduced during exercise when intensity is greater than 70% VO_2max (Costill and Saltin, 1974) and that this is exacerbated during intermittent exercise (Leiper et al. 2001). This is the first study to examine gastric emptying characteristics of a solution after completing exercise of different intensities. The results suggest that gastric emptying of a carbohydrate solution is not impaired following the completion of high intensity exercise. The main mechanisms for the observed reduction in gastric emptying rate during high intensity exercise are thought to be the reduction in splanchnic blood flow and/or changes in central nervous system activation. A number of gut derived hormones including ghrelin (Levin et al. 2006), GLP-1 (Wishart et al. 1998) and PYY (Chen et al. 1996) have been implicated in the regulation of gastric emptying rate. Exercise has been shown to effect the secretion of a number of these hormones (Broom et al. 2007; Martins et al. 2007) with some evidence that exercise intensity effects the extent of secretion of PYY in particular (Deighton et al. 2013; Ueda et al. 2009). As no differences in gastric emptying rate were observed between the trials in the present study, this would suggest that factors that result in the reduction in emptying rate during high intensity exercise are removed relatively quickly after the cessation of exercise. It should be noted that, as there were no previous studies in this area, a power analysis was not able to be performed. While the number of participants recruited was similar to studies that have investigated gastric emptying rates during exercise, the power of this study to detect statistical differences between trials may be relatively low.



Post-exercise recovery strategies tend to focus on the provision of carbohydrate, protein and water in an attempt to maximise muscle glycogen resynthesis, protein synthesis and restore water balance (Burke and Mujika, 2014). The main factor determining muscle glycogen resynthesis after exercise is the amount of carbohydrate consumed (Burke et al. 2004) however the timing of carbohydrate ingestion may affect the rate of resynthesis. Ivy et al. (1988) observed that ingesting a carbohydrate solution immediately post-exercise resulted in faster rates of muscle glycogen resynthesis than when this was ingested 2 hours after finishing exercise. Richter et al. (1989) observed that insulin sensitivity after exercise was increased in an exercising limb compared to a non-exercising limb and this may be one mechanism by which carbohydrate feeding in the immediate post-exercise period may lead to greater muscle glycogen resynthesis. In addition, activation of glycogen synthase following glycogen depleting exercise may be another mechanism for this observation (Wojtazsewski et al. 2001). The results of the present study suggest that exercise intensity does not affect gastric emptying rate or carbohydrate delivery to the intestine after exercise completion. Indeed, of the 30g of glucose ingested nearly all of this was available for absorption within 1.5 hours after finishing exercise.

Similarly, much recent attention has been placed on post-exercise rehydration with studies suggesting that drink volume (Shirreffs et al. 1996) and composition are important considerations in the restoration of water balance after exercise. Sodium composition (Shirreffs and Maughan, 1998) of an ingested drink appears to have a large influence on water retention after exercise due to the effect on plasma osmolality and arginine vasopressin response (Nose et al. 1988). Carbohydrate (Evans et al. 2009; Osterberg et al. 2010) and milk protein (James et al. 2011) also appear to be important considerations due to the effect that the addition of these macronutrients have on overall fluid uptake (Evans et al. 2011). In particular, the addition of carbohydrate and protein to a solution reduce gastric emptying rate and prevent large reductions in plasma osmolality which leads to greater water retention. Rehydration advice has focussed largely on the volume and composition of a solution to be ingested and has not investigated whether the intensity of exercise undertaken has an effect on water retention. The results of this study would suggest that water availability in the post-exercise period is not effected by prior exercise intensity as gastric emptying rate was similar during all trials.

Guidelines for nutrition during the post-exercise period are well established however athletes and exercisers face a number of challenges in order to meet these suggestions. These include the suppression of hunger after high intensity exercise, access to appropriate foodstuffs and fatigue (Burke 2010). The drink ingested in this study only contained glucose and is, therefore, not necessarily representative of what athletes and exercisers are advised to ingest in the post-exercise period however as the drink composition was the same during all trials this does allow comparison of the effect of exercise intensity on post-exercise gastric emptying rate. A recent survey of male and female veteran cyclists observed that only 38% of participants ingested a carbohydrate-protein mix as part of their post-exercise recovery strategy (Reaburn et al. 2013) suggesting that some athletes and regular exercisers are unable to meet suggested nutrient guidelines in the post-exercise period. Future investigations should, however, ensure that similar results to those presented are observed when a combined carbohydrate-protein solution is ingested in the post-exercise period.

In conclusion, the results of the present study suggest that exercise intensity does not have a significant effect on post-exercise gastric emptying rate of a glucose solution. Consequently, it is likely that exercise intensity does not have a major effect on post-exercise recovery strategies related to timing of carbohydrate ingestion or rehydration.

Acknowledgments

The study was designed by GHE, SMS and RJM. Data were collected by GHE, PW and SMS and analysed by GHE. Data interpretation and manuscript preparation was undertaken by GHE, PW, SMS and RJM. All authors approved the final version of the manuscript.

References

Beckers, E.J., Rehrer, N.J., Brouns, F., Tenhoor, F. and Saris, W.H.M. (1988). Determination of total gastric volume, gastric secretion and residual meal using the double sampling technique of George. *Gut, 29,* 1725-1729.

Broom, D.R., Stensel, D.J., Bishop, N.C., Burns, S.F. and Miyashita, M. (2007). Exercise-induced suppression of acylated ghrelin in humans. *Journal of Applied Physiology, 102,* 2165-2171.

Burke, L. Nutrition for recovery after training and competition. (2010). In L. Burke and V. Deakin (Ed.), *Clinical Sports Nutrition* (pp. 358-388). Australia: McGraw-Hill Education.

Burke, L.M., Kiens, B. and Ivy, J.L. (2004). Carbohydrates and fat for training and recovery. *Journal of Sports Sciences, 22,* 15-30.

Burke, L.M. and Mujika, I. (2014). Nutrition for recovery in aquatic sports. *International Journal of Sport Nutrition and Exercise Metabolism, 24,* 425-436.

Chen, C.H., Rogers, R.C. and Stephens, R.L. (1996). Intracisternal injection of Peptide YY inhibits gastric emptying in rats. *Regulatory Peptides, 61,* 95-98.

Costill, D.L. and Saltin, B. (1974). Factors limiting gastric emptying during rest and exercise. *Journal of Applied Physiology, 37,* 679-683.

Deighton, K., Barry, R., Connon, C.E. and Stensel, D.J. (2013). Appetite, gut hormone and energy intake responses to low volume sprint interval and traditional endurance exercise. *Applied Physiology, Nutrition and Metabolism, 113,* 1147-1156.

Evans, G.H., Shirreffs, S.M. and Maughan, R.J. (2009). Post-exercise rehydration in man: The effects of osmolality and carbohydrate content of ingested drinks. *Nutrition, 25,* 905-913.

Evans, G.H., Shirreffs, S.M. and Maughan, R.J. (2011). The effects of repeated ingestion of high and low glucose-electrolyte solutions on gastric emptying and blood ^2H_2O concentration after an overnight fast. *British Journal of Nutrition, 106,* 1732-1739.

George, J.D. (1968). New clinical method for measuring the rate of gastric emptying: the double sampling technique. *Gut, 9,* 237-242.

Gill, R.C., Murphy, P.D., Hooper, H.R., Bowes, K.L. and Kingma, Y.J. (1987). Effect of the menstrual cycle on gastric emptying. *Digestion, 36,* 168-174.

Hassan, M.A. and Hobsley, M. (1970). Position of subject and of nasogastric tube during a gastric secretion study. *British Medical Journal, 1,* 458-460.

Horowitz, M., Maddern, G.J., Chatterton, B.E., Collins, P.J., Petrucco, O.M., Seamark, R. and Shearman, D.J.C. (1985). The normal menstrual cycle has no effect on gastric emptying. *British Journal of Obstetrics and Gynaecology, 92,* 743-746.

Ivy, J.L, Katz, A.L., Cutler, C.L., Sherman, W.M. and Coyle, E.F. (1988). Muscle glycogen synthesis after exercise – effect of time of carbohydrate ingestion. *Journal of Applied Physiology, 64,* 1480-1485.

James, L.J., Clayton, D. and Evans, G.H. (2011). Effect of milk protein addition to a carbohydrate-electrolyte rehydration solution ingested after exercise in the heat. *British Journal of Nutrition, 105,* 393-399.

Leiper, J.B., Broad, N.P. and Maughan, R.J. (2001). Effect of intermittent high-intensity exercise on gastric emptying in man. *Medicine and Science in Sports and Exercise, 33,* 1270-1278.

Leiper, J.B., Prentice, A.S., Wrightson, C. and Maughan, R.J. (2001). Gastric emptying of a carbohydrate-electrolyte drink during a soccer match. *Medicine and Science in Sports and Exercise, 33,* 1932-1938.

Levin, F., Edholm T., Schmidt, P.T., Gryback, P., Jacobsson, H., Degerblad, M., Hoybye, C., Holst, J.J., Rehfeld, J.F., Hellstrom, P.M. and Naslund, E. (2006). Ghrelin stimulates gastric emptying and hunger in normal-weight humans. *Journal of Clinical Endocrinology and Metabolism, 91,* 3296-3302.

Martins, C., Morgan, L.M., Bloom, S.R. and Robertson, M.D. (2007). Effects of exercise on gut peptides, energy intake and appetite. *Journal of Endocrinology, 193,* 251-258.

Noakes, T.D., Rehrer, N.J. and Maughan, R.J. (1991). The importance of volume in regulating gastric emptying. *Medicine and Science in Sports and Exercise, 23,* 307-313.

Nose, H., Mack, G.W., Shi, X.R. and Nadel, E.R. (1988). Role of osmolality and plasma volume during rehydration in humans. *Journal of Applied Physiology, 65,* 325-331.

Osterberg, K.L., Pallardy, S.E., Johnson, R.J. and Horswill, C.A. (2010). Carbohydrate exerts a mild influence on fluid retention following exercise induced dehydration. *Journal of Applied Physiology, 108,* 245-250.

Reaburn, P.R., MacGregor, C. and Climstein, M. (2013). Poor use of post-exercise recovery strategies in veteran cyclists: An Australian study. *Medicine and Science in Sports and Exercise, 45,* 85.

Richter, E.A., Mikines, K.J., Galbo, H. and Kiens, B. (1989). Effect of exercise on insulin action in human skeletal muscle. *Journal of Applied Physiology, 66,* 876-885.

Shirreffs, S.M. and Maughan, R.J. (1998). Volume repletion after exercise-induced volume depletion in humans: replacement of water and sodium losses. *American Journal of Physiology Renal Physiology, 274,* F868-F875.

Shirreffs, S.M., Taylor, A.J., Leiper, J.B. and Maughan, R.J. (1996). Post-exercise rehydration in man: effects of volume consumed and drink sodium content. *Medicine and Science in Sports and Exercise, 28,* 1260-1271.

Ueda, S.Y., Yoshikawa, T., Katsura, Y., Usui, T. and Fujimoto, S. (2009). Comparable effects of moderate intensity exercise on changes in anorectic gut hormone levels and energy intake to high intensity exercise. *Journal of Endocrinology, 203,* 357-364.

Vist, G.E. and Maughan, R.J. (1994). Gastric emptying of ingested solutions in man – effect of beverage glucose concentration. *Medicine and Science in Sports and Exercise, 26,* 1269-1273.

Vist, G.E. and Maughan, R.J. (1995). The effect of osmolality and carbohydrate content on the rate of gastric emptying of liquids in man. *Journal of Physiology, 486,* 523-531.

Wishart, J.M., Horowitz, M., Morris, H.A., Jones, K.L. and Nauck, M.A. (1998). Relation between gastric emptying of glucose and plasma concentrations of glucagon-like-peptide 1. *Peptides, 19,* 1049-1053.

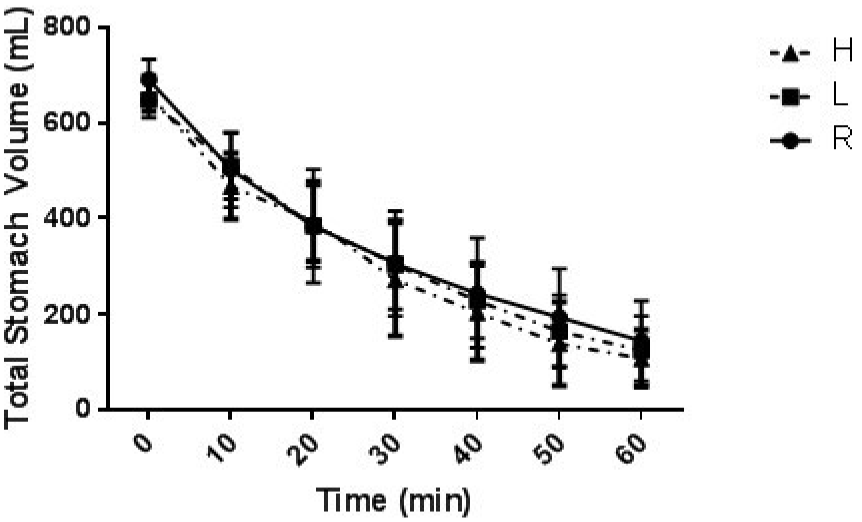
Wojtazsewski, J.F.P, Nielsen, P., Kiens, B. and Richter, E.A. (2001). Regulation of glycogen synthase kinase 3 in human skeletal muscle – effects of food intake and bicycle exercise. *Diabetes, 50,* 265-269.

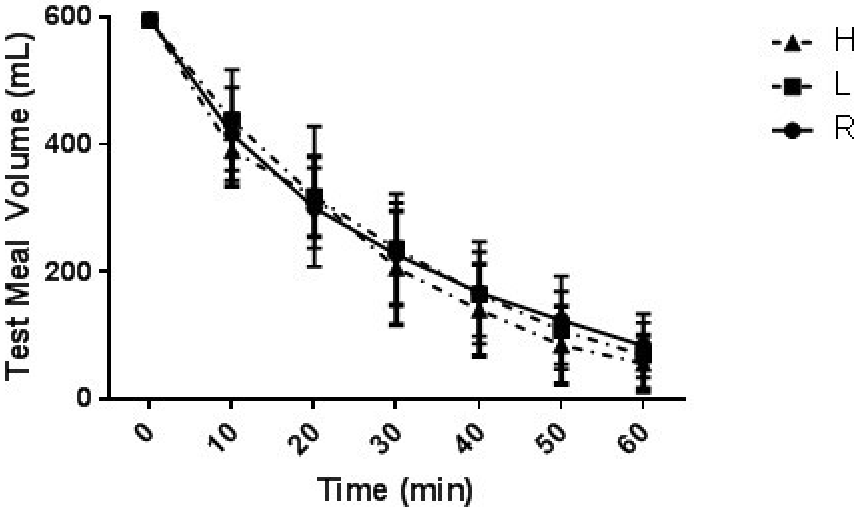
Figures legends

Figure 1: Total stomach volume (mL) following ingestion of 595 mL glucose solution after completion of R, L and H trials. Values are mean ± SD. Total stomach volume significantly reduced from “0” from 10 minutes on R and H and from 20 minutes on L.

Figure 2: Test meal volume (mL) following ingestion of 595 mL glucose solution after completion of R, L and H trials. Values are mean ± SD. Total stomach volume significantly reduced from “0” from 10 minutes on all trials.

Figure 3: (a) Half emptying time (min) of 595 mL glucose solution after completion of R, L and H trials. Values are mean ± SD. (b) Half emptying times (min) of 595 mL glucose solution after completion of R, L and H trials for each participant.

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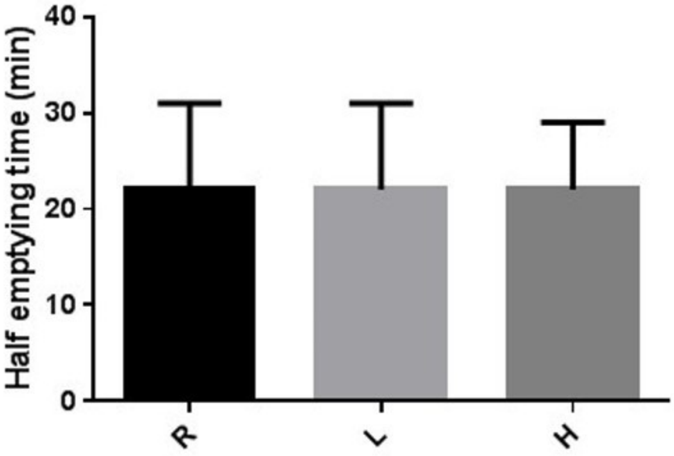
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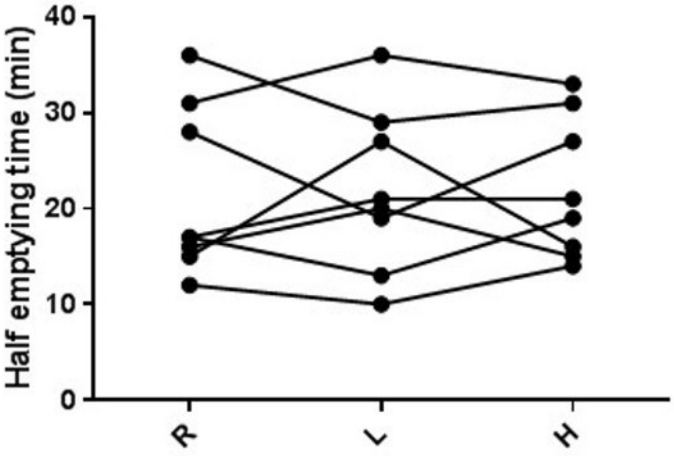
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