Very light Physical Activity after a Meal Blunts the Rise in Blood Glucose and Insulin

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Abstract: The objective of this study was to examine the impact of post-meal light exercise on the rise in blood glucose and insulin. After fasting overnight, nine healthy subjects (age 37.3 ± 12.2 years) participated in three experiments in a crossover design: Day 1 (no exercise), the subjects were given cornflakes, and blood glucose and plasma insulin were determined before meal, and each 15 min for the next 165 min. Day 2 and 3 were similar to Day 1, but included 30 min very light and light intensity bicycle exercise after the meal. Both levels of exercise blunted and delayed the rise in blood glucose and plasma insulin. Bicycling-related reductions in peak glucose and insulin values correlated with peak values the control day (r = -0.83 to -0.93, P < 0.006), as did reductions in AUC and IAUC. We conclude that even very light exercise after a carbohydrate meal blunts the rise in blood glucose and insulin.

Keywords: Glucose, insulin, exercise, postprandial.

INTRODUCTION

The prevalence of impaired glucose tolerance and type 2 diabetes is increasing [1] and it is estimated that the number of individuals with the disease will double from year 2000 to 2030 [2]. The cost of treatment is high and type 2 diabetes is characterized as one of the main health concerns in the 21. century [3]. Both high fasting glycaemia and high postprandial glycaemia increase the risk of morbidity and mortality [4, 5], and some studies suggest that postprandial glycaemia may be the most important of the two [6-8]. Longitudinal studies have shown that intake of acarbose, an alpha glucosidase inhibitor, decreases the incidence of type 2 diabetes and cardiovascular disease [9-11]. Hanefeld et al. [12] found a total reduction in incidence of cardiovascular disease of 35% in a metaanalysis of seven randomized controlled trials using acarbose three times a day over a mean period of 403 days. It is now generally agreed on that high postprandial glycaemia should be reduced in susceptible individuals [13-18].

The research as to what extent exercise performed immediately after a meal can reduce postprandial glycaemia is scarce. It has been reported that light exercise blunts the increase in both glycaemia and insulinaemia after a meal [19, 20]. To our knowledge, the study of Høstmark et al. [20] is the only one to examine the effect of exercise performed immediately after a carbohydrate meal on the postprandial blood glucose concentration. The study examined the effect of 30 min light bicycle exercise (~70% of maximal heart rate [HRmax]) initiated immediately after consumption of a high glycaemic meal (cornflakes) in 19 young and 20 middle-aged women. There was a consistent decrease in blood glucose in the time interval when the exercise was executed, and a greater benefit provided by the work for middle-aged, compared to young women. Since glucose tolerance is negatively associated with age [21], this could mean that the effect of work in the postprandial period depends on the glucose tolerance of each and every individual, as shown in rats [22]. Hence, one of the objectives in the present study was to examine this relationship in humans. Furthermore, the effect of the intensity of the work performed is unsettled [23]. Achten & Jeukendrup [23] found no difference in blood glucose or insulin between work of differing intensities (~55, 77 and 90% of maximal oxygen consumption) performed by eight men 45 min after intake of 75 g carbohydrate. Consequently, the other objective of our study was to examine the effect of exercise at a somewhat lower intensity than used by Høstmark et al. [20], on postprandial glycaemia and insulinaemia.

MATERIALS AND METHODOLOGY

After approval by the regional ethics committee in Norway South, the participants received written information about the study and gave their written informed consent to participate. Inclusion criterion was age over 20 years and exclusion criteria were known diabetes or cardiovascular disease. Nine subjects took part in the study, six men and three women ([mean ± SD] 37.3 ± 12.2 years, 77.8 ± 14.9 kg, 174.9 ± 7.5 cm, 5.0 ± 2.6 hours of physical activity per week). The study had a crossover design. Each subject, commencing after an overnight fast, participated in three diet experiments carried out on three separate days with at least one day between each experiment. Day I served as control in which the subjects ate a high glycaemic meal (cornflakes (glycemic index (GI): 81 ± 3 with glucose as reference food [24] and 300 ml skimmed milk (GI: 32 ± 5)) [24], providing 1 g carbohydrate per kg body weight) in 15 min, and then rested sitting calm for the rest of the experiment, while the...
same subjects on Day II and III carried out 30 min very light (VLI) and light (LI) bicycle-ergometer exercise on a stationary bicycle (Ergomedic 828E/ Ergomedic 818E, Monark, Sweden) immediately upon finishing the meal. The experiments were executed in this specific order, as this gave the opportunity to set the load on Day II and III after finishing the experiment on Day I. The intensities were aimed at a Borg scale of perceived exertion value of nine and 11 on Day II and III, respectively, i.e. very light (VLI) and light (LI) exercise. Body weight and height were measured every day at attendance. Venous blood samples (~5 ml) were drawn through a catheter and heart rate was measured (S610, Polar Electro Oy, Kempele, Finland) for every 15 min from before the meal throughout the experiment (165 min). In addition we noted perceived exertion on Borg scale during the work period, and self-reported weekly physical activity the last three months. Glucose was analyzed in whole blood immediately, using glucometer (Ascensia Contour, Bayer HealthCare LCC, Mishawaka, USA) and stix (Ascensia Microfill, Bayer HealthCare LCC, Mishawaka, USA). Plasma was stored at -80 ºC until insulin analyses were carried out using an ELISA-kit (Dako Cytomation, Cambridgeshire, United Kingdom).

Statistical Analyses

Maximal heart rate was estimated by subtracting age from 220. Area under the curve (AUC) and incremental area under the curve (IAUC) were calculated using the trapezoidal rule. A two-factor repeated measures ANOVA was used to identify significant interactions between time and experiments. Repeated measures ANOVA was also used to assess differences in blood glucose (insulin) at single points of time, as well as AUC, IAUC and peak glucose (insulin) values between the three experiments. Significant differences were also analyzed by pairs, using t-test for dependent groups, with Bonferroni correction. Relationships were analyzed using Pearson correlation coefficient. All analyses were performed using SPSS 15.0 (Chicago, USA). Data are presented as mean values ± SD. Level of statistical significance was set to p ≤ 0.05.

RESULTS

Resting heart rate was 64.8 ± 7.5 beats/min in the control experiment, and rose to 107.1 ± 13.3 (58.7 ± 6.2 % of HR$_{\text{max}}$) and 121.3 ± 19.1 beats/min (66.6 ± 10.6 % of HR$_{\text{max}}$) after 30 min exercise in the VLI and LI experiment, respectively. Corresponding rates of perceived exertion were 10.1 ± 0.9 and 11.8 ± 0.7.

Fig. (1a) shows the blood glucose concentration in the three experiments. On Day I the mean peak value was reached after approximately 30 min, and then decreased for the rest of the observation period. The postprandial increase in the glucose concentration was appreciably decreased on both days of post-meal exercise compared to control, as observed both at 30 min (control: 7.5 ± 1.6, VLI: 6.0 ± 1.0 [p = 0.002 vs control], LI: 5.8 ± 1.1 mM [p = 0.001 vs control]) and 45 min (control: 7.3 ± 2.5, VLI: 5.2 ± 1.0 [p = 0.011 vs control], LI: 5.1 ± 1.1 mM [p = 0.013 vs control]). It seemed, however, that post meal exercise caused a displacement to the right of the blood glucose response curve, as shown by a significantly higher value at 75 min in both VLI (6.5 ± 1.8 mM [p = 0.015]) and LI experiment (6.8 ± 1.5 mM [p = 0.009]) as compared to control (5.2 ± 2.5 mM). In the LI experiment blood glucose concentration was also significantly higher at 90 min compared to control (6.1 ± 1.9 vs 4.7 ± 2.0 mM, p = 0.001). This was also confirmed by a significant repeated measures ANOVA for interaction between

Fig. (1). Blood glucose (a) and insulin (b) concentrations throughout the three experiments carried out in the study. Nine subjects ([mean ± SD] 37.3 ± 12.2 years, 77.8 ± 14.9 kg, 174.9 ± 7.5 cm, 5.0 ± 2.6 hours of physical activity per week) participated in three diet experiments. Commencing after an overnight fast the same subjects ate cornflakes (1 g carbohydrate per kg body weight) and then rested (control; ▼), or did 30 min very light exercise (58.7 ± 6.2 % of HR$_{\text{max}}$ (VLI; ●), or 30 min light exercise (66.6 ± 10.6 % of HR$_{\text{max}}$ (LI; ○) in the time period 15 to 45 min. * p < 0.05 for the difference between the control experiment and both exercise experiments; # p < 0.05 for the difference between the control and LI experiment. Data are shown as means ± SEM. The study was carried out at The Norwegian School of Sport Sciences in Oslo, spring 2006.
time and experiment ($F = 6.66, p = 0.002$). We found no differences between the three experiments in AUC or IAUC, but a significant difference between the VLI experiment and the control experiment existed for the mean of the individual peak values ($7.2 \pm 1.5$ vs $8.1 \pm 1.1$ mM, respectively [$p = 0.006$]), which was reduced by $10.3 \pm 6.3\%$. The reduction in mean of individual peak values caused by the exercise in the LI experiment was somewhat lower ($7.8 \pm 8.9\%$) and did not reach statistical significance after Bonferroni correction ($p = 0.040$).

Insulin concentration for the three experiments is shown in Fig. (1b). After cornflake intake Day I the insulin concentration rose to reach the peak value after 30 min and then decreased gradually during the rest of the observation period. The insulin concentration was significantly decreased on both days of exercise both at 30 min (control: $46.0 \pm 18.9$, VLI: $21.0 \pm 15.0$ [$p < 0.001$ vs control], LI: $17.5 \pm 9.9$ $\mu$IU/ml [$p = 0.001$ vs control]) and at 45 min (control: $42.8 \pm 9.8$, VLI: $19.4 \pm 11.8$ [$p = 0.001$ vs control], LI: $13.8 \pm 10.0$ $\mu$IU/ml [$p < 0.001$ vs control]), as compared to control. A repeated measures ANOVA showed a significant interaction of time and experiment ($F= 3.51, p = 0.047$), which means that the work caused a shift in the insulin curves to the right. In addition, we found significant differences between the VLI and control experiment in AUC ($3655.8 \pm 1834.6$ vs $4905.1 \pm 2807.1$ ($\mu$IU/ml)*min, respectively [$p= 0.014$]), IAUC ($2751.2 \pm 1588.1$ vs $4067.3 \pm 2539.7$ ($\mu$IU/ml)*min, respectively [$p = 0.010$]) and peak value ($44.3 \pm 15.1$ vs $68.3 \pm 27.4$ $\mu$IU/ml, respectively [$p = 0.005$]), in which the decreases were $24.8 \pm 12.2$, $31.2 \pm 12.0$ and $27.9 \pm 16.6\%$, respectively. After Bonferroni correction neither AUC, IAUC nor peak value differed significantly between the LI and control experiment ($p = 0.033$, $p = 0.030$ and $p = 0.026$, respectively), but still we found decreases of $\sim 20\%$. Because of missing data the calculations of AUC and IAUC for insulin are based on eight subjects. No significant differences were found between the two exercise experiments in neither glucose nor insulin.

For both glucose and insulin we found strong relationships between the rise observed in the control experiment and the decrease caused by exercise in the VLI and LI experiments. The peak value on the control day (Day I) vs. delta peak values (Day II and III) are shown in Fig. (2a) (glucose) and Fig. (2b) (insulin). Correlation coefficients for peak glucose values were $r = -0.87$ ($p = 0.003$) and $r = -0.93$ ($p < 0.001$) for the VLI and LI experiment, respectively. Corresponding relationships for peak insulin values were $r = -0.90$ ($p = 0.001$) and $r = -0.83$ ($p = 0.006$). Strong relationships were also found for concentration after 30 min of exercise, AUC and IAUC, in which the correlation coefficients for glucose were $r = -0.93$ ($p < 0.001$), $r = -0.91$ ($p = 0.001$) and $r = -0.59$ (NS) respectively in the VLI experiment, and $r = -0.90$ ($p = 0.001$), $r = -0.86$ ($p = 0.003$) and $r = -0.54$ (NS) in the LI experiment. Relationships for concentration after 30 min of exercise, AUC and IAUC for insulin were $r = -0.57$ (NS), $r = -0.89$ ($p = 0.003$) and $r = -0.92$ ($p = 0.001$) respectively in the VLI experiment, and $r = -0.52$ (NS), $r = -0.86$ ($p = 0.006$) and $r = -0.91$ ($p = 0.003$) in the LI experiment. Because of missing data the calculations of AUC and IAUC for insulin are based on eight subjects.

![Fig. (2). Relationships between peak value in the control experiment and peak values in the two exercise experiments performed in the study, for glucose (a) and insulin (b). Nine subjects ([mean ± SD] 37.3 ± 12.2 years, 77.8 ± 14.9 kg, 174.9 ± 7.5 cm, 5.0 ± 2.6 hours of physical activity per week) participated in three diet experiments. Commencing after an overnight fast the same subjects ate cornflakes (1 g carbohydrate per kg body weight) and then rested, or did 30 min very light exercise (58.7 ± 6.2 % of HRmax) (VLI; ●), or 30 min light exercise (66.6 ± 10.6 % of HRmax) (LI; □) in the time period 15 to 45 min. Strong correlations were found between the peak value the control day (without exercise) and the reduction in the peak value caused by exercise, observed for both glucose (VLI: $r = -0.87$ ($p = 0.003$); LI: $r = -0.93$ ($p < 0.001$)) and insulin (VLI: $r = -0.90$ ($p = 0.001$); LI: $r = -0.83$ ($p = 0.006$)). Dots are individual values. The study was carried out at The Norwegian School of Sport Sciences in Oslo, spring 2006.](image-url)
DISCUSSION AND CONCLUSION

The main findings in the present study were that 30 min of very light and light bicycle exercise (~59 to 67% of \(HR_{\text{max}}\)) performed immediately after a high glycaemic breakfast blunted the rise in blood glucose and insulin, and caused a delayed and attenuated increase. Additionally, the effects of the work performed at the two intensities were strongly associated with each and every individual’s level of rise in both glucose and insulin in the absence of post meal exercise.

We found a decrease in blood glucose of 24.5 ± 21.2 and 25.8 ± 19.8 % after 30 min of exercise for the VLI and LI experiment, respectively, compared to control. Unfortunately, Høstmark et al. [20] did not measure insulin levels. However, Nelson et al. [19] reported decreases in insulin in excess of 50 %, exercising for 45 min at ~70 % of \(HR_{\text{max}}\), using the same protocol as this study. Unfortunatly, Høstmark et al. [20] did not measure insulin levels. However, Nelson et al. [19] reported decreases in insulin in excess of 50 %, exercising for 45 min at ~70 % of \(HR_{\text{max}}\), starting 30 min after breakfast. This is in accordance with our findings of a decrease in insulin after 30 min of exercise by 53.4 ± 31.4 and 68.2 ± 21.0 % in the VLI and LI experiment respectively, compared to control. Furthermore, the second rise in glucose and insulin found when the exercise terminated are also in agreement with Høstmark et al. [20] and Nelson et al. [19]. Hence, the present findings are in accordance with earlier findings. We have no data to speculate about the mechanisms involved, but it is suggested that decreased glycaemia during exercise is due to increased uptake and utilization of glucose by muscles [25-29].

In an attempt to interpret our results we have to compare our findings with studies using drugs to lower postprandial glycaemia. However, longitudinal studies reporting on health benefits of acarbose have not measured the acute effect of the drugs on glucose and insulin [9-12], which makes the comparison difficult. However, other studies have examined the acute effect of a single administration of acarbose on glycaemia and insulinemia. The findings are a -9 to 31 and -4 to 39 % decrease in glucose and insulin respectively, in type 2 diabetics [30-32]. To our knowledge, only one study has reported on the acute effect of acarbose in healthy subjects [33]. Kageyama et al. [33] examined the effect of 50 and 100 mg acarbose in relation to placebo taken three times a single day, in a crossover design in 20 subjects (26.4 ± 4.6 years). The effect was a decrease of 0 - 12 and 24 - 38 % in glucose and insulin concentration, respectively. Corresponding decreases in the present study were 2 - 10 and 20 - 28 %. As the effect of exercise in the present study is in the same range as the effect of acarbose in the study by Kageyama et al. [33], we think light exercise in the postprandial period may provide similar health benefits as acarbose. Yet, a problem with physical activity is ‘the size of the pill’, which many people probably would find hard to swallow. Hence, because of the effort it takes, we do not think most people are willing to be physically active 30 min after every meal every day for extended periods of time. Based on this, our opinion is that light exercise in the postprandial period probably can provide a health benefit, but should not be recommended as a complete substitute for drugs having similar effect. However, it is important to recognize that exercise in addition to the acute glycaemia-reducing effect, also can provide a wide range of long-lasting health benefits, like qualitative changes in muscles or body composition [34, 35].

We found strong relationships between the rise in glucose and insulin in the control experiment and corresponding lowering effect of post meal exercise, at both intensities. Based on Elahi & Muller’s [21] findings that glucose tolerance decreases along with older age (probably mostly because of inactivity and not age per se), it would appear that exercise in the postprandial period has a greater blood glucose reducing effect in middle-aged and elderly people than at younger age, as was previously shown by Høstmark et al. [20]. One interpretation of this observation is that people at most risk of morbidity and mortality of diabetes and cardiovascular diseases, are probably also those who would benefit the most being physically active after a meal.

At no point of time we found differences between the two exercise experiments. However, peak value for glucose, together with AUC, IAUC and peak value for insulin were significantly lowered only in the VLI experiment, compared to control. Yet, it should be noticed that differences in both the VLI and LI experiments are about the same magnitude, but differences between the LI and control experiment just missed being significant after Bonferroni correction (p = 0.026 to 0.040). Hence, we consider differences between the two exercise intensities to be minimal, but notice with some surprise that if one of the intensities should be the better, it is the lowest one (58.7 ± 6.2 % of \(HR_{\text{max}}\), rate of perceived exertion of 10.1 ± 0.9). However, this can be explained by a higher catecholamine secretion during heavier work [36], which in turn would stimulate a higher glycolysis by the liver and increased blood glycaemia.

Overall, we consider our findings to be in accordance with findings of Achten & Jeukendrup [23], who did not find any difference in postprandial glycaemia or insulinemia as a result of exercise intensities between ~55 and 90 % of maximal oxygen consumption. This means that exercise of an intensity that is not considered high enough to increase aerobic capacity [37], can have important glycaemia-lowering effects. This finding is interesting and positive of two reasons. Firstly, lower intensity exercise cause less strain to be put upon the body and hence, cause less musculoskeletal injuries and gives a higher number of susceptible individuals the opportunity to take part in physical activity. Secondly, light exercise are easier to keep up trough extended periods of time, compared to heavier exercise [37, 38]. For people who find bicycle-exercise difficult, it should be noticed that walking at self-paced speed is generally carried out at intensities between ~60 and 70 % of \(HR_{\text{max}}\) (Borg rating of ~10 to 11) [39-44], which corresponds very well to the intensity found to be effective in lowering postprandial glycaemia and insulinemia in the present study. Even though walking was not examined in the present study, we consider it very likely that walking should provide the same benefit as do light bicycle exercise.

As we found an effect of even very light intensity exercise (58.7 ± 6.2 % of \(HR_{\text{max}}\); rate of perceived exertion of 10.1 ± 0.9), the threshold of effect should be somewhat lower. Hence, further research should determine the lowest intensity which could lower the postprandial rise in glucose and insulin, in addition to study the influence of other vari-
ables, eg duration, point of start after meal and mode of exercise, type of meal and time of day.

In conclusion, this study shows that 30 min of very light and light bicycle exercise (~59 to 67 % of HRmax) performed immediately after a high glycaemic breakfast can blunt the rise in blood glucose and insulin. The effect of post meal light work is strongly associated with each and every individual’s level of rise in both glucose and insulin. Hence, individuals with impaired glucose tolerance, who are at most risk of developing type 2 diabetes and early death, are also those who probably would benefit the most of after-meal physically activity. Interestingly, there is an old Chinese saying: “One hundred steps after a meal make you live to be 99 years old”.

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