Let Hunger Be Your Guide? An Association between Hunger and Post-Meal Blood Glucose

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Abstract

Accumulating evidence suggests that when people eat might be as important for their health as what or how much they eat. Consumers initiate eating behavior in response to a number of factors including time of day, food availability, and hunger. The present research examines whether feeling hungry might reflect a time at which it is relatively healthy for individuals to initiate eating. Specifically, the present research examines whether differences in hunger predict differences in an important health measure, namely post-meal blood glucose. The results show that post-meal blood glucose is highest when people are not at all hungry and relatively lower when people are moderately hungry or very hungry. When people are very hungry, post-meal glucose is not lower and possibly slightly higher than when people are moderately hungry. The implications of the findings for regulating food consumption as well as limitations of the findings are discussed.

An important topic in consumer research is identifying means to help individuals regulate their food consumption in a healthy manner. To date, the majority of consumer researchers' attention in this area has focused on understanding the drivers of consumer food choice and on using this understanding to aid consumers to choose healthier options and smaller portion sizes when they choose to eat. This line of research has revealed many important insights regarding the motivational (e.g., Dewitte, Bruyneel, and Geyskens 2009; Finkelstein and Fishbach 2010; Mukhopadhyay, Sengupta, and Ramanathan 2008; Redden and Haws 2013; Thomas, Desai, and Seenivasan 2011; Vohs and Faber 2007; Wilcox et al. 2009) and contextual (e.g., Chandon and Wansink 2007; Chernev and Gal 2010; McFerran et al. 2010; Mishra and Mishra 2011; Scott et al. 2008; Soman and Cheema 2008;Ittersum and Wansink 2012; Van Ittersum and Wansink 2012; Wansink and Chandon 2006) factors that drive consumer food intake.

However, accumulating research reveals that the question of when people eat might be as important for health as what people eat (Garaulet et al. 2013) or how much people eat (Berg and Forslund 2015). Among other associations, meal timing has been associated with the likelihood of developing obesity, metabolic syndrome, and non-alcoholic fatty liver disease (Bandín et al. 2014; for a review, see Sofer, Stark, and Madar 2015). For example, one short-term study found that eating meals outside of circadian alignment caused 3 of 8 healthy subjects to exhibit post-meal glucose elevations in the range typical of those with prediabetes (Scheer et al. 2009). Other studies have found that eating later in the day is associated with the metabolic syndrome (Bandín et al. 2014; Bo et al. 2014). It has even been speculated that shifts in meal timing might be responsible for changes in population health outcomes: significant changes in the timing and number of snacks and meals consumed among American adults over a 40 year period are correlated with the obesity epidemic (Kant and Graubard 2015). Yet despite the likely importance of meal timing to health outcomes, behavioral researchers have paid relatively little attention to consumer behaviors related to meal timing.

Meal timing can encompass many related variables, such as the number of meals an individual consumes in a day, the number of snacks an individual consumes in a day, the circadian timing of meals, whether an individual engages in intermittent periods of fasting or reduced caloric intake, meal duration, and whether meals are set according to external cues, such as time of day and food availability, or according to internal cues, such as hunger and satiety (for a review, see Sofer et al. 2015). In the present research, I focus on how one aspect of meal timing, namely whether initiating meals according to hunger, may be healthy for consumers, using post-meal blood glucose as a proxy for healthiness. I next describe the logic of focusing on the effect of eating according to hunger on health, and of using post-meal glucose as a proxy for healthiness. Afterwards, I describe the study that I performed and discuss the results.

CURRENT RESEARCH

In the present research, I focus on the question of whether initiating meals according to hunger may be healthy for several key reasons. First, there is intuitive appeal to the idea that eating according to hunger is healthy. From an evolutionary perspective, sensations of hunger and satiety likely evolved as part of an organism's homeostatic mechanisms for the regulation of energy balance. As such, it stands to reason that subjective feelings of hunger will correspond to a physiological state in which body tissues are relatively receptive to the absorption of nutrients (i.e., a state in which the body efficiently processes and stores energy). Although studies examining the relationship between hunger and the efficiency with which the body processes and stores energy are lacking, animals studies do show a relationship between calorie restriction and both increased pre-meal concentrations of ghrelin, a hormone associated with increased subjective hunger, in the blood and with the efficient clearing of nutrients, in particular glucose, from the blood (Barretero-Hernandez, Galyean, and Vizcarra 2010). Such findings provide some suggestive evidence that pre-meal hunger may be associated with more efficient processing of nutrients.

Second, there is already existing evidence suggesting that whether individuals regulate their food intake according to hunger is associated with consequences for health. For instance, normal weight individuals tend to regulate their food intake according to internal cues like hunger and satiety, whereas obese individuals are more likely to regulate their food intake according to external cues such as food availability or palatability (Schachter 1968; Schachter 1971; Wansink, Payne, and Chandon 2007). Moreover, dieters are likely to restrict their food consumption when they are hungry, a phenomenon associated with negative psychological consequences (for review, see Polivy 1996).

Finally, feeling hungry is closely related to circadian cycles (Garaulet and Gómez-Abellán 2014) and the time of day at which a meal is eaten has been shown to affect how individuals' glucose (and lipid) levels respond to its consumption (Johnston 2014; more on the importance of postprandial, i.e., post-meal, glucose as an important health marker measure below). However, unlike circadian cycles, which may shift when individuals travel, have shift work, disordered sleep etc., hunger is likely to be relatively easy for individuals to monitor because it is a subjective state. Thus, if eating according to hunger is indeed healthy, eating when hungry is likely to serve as a practical guide by which consumers can regulate their food consumption behavior.

In order to examine the effect of eating according to hunger on health, I specifically focused on the association between individuals' feelings of hunger and their blood glucose levels following a meal (i.e., post-meal glucose). Individuals always have a level of glucose in the blood, but blood glucose levels tend to spike after a meal that includes carbohydrates. I relied on blood glucose levels following a meal as a measure of healthiness for two main reasons. First, blood glucose is easy to measure and commonly increases after any meal containing carbohydrates, and thus is highly practical. Second, and more importantly, the level of post-meal blood glucose is increasingly recognized as an important independent predictor of health outcomes, likely because exposure to elevated glucose concentrations is damaging to cells (Gleason et al. 2000; for review, see Heine et al. 2004).

An example of a recent finding illustrating the importance of post-meal blood glucose as a measure of health is the finding that elevated blood glucose following glucose ingestion predicted diabetic complications independent of fasting blood glucose and HbA1c (a proxy for average blood glucose levels over a period of months) (Singleton, Smith, and Bromberg 2001; for similar results, see Sumner et al. 2003). Likewise, in individuals with otherwise normal glucose tolerance, blood glucose readings one hour after glucose ingestion were linked to markers of subclinical inflammation, abnormal lipids, and reduced insulin sensitivity, leading the authors to suggest that blood glucose levels greater than 155 mg/dl one hour after glucose ingestion be considered a new marker for cardiovascular risk (Bardini et al. 2009). Elevated blood glucose levels following glucose ingestion has also been independently linked to cancer (Stattin et al. 2007), kidney damage (Polhill et al. 2004), cardiovascular disease (Cavalot et al.

2011), and death (Cavalot et al. 2011). Thus, post-meal blood glucose is relatively easy to measure and bears important implications for health.

The factors that determine how much glucose spikes after a meal are numerous, but include the individual's sensitivity to insulin (a hormone that regulates blood glucose levels), the size of the meal, the ease with which a meal is digested, the speed of gastric emptying, and the speed with which the meal is eaten, among others (Gagliardino 2005). In the present research, I am positing that one factor that might affect the degree to which blood glucose spikes after a meal is an individual's level of hunger prior to the meal, and that this might occur because hunger signals that the body is in a state where it is relatively receptive to absorb nutrients (i.e., in a state where using and storing incoming energy is relatively efficient). If this is indeed the case, then it would suggest that it might be healthy for individuals to initiate eating when hungry.

I next describe the study I performed to examine the association between feelings of hunger and post-meal blood glucose.

METHOD

Participants were 45 undergraduates at a large US university. The study was performed in a behavioral laboratory and involved two separate sessions. The procedure during each session was identical and the sessions were held exactly one week apart. The purpose of having each participant attend two separate sessions was to account for both within- and between-subject variation. Moreover, individual participants completed the experiment at the exact same time across each of their two sessions to control for within-participant diurnal effects.

Upon registering for the study, participants were instructed not to eat for at least 2 hours prior to the study and this instruction was repeated in a reminder message sent to participants the evening before the study. One participant reported not complying and was excused from the experiment.

Participants were seated at individual cubicles equipped with computers, the One Touch Ultra Mini blood glucose meter (rated the most accurate home glucose meter by Consumer Reports and evaluated to have high interassay and intra-assay precision; Ramljak et al. 2013), a fingerstick device, and blood glucose test strips. Participants received instructions on how to use the blood glucose meter, fingerstick device, and test strips to measure their blood glucose and were instructed to perform a practice measurement, which also served as a baseline glucose measurement. After completing this practice measurement, participants were asked to rate their subjective hunger on a 7-point scale from 1 ("not at all hungry") to 7 ("very hungry"). As participants may misreport feeling hungry based on environmental cues (e.g., time since last meal), participants were explicitly instructed to pay attention to their internal feelings when rating their hunger.

Participants were also asked to write down how much time had elapsed since they last ate ("How long ago did you last eat?") so it could be identified whether subjective hunger predicted post-meal blood glucose independent of this more 'objective' proxy for hunger. Afterwards, participants were provided with a can of Sprite (38 g. sugar) and a dinner roll (17 g. carbohydrate, 2 g. sugar, 1 g. fiber, 2 g. fat, 3 g. protein) and asked to consume them within a five minute window. After finishing the Sprite and dinner roll, participants were instructed to rate how much they enjoyed consuming them on a 7-point scale from 1 ("not at all") to 7 ("very much”). After providing their enjoyment rating, participants were instructed to wash their hands thoroughly in order to remove any food residue.

After washing their hands, participants were instructed to measure their blood glucose at 20 minutes, 35 minutes, and 50 minutes post-consumption. Between measurements, participants were instructed to remain seated and entertain themselves by browsing the web on their computer (they were provided with headphones so they could listen to audio).

Participants completed the identical procedure when they returned to the lab the following week.

RESULTS

Two participants did not consume the entire meal during both sessions and were excluded from further analysis. One participant did not consume the entire meal in the first session, but did during the second session and thus, only the participants’ data from the second session was included in the analysis. Four participants completed the first session, but either did not consume the entire meal or did not appear for the second session, and thus only these participants’ data from the first session was included in the analysis. One participant in the first session misinterpreted the instructions and recorded three glucose measurements at each time period; only the first recorded glucose measurement from each time point was used in the analysis.

The raw means of post-meal glucose at each level of hunger at each time period are depicted in Figure 1.

Figure 1 about here

I used a mixed effects model that included each of the three time measurements (at 20, 35, and 50 minutes post-meal) for all participants to estimate glucose levels as a function of subjective hunger. Mixed-effects models are the appropriate statistical test for studies where it is not feasible to randomize participants to experimental and control groups, and where individuals are the unit of analysis (Lindstrom and Bates 1988). The model included hunger, hunger squared, and time; time entered the model non-parametrically via indicator functions (or dummies) indicating the time of the three measurements (i.e., 20, 35, and 50 minutes post-consumption) to allow for non-linear temporal effects.

The adjusted R-square for the model is 0.55 (AIC=2126, deviance=2127; for fixed effects estimates, see Table 1). Both the hunger and hunger squared terms are significant predictors of glucose (p's $< .001$). Graphing the relationship between glucose and hunger suggests a reversed j-curve relation between the variables (Figure 2), with low levels of hunger associated with the highest levels of glucose and modest levels of hunger associated with the lowest levels of glucose. However, as can be seen from the raw means, the increase in blood glucose levels at the highest levels of hunger compared to moderate levels of hunger is quite modest.

Table 1 about here

Figure 2 about here

In addition to this principal model specification, I also examined a simple linear model (i.e., the same model, except excluding the hunger squared term), and while hunger remained a significant predictor of post-meal glucose ($t = -3.98$, $p < .01$), the linear model yielded a substantially poorer fit to the data (adjusted R-square=.49, AIC=2142, deviance=2143). I also tried a model specification that included a time × hunger interaction term, but there was no material difference in the results. I further tried adding the time since the participants' last meal and the participants' initial blood glucose measurement to the model; neither of these terms were strong predictors of post-meal blood glucose nor did they materially impact the relation between subjective hunger and post-meal glucose.

We can formalize the differences across these models using the deviance of the various models (the deviance of a model is equal to –2 × log-likelihood). When one model is a nested subcase of another model, the deviance of the reduced model minus the deviance of the larger model is distributed as a chi-square random variable where the degrees of freedom is equal to the number of fixed parameters, and where a significantly lower deviance reflects a statistically better fitting model. The deviances for each of the different model specifications are reported in Table 2. It can be seen that model specifications that drop either hunger-squared from the model, both hunger and hunger-squared, or time from the model yield highly statistically significant increases in deviance, reflecting poorer model fit relative to the principal specification. On the other hand, neither adding the hunger × time interaction term, the hunger × time interaction term and its squared term, baseline glucose, nor time since last meal led to a significance decrease in deviance, and thus, adding these terms does not appear to significantly improve the fit of the principal model specification.

<u>Table 2 about here</u>

I next examined the effect of hunger on enjoyment. Hunger and enjoyment were significantly correlated (*r*=.61; $p<.001$). Further, a mixed effects model estimating enjoyment as a function of hunger showed that hunger was a significant predictor of enjoyment ($\beta=.55$, $t=6.30$, $p<.001$). An alternative model specification that included a hunger squared term showed that hunger squared was not a significant predictor of enjoyment. These results suggest that in contrast to the relationship between hunger and glucose, the relationship between hunger and enjoyment is linearly increasing.

<u>Figure 3 about here</u>

As a final consideration, I added enjoyment to the principal model estimating glucose as a function of subjective hunger and time indicators. Enjoyment was not a significant predictor of glucose, nor did inclusion of enjoyment in the model materially change the pattern of results discussed above.

DISCUSSION

This study is the first specifically designed to examine the relationship between the subjective sensation of hunger and post-consumption glucose levels. It was hypothesized that regulating food intake according to subjective hunger may be physiologically healthy as hunger was posited to signal a physiological state in which body tissues are particularly prepared to absorb nutrients. Consistent with this prediction, post-meal glucose tended to decrease with increasing subjective hunger. However, it was also found that at the highest levels of hunger, glucose levels did not decrease relative to moderate levels of hunger and might even have increased. A possible explanation for why glucose levels do not linearly decrease with increasing hunger is that as the body's need for nutrients, and glucose in particular, becomes acute, physiological mechanisms act to shut off glucose supply to muscles (where a large share of glucose is ordinarily consumed) so that the glucose from the blood stream is preserved for essential organs, particularly the brain. This is because the brain depends on glucose for fuel, whereas muscles can preferentially switch to oxidizing fat for energy when glucose stores are low. Indeed, there is evidence that when glucose availability is low, the muscles' resistance to the actions of insulin (which normally acts to divert glucose into muscle tissue) is increased (Wolever 2000). Another possibility is that high levels of hunger might lead to rapid gastric emptying (Levin et al. 2006), which tends to lead to a more rapid increase in blood glucose levels, and which might counteract any effect of increased glucose absorption associated with high hunger..

Unlike the relation between hunger and post-meal glucose, the relationship between hunger and enjoyment of the meal was monotonic and linear. This finding is consistent with the notion of alliesthesia, which refers to the idea that the pleasure associated with a given stimulus is influenced by changes in one's physiological state (Berridge 1996; Cabanac 1971; Wadhwa, Shiv, and Nowlis 2008).

Limitations and Future Research Directions

The current study has several important limitations that need to be noted. First, the findings are correlational, and hence are limited in their ability to yield insight into the causal link between subjective hunger and post-meal glucose levels. I have posited that hunger may be associated with post-meal glucose because hunger reflects a physiological state in which body tissues are relatively receptive to the absorption of nutrients. Consistent with this viewpoint, the level of the brain-gut peptide ghrelin, which is correlated with feelings of subjective hunger, tends to rise in anticipation of a meal and appears to prepare the body to absorb nutrients through facilitating fat storage and carbohydrate oxidation (Gagliardino 2005). On the other hand, post-meal glucose levels depend not only on absorption of glucose into body tissues, but also on a number of other factors, including the velocity of gastric emptying, the digestion of food in the intestine, and the production of glucose and its release into the bloodstream from stored glycogen (for a review, see Gagliardino 2005), all of which might be correlated with hunger, and thereby account for the association of hunger with post-meal blood glucose.

A related limitation in interpreting the present findings is that participants' subjective hunger may have simply been a reflection of diurnal rhythm (Garaulet and Gómez-Abellán 2014). That is, hunger may simply have been a proxy for the time in the diurnal cycle in which it was optimal for individuals to consume food. However, as noted previously in the introduction, even if hunger merely proxies for the time in the diurnal cycle at which it is optimal to eat, from a practical perspective, it is more practical for individuals to eat according to feelings of hunger than according to the time in the diurnal cycle at which it is optimal to eat, since the former is a subjective feeling that individuals can recognize whereas the latter can vary with jetlag, disordered sleep, shift work, and so forth. Moreover, since each participant attended two sessions exactly one week apart at the exact same time of day, I examined whether hunger could predict post-meal glucose within subjects. That is, could within-subject differences in hunger across the two sessions predict within-subject differences in glucose across the two sessions? If so, it would suggest that the association between subjective hunger and post-meal glucose is not just a time-of-day effect, since time-of-day is constant within subjects across the two sessions. Indeed, I found a significant inverse correlation between the within-subject change in hunger and the within-subject change in post-meal glucose (using the average of the 3 post-meal measurements; $r = -.38$, $p = .02$).

An additional potential concern is that in the present study, participants' premeal conditions, including the meal they ate before the test meal (typically referred to as a "preload") and their activity before the test meal, were not controlled. These factors can have a significant impact on post-meal glucose levels as well as on hunger and are often tightly controlled in physiological experiments examining the effect of a meal on post-meal markers so as to ensure that any effects on these markers are the result of the test meal. Despite this limitation, which restricts the ability to make causal inferences, the naturalistic context of the present study likely yielded more natural variation in hunger than might be expected under more tightly controlled conditions, and thus may have been more suited to the purpose of identifying an association between hunger and post-meal glucose.

An additional important question about the present study is the degree to which the present findings can be generalized to other foods. In particular, because the focus of the present study involved the consumption of a single standardized meal, the degree to which the present findings might be generalized to other foods is unknown and is an important topic for future research. For instance, the meal consumed in the present study was comprised of easily digestible foods (a white dinner roll and Sprite). The use of easily absorbed foods might mask differences in gastric emptying associated with hunger that might emerge when less easily digestible foods are consumed. In particular, hunger might increase gastric emptying (Levin et al. 2006), which, if it were the case, would increase the velocity at which glucose enters the blood stream and thereby lead to an effect opposite of what was observed in the present study (assuming the rate of gastric emptying is a more important factor than other factors that also influence the relationship between hunger and post-meal blood glucose, such as greater absorption of glucose into tissues). Future research should examine whether the digestibility of different foods influences the association between hunger and post-meal blood glucose.

An additional limitation of the current study is that it examined the association between hunger and post-meal glucose in response to a standardized meal. However, in a free choice context, it is likely that individuals might choose to eat different quantities depending on their level of hunger (i.e., hungry individuals might consume more). Such differences in food consumption might eliminate or otherwise affect differences in post-meal glucose associated with different hunger levels observed in the current study. Thus, examining how hunger levels affect post-meal glucose levels following a meal in a context where individuals are able to freely choose how much to eat will be an interesting question for future research. Nonetheless, we know that people often eat irrespective of hunger, and thus the present study provides insight that given a fixed quantity of food, it may be healthier to eat that quantity of food when feeling hungry than when not feeling hungry.

In addition to addressing the limitations of the present study, the findings of the present research also call for more research to extend the findings in new directions. For example, research might examine long-term markers associated with eating according to hunger, such as markers of glycation and inflammation. More broadly, research might examine how other subjective feelings related to appetite, such as cravings, influence physiological markers. For instance, is a craving for sweetness associated with differences in post-meal glucose after consumption of sweet foods vs. non-sweet foods containing a similar quantity of carbohydrates? Such research extensions will help illuminate the implications of regulating food consumption according to subjective feelings.

The Bigger Theme: Eating According to Internal Versus External Cues

Although the present findings are only correlational, they fit within a broader collection of research findings on the consequences of eating according to internal versus external factors. In particular, the present research, combined with prior research linking a focus on internal feelings (namely hunger and satiety) to guide food intake with normal-weight, suggests that it may be relatively productive from a health standpoint to regulate one's food consumption according to internal feelings, and specifically that it may be beneficial to eat when moderately hungry (rather than when not hungry or, possibly, when very hungry). This may be especially important in the modern food consumption environment where external cues to eat are ubiquitous. It also suggests that healthy eating is not incompatible with enjoyment (as some lay theories presume; Raghunathan, Naylor, and Hoyer 2006), since eating when moderately hungry was associated both with relatively modest increases in post-meal glucose and with enjoyment.

In addition to food being more enjoyable to consume when one is subjectively hungry, regulating food intake according to hunger (as opposed to willpower) is likely to be relatively easy since it does not require effort. Indeed, prior research has shown that regulating food intake according to external factors, such as attempting to restrict one's consumption of 'unhealthy' foods through willpower, can result in detrimental psychological consequences such as irritation and anger (Gal and Liu 2011) and often tends to backfire (for review, see Polivy 1996).

Likewise, research in this issue shows that attempting to control people's food consumption through negative messaging, such as telling them that cookies are bad for them, can lead to psychological reactance and increased rather than decreased food consumption (Pham, Morales,and Mandel, JACR 2016).

On the other hand, the modern food consumption environment makes regulating food according to hunger more difficult than in a traditional environment because of the constant availability of palatable food cues, which lead people to eat in the absence of hunger (for review, see Chandon and Wansink 2012). To facilitate eating according to hunger, as opposed to mindless eating or eating due to cravings induced by palatable food cues, consumers might attempt to control their home food environment by minimizing the availability of highly palatable engineered foods. One is probably more likely to eat when hungry (than when not hungry) when the available options are bananas and nuts than when one is surrounded by brownies and sweetened beverages.

Recent research, including in this issue, illuminates additional strategies that might help consumers eat better, likely by facilitating consumption according to internal feelings of hunger and satiety. Research in this issue shows that simple changes to the dishware and flatware with which meals are consumed can limit individuals' consumption amounts (Block, Williamson, and Keller, 2016; Szocs and Biswas, 2016; Zlatevska, Holden, and Dubelaar, 2016). Though more process evidence is needed, it is likely that such changes induce individuals to focus more on internal feelings of hunger and satiety than on external cues by shifting individuals' focus away from food palatability (Szocs and Biswas, 2016) or from heuristics that favor filling one's plate with food (Zlatevska, Holden, and Dubelaar, 2016) and eating everything on one's plate (Block, Williamson, and Keller, 2016). Moreover, because people often eat for the reward value of food rather than because they are hungry, research suggests that one means to decrease people's consumption of this sort is to substitute other rewards, such as the small toys found in Happy Meals, for some of the food people would otherwise consume (Reimann, MacInnis, and Bechara, 2016). Finally, eating according to internal feelings should minimize the effects of consumers' lay theories on overconsumption, such as the belief that healthy food is less filling, which might cause consumers to eat beyond satiation (Suher. Raghunathan, and Hoyer, 2016).

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TABLE 1

GLUCOSE MODEL FIXED EFFECTS ESTIMATES

	Estimate	**Std. Error**	**t value**	**sig**
Intercept	202.385	9.077	22.297	***
Hunger	-24.103	4.766	-5.057	***
Hunger^2	2.525	0.590	4.279	***
(Time)35	-17.810	3.085	-5.773	‡
(Time)50	-30.266	3.085	-9.811	‡

***indicates *p*-values < .001

‡ indicates *p*-value < .001 for the group variable for time (i.e., time (20), time (35), and time (50))

TABLE 2

MODEL COMPARISON

Model	Deviance	Chisq	df	p
Main Model	2126.5			
Subtract: Hunger^2	2143	16.533	1	***
Subtract: Hunger, Hunger^2	2157.4	30.888	2	***
Subtract: Time	2206.3	79.828	2	***
Add: Hunger*Time	2126.2	0.3	2	.87
Add: Hunger*Time, Hunger^2*Time	2126	0.5	4	.97
Add: BaselineGlucose	2126.5	0.029	1	.86

***indicates *p*-values < .001

Main Model	1872.5			
Add: TimeSinceLastAte	1870.4	2.09	1	.15

Note: The comparison of the main model with a model adding the time since the participant last ate is based on a subsample of subjects who entered an interpretable time since they last ate (hence the Main Model deviance does not match the Main Model deviance above).

FIGURE 1

GLUCOSE AS A FUNCTION OF HUNGER AND TIME (RAW MEANS)

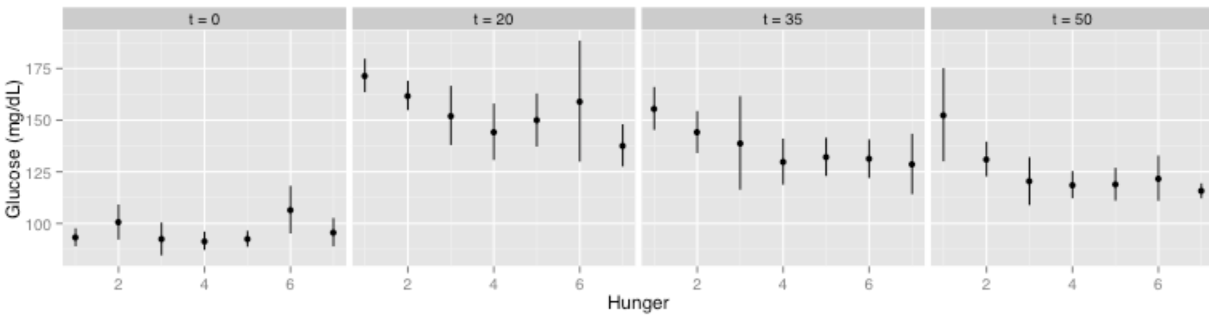
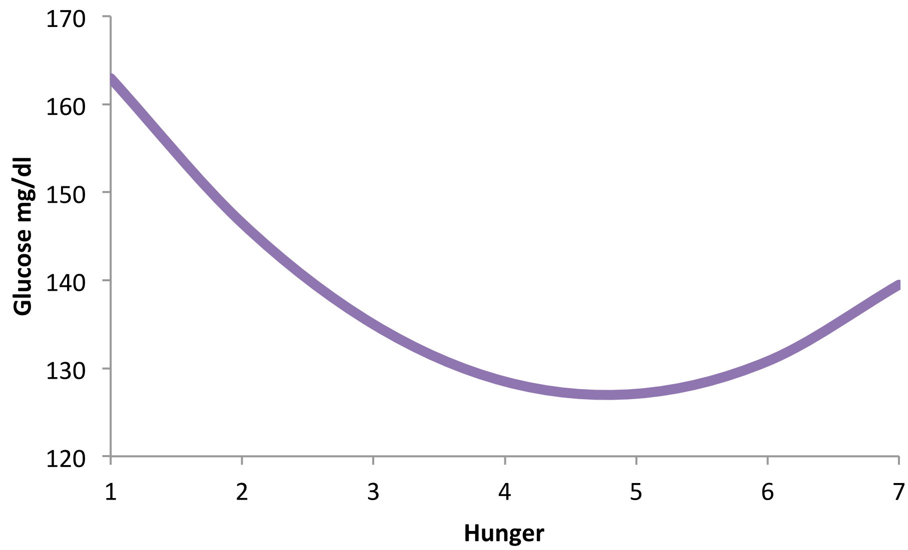


FIGURE 2

GLUCOSE AS A FUNCTION OF HUNGER (FROM MODEL)



Note: Plot shows glucose at t = 35 minutes.