Adolescents with Type 1 Diabetes and Hyperglycemia:

Arousal, Moods, Social Interactions, and Insulin Insensitivity

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A Dissertation proposal submitted to the Faculty of Graduate Studies

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FIGURE

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Abstract

Psychological models of arousal suggest that subtle physiological conditions, like abnormal glucose levels, can affect the moods and interpersonal interactions of individuals. This study focussed on how hyperglycemia (abnormally high-glucose levels) relates to the moods and social interactions of adolescents with Type 1 diabetes. The first hypothesis was that more extreme glucose levels would be associated with more extreme mood and social interaction ratings. Researchers have had difficulty identifying reliable associations between hyperglycemia and moods. Thus, a new, dualistic model of hyperglycemia was proposed suggesting that the psychological consequences of hyperglycemia might be differentiated on the basis of relative insulin deficiency or relative insulin insensitivity. The second hypothesis was that insulin-insensitivity (impaired glucose metabolism) hyperglycemia would show the stronger relation with moods and social interactions. Twenty adolescents (12 to 18 years of age, 10 male) with Type 1 diabetes participated in this prospective field study. Using handheld computers, adolescents rated their physical symptoms, moods, and social interactions, and provided both subjective and objective measures of their current glucose levels. Each adolescent participated for 3 weeks and completed a mean of 51 trials, producing a total of 1028 observations. Multilevel regression analysis was used to assess the associations. Partial support was found for the hypotheses. Hyperglycemia was associated with fewer positive moods and more negative social interactions for some subgroups of the sample. Insulin-insensitivity was associated with fewer positive social interactions. This initial study provides the first systematic evidence that hyperglycemia and insulin-insensitivity hyperglycemia are associated with adolescents' social interactions.

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INTRODUCTION

People's moods and social interactions are influenced by many factors including the presence of circumstantial stressors, the pleasantness of their social companions, the characteristic tendencies of the people themselves, and the actions of underlying biological forces. Biological influences are interesting in that they are likely to be relatively opaque to the individual under their influence, and yet, powerful in their persistent effects. The subtleness of the effect may be particularly important when investigating social interactions among people. A subtle cause is more likely to go unrecognized and its effect to be misattributed to other more salient factors found in the social environment, such as the agreeableness or disagreeableness of one's social companions or the fairness or unfairness of one's social circumstances.

Blood glucose levels may exert subtle, yet persistent influences on people's moods and social interactions. Abnormally low-blood glucose level are associated with changes in both brain function and other biological conditions (e.g., hormone responses) that are known to influence moods and social behaviours (Benton, 2002; Gold, Deary, & Frier, 1997; Gonder-Frederick, Clarke, & Cox, 1997). Although anecdotal evidence is easily found to suggest that abnormally high-glucose levels also influence individuals' moods and social interactions, with a few exceptions (Gonder-Frederick, Cox, Bobbitt, & Pennebaker, 1989; Moses & Bradley, 1985), systematic evidence of such high-glucose effects is difficult to find. In an attempt to resolve this apparent empirical discrepancy, an alternative, dualistic view of hyperglycemia is offered and tested as a more precise representation of hyperglycemia and how it relates to individuals' moods and behaviours.

In this investigation, the mechanism or explanation of how glucose levels can be affecting the moods and social interactions of adolescents needs to be considered. I will be considering a relatively macroscopic, psychologically-oriented explanation that focuses on general physiological arousal rather than more microscopic, biologically-oriented explanations that have been put forth (see review by Benton, 2002). More specifically, arousal-related models provide a general description of how glucose levels may affect the moods and social interactions of people (Allen, Kendrick, Linder, & McCall, 1989; Cacioppo, Berntson, & Crites, 1996; Maslach, 1979; Schachter & Singer, 1962; Zillman, 1984; Zillman & Zillman, 1996).

The *Transfer of Excitation* model and associated models suggest that general arousal can excite or magnify a person's reaction to unrelated stimuli (Allen et al., 1989; Anderson, Anderson, Dorr, DeNeve, & Flanagan, 2000; Cacioppo et al., 1996; Foster, Witcher, Campbell, & Green, 1998; Sinclair, Hoffman, Mark, Martin, & Pickering, 1994; Zillman, 1984). Another important component of some of these models is that this magnification effect can be dampened (if not completely eliminated), if the person is made aware of the true source of the underlying arousal. This relation to awareness implies that the extent to which glucose-related arousal is recognizable will determine the extent to which it is associated with moods and social interactions. Therefore, in this research project perceptions of glucose-related effects, as well as the glucose-related effects themselves, were investigated as predictors of the moods and social interactions of adolescents with Type 1 diabetes.

Individuals with Type 1 Diabetes: An Ideal Population

Among healthy individuals, the frequency and duration of relatively extreme glucose states are minimized by homeostatically-driven regulatory glucose mechanisms (Dunger & Edge, 1994; Stirling & Kelnar, 1994). The normal blood glucose range in

healthy individuals is 3.9 to 5.5 mmol/L (Benton, 2002). However, greater variability in glucose levels can be found among individuals with Type 1 Diabetes Mellitus (Ruggiero & Javorsky, 1999). They experience greater than normal fluctuations in glucose levels because of impaired-insulin production or utilization (see Appendix A for more details). More extreme glucose fluctuations produce more extreme and more easily identifiable behavioural changes (Cox, Gonder-Frederick, Kovatchev, Julian, & Clarke, 2000; Jones et al., 1997; Widom & Simonson, 1992).

As well, there is a practical barrier to evaluating glucose-behaviour relations among healthy populations. Obtaining glucose estimates multiple times per day is intrusive and costly in healthy individuals. Such estimates require a blood sample and an immediate biochemical blood test. Individuals with diabetes perform such glucose assessments multiple times per day as part of their day-to-day health care (Ruggiero & Javorsky, 1999). Thus, individuals with diabetes provide an unique and viable opportunity to study the relations between glucose levels and moods and social interactions.

Adolescents

To examine the relation between glucose levels and people's moods and social interactions, a reasonable amount of variability is needed in each of these characteristics. Adolescents exhibit greater variability in moods than other age groups (e.g., Arnett, 1999). They also spend considerable portions of their discretionary time in social interactions (e.g., Larson & Verma, 1999). Therefore, the selection of adolescents for a study of moods and social interactions seems most appropriate.

Evidence of volatility in moods is one of the key characteristics of the storm and stress notion. Although *all* adolescents are not the epitome of "sturm und drang" as once thought, neither is this idea simply a myth (Arnett, 1999). In a recent review, Arnett concluded that "adolescence is the period when storm and stress is *more* likely to occur

than at other ages" (p. 317, 1999). Longitudinal studies show that moving from preadolescence to adolescence is associated with greater negative affect (see review Buchanan, Eccles, & Becker, 1992). Moreover, "Experience Sampling Method" studies show that adolescents report greater variability in moods, both positive and negative, compared to their parents (Larson & Richards, 1994). However, adolescent-related increases in negative moods, rather than positive moods, are probably somewhat more common (Arnett, 1999).

Adolescents spend a high proportion of their time in social interactions (see review by Larson & Verma, 1999). One recent review of how adolescents spend their time made use of three types of data: 24-hour diaries, experience sampling methodologies, and random naturalistic observations of individuals' activities at various times throughout the day (Larson & Verma, 1999). The results were very similar across these different methodologies. Time spent with other family members tends to drop during adolescence from about 33% to 14% of waking time. In contrast, the amount of time adolescents spend with their peers increases from 18-20% to 29-30% of their waking time (Larson, Richards, Moneta, Holmbeck, & Duckett, 1996; Larson & Verma, 1999). These findings reflect the daily patterns of adolescents from industrialized countries of North America and Europe[1]. Consistent with recent theories of adolescent development (Harris, J. R., 1995), adolescents spend less time with their parents, and the social interactions with peers become increasingly important.

Another benefit of using adolescent participants is that, unlike younger children, they are able to describe and report on their various activities, feelings, and social interactions throughout the day. This is most evident in studies using the Experience

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[1] Minority groups within these cultures tend to show a somewhat different pattern in how they spend their time.

Sampling Method (ESM) developed by Csikszentmihalyi and Larson (e.g., 1987; Larson, 1989). This method has proven quite valuable in assessing various aspect of adolescents' daily lives. The ESM studies typically have adolescents carry pagers or watches that beep at semi-randomly determined times throughout the day. Upon hearing the beep, the participants report on their current context, activities, and/or feelings. Adolescents' reports using the ESM generally converge with other time sampling methods of adolescent activities (Larson & Verma, 1999).

Adolescents with Type 1 Diabetes

As indicated earlier, variability in glucose levels is also an important component in being able to identify relations between glucose levels and moods and social interactions. Among individuals with diabetes, adolescence is the period of poorest metabolic control, and adolescents show considerable variability in their glucose levels (Anderson, 1994; Anderson, Ho, Brackett, & Laffel, 1999). Adolescents tend to show poorer metabolic control, in part due to hormonal changes (e.g., growth hormone surges, insulin-like growth factor) that appear to result in insulin resistance (Dunger & Edge, 1994; Anderson, 1994). Deterioration in self-management activities, including poorer diet control, less consistent glucose monitoring, or less reliable insulin administration, represent the other major source of poorer metabolic control among adolescents (Anderson, 1994; Ruggiero & Javorsky, 1999).

Therefore, adolescents with Type 1 diabetes were expected to show considerable variability in their moods, social interactions, and glucose levels. Taken together, these characteristics and vulnerabilities unique to an adolescent population with Type 1 diabetes, make them ideal participants for a study on the relations between glucose levels and moods and social interactions.

Arousal-Related Models and Glucose

Glucose levels may act as a form of general physiological arousal in how they affect moods and social behaviours. Arousal-related psychological models and findings offer a reasonable explanation for the underlying mechanism describing how glucose levels relate to adolescents' moods and social interactions. These models and findings are described next.

A hypothetical scenario. The focus of this research project is on how glucose fluctuations influence adolescents' moods and social interactions. The following is a fictional illustration of how glucose may act as a form of arousal to affect adolescents' social interactions. Sarah, an adolescent with diabetes, got into an argument with one of her friends while at the mall. At the time, Sarah's glucose levels were elevated. For Sarah, elevated glucose levels tend to be associated with increased social conflict. Sarah, however, did not realize that her glucose levels were elevated, nor did she realize that she was reacting more intensely than the situation warranted. If Sarah had known that her glucose levels were high, she might have realized that her behaviour was overly intense, and could have avoided the argument. Such a scenario is quite consistent with arousal-related models such as Zillman's (1984) *Transfer of Excitation* model.

Arousal-Related Models

The *Transfer of Excitation* model is an application of Schachter and Singer's (1962) earlier *Misattribution of Arousal* model. Of the various applications and tests of the general misattribution of arousal model, the *Transfer of Excitation* model has received the most consistent support (see reviews by Cotton, 1981; Reisenzein, 1983). Researchers have applied the *Transfer of Excitation* model to explain a variety of emotional and interpersonal effects including changes in emotional states (Bunce, Larsen, & Cruz, 1993; Cacioppo et al., 1996) interpersonal liking, prosocial behaviour, romantic attraction, and

aggression (see reviews by Anderson, 1989; Cacioppo et al., 1996; Cotton, 1981; Reisenzein, 1983; Zillman, 1984).

The *Transfer of Excitation* model proposes that an individual's response to a current event can be intensified by arousal due to prior or current unrelated events (Zillman, 1984). The earlier or unrelated events are assumed to cause a general, sympathetic, non-specific arousal, and to provide little information about their original cause or source. In ambiguous circumstances, this non-specific arousal can lead to exaggerated interpretations or attributions of the events. Another model assumption is that individuals tend to ascribe their current levels of excitation to one specific source rather than partition and allocate it into its various originating sources. Lastly, excitation, particularly autonomic excitation, is assumed to dissipate gradually rather than abruptly, consistent with hormonal responses associated with a sympathetic response (for more details see Zillman, 1984). Thus, physiological arousal from an earlier arousing experience may remain even after the event that caused the arousal is no longer present. This residual arousal is *added* to current experience-related levels of arousal, and so intensifies the excitatory nature of the current event (Zillman, 1984).

Ambiguous arousal. A tense and aggressive interaction between two adolescent peers at school would likely produce physiological arousal. This residual physiological arousal may be still present after the event is over and the adolescent has returned home. The residual arousal might cause the adolescent to react more intensely than usual to a parent's suggestion to help around the house, for example. In the case of concurrent arousal, physiological arousal from one experience is transferred to another unrelated experience, intensifying a person's response to the second, unrelated event. For example, an angry response to a referee's penalty may be intensified by arousal due to the physical activity exerted while playing the game.

Automatic arousal effects. Not too surprisingly, various counter-explanations and model variations of the *Transfer of Excitation* model have been put forth. For example, Allen et al. (1989) suggested that arousal-related effects on interpersonal attraction are due to response facilitation rather than a misattribution of arousal. The key difference between the two types of models is that awareness of the source of the *unrelated* arousal is critical to the *Transfer of Excitation* model, but irrelevant to the *Response Facilitation* model. In this latter model, arousal, whether salient or not, directly amplifies a persons' response to a given stimulus or situation. Therefore, arousal will magnify either positive or negative responses depending upon the valence of the specific stimulus or situation. Under this perspective, arousal was viewed as independent of the individual's level of awareness.

Automatic arousal adjusted by awareness. Another common variation of these arousal-related explanations of moods, behaviours, and interpersonal evaluations is the proposal that both arousal and awareness of the arousal are important (Cacioppo et al., 1996; Foster et al., 1998). For example, Foster et al. (1998) proposed a two-stage model to explain the arousal-attraction relation. They suggested that initially, upon meeting an attractive person, prior arousal will amplify the automatic judgement of attractiveness. If the source of arousal is relatively salient and the evaluator is motivated and able to reflect on this evaluation (i.e., has the available cognitive resources), the initial evaluation of attractiveness will be lowered, accordingly. In other words, under the two-stage arousal-attraction model, initial attraction is amplified by arousal via a relatively automatic effect. This automatic effect is followed by a more effortful adjustment stage based upon cognitive reflection. Such a two-stage model is similar to other models of social inference or decision making (see Trope & Gaunt, 2000; Tversky & Kahneman, 1974).

Based on these various models, it is clear that some debate exists about the importance of awareness of arousal on people's emotions and interpersonal behaviours and reactions. If abnormal glucose levels affect people's moods and social behaviours, is this

effect relatively automatic and independent of glucose awareness? Or, does subjective awareness of glucose effects alter the affect glucose has on one's moods and social behaviours? In the scenario of Sarah's argument in the mall, does her awareness of her elevated blood glucose moderate how her glucose levels affect her social interactions? Under the *Transfer of Excitation* model, if Sarah knows her glucose levels are high, she will not "let" her high-glucose levels affect her social interactions (i.e., there would be no relation between her glucose levels and the quality of her social interactions). Under the *Response-Facilitation* model, however, Sarah knowing that her glucose levels are high will not prevent her glucose levels from affecting her social interactions (i.e., there would remain a significant negative relation between her glucose levels and the quality of her social interactions).

A negative bias. Earlier studies also suggested that arousal may have an inherently negative bias (Marshal & Zimbardo, 1979; Maslach, 1979). That is, unexplained arousal will be biased towards causing negative emotional moods or social interactions rather than valence-free and situationally determined. I am referring to this model as the *Negatively Biased* arousal model. Considerable evidence has accumulated that arousal can amplify either positive or negative reactions depending upon the nature of the environmental stimulus (Cacioppo et al., 1996; Cotton, 1981; Foster et al., 1998; Reisenzein, 1983; Zillman, 1984). This *Negatively Biased* model may be relevant to the current study of glucose-related arousal effects for two reasons. One, the glucose levels proposed to cause arousal effects are pathological in nature. Two, anecdotal reports of high and low glucose effects tend to emphasize negative reactions in individual with diabetes (see anecdotal evidence review below). Such reports themselves, however, may be biased. Systematic evidence is needed to assess if glucose-based arousal effects are negatively biased or valence-free.

Glucose level as physiological arousal. Glucose levels seem to function as a form of physiological arousal. Both abnormally high and low glucose levels appear to represent a form of internal physiological arousal. Changes in glucose levels are a basic component of physiological arousal or excitation (Cryer, 1997; Zillman & Zillman, 1996). High glucose levels and peripheral insulin levels are involved in glucoregulatory processes which involve glucagon, epinephrine, and cortisol regulatory responses (for a more details see Zillman & Zillman, 1996). An examination of how pathological levels of hyperglycemia may interact with these arousal related hormonal responses was beyond the scope of this project, but the basic relation between hyperglycemia and adrenocortical regulation suggests that a relation between psychological arousal and hyperglycemia is plausible. As well, clinically low glucose levels can lead to the release of a variety of hormones including epinephrine (see Cryer, 1997), one of the more well-recognized general arousal-related hormones. Thus, we might expect to see psychological effects of arousal occurring in association with either high or low-blood glucose levels.

The ambiguity of glucose level. Subjectively, the effects of glucose fluctuations appear fairly subtle, particularly in contrast to the individual's much more salient day-to-day behaviours and social interactions (Cox, Gonder-Frederick, Antoun, Cryer, & Clarke, 1993). Thus, the psychological effects of abnormal glucose levels could go unrecognized. Furthermore, the physiological effects associated with glucose levels represent relatively general, unfocussed forms of physiological arousal (Zillman & Zillman, 1996), a form of arousal thought to be most susceptible to misattributions. In other words, abnormal glucose fluctuations may go unnoticed and remain relatively ambiguous to adolescents with diabetes.

Summary. Psychological models of arousal-related effects provide a reasonable representation of how glucose levels may influence the moods and interpersonal interactions of adolescents with diabetes. To date, there have been no systematic studies of

the relation between glucose levels and interpersonal interactions. This dissertation provides an initial examination of glucose effects on social interactions. Some of these arousal models (*Transfer of Excitation* and *Arousal-Adjustment* models) suggest that awareness of glucose-related effects should lessen the influence of glucose-related arousal on the adolescent's moods and social interactions. Thus, the potentially moderating effect of awareness also was evaluated. From a hypothesis-testing perspective, a simple main effect of glucose level on mood and social interaction ratings would imply that glucose exerts a relatively automatic effect on people's feelings and behaviours. If, however, a significant interaction between glucose level and glucose-related awareness measures emerge, then this implies that glucose-related effects vary as a function of glucose-related awareness. Both positive and negative outcomes also were assessed to evaluate wether glucose-related arousal effects are valence-independent or negatively biased.

The Glucose Dichotomy

Before turning to a review of the evidence for a relation between glucose levels and the moods and behaviours of individuals with diabetes, I will first review the physiology, symptomatology, and frequency of low and high glucose level aberrations. I will also present a critique of current models of high-glucose levels. This information should help in understanding the glucose-related findings that follow.

Among healthy individuals, glucose levels are thought to range from 3.9 to 5.5 mmol/L (Benton, 2002); however, others cite a somewhat larger range of 4.0 and 6.7 mmol/L (Driesen, Cox, Gonder-Frederick, & Clarke, 1995). Among people with Type 1 diabetes, however, glucose levels are much more variable. For example, the goal of maintaining glucose levels between 3.6 and 10.0 mmol/L was not achieved in the sample of intensively treated patients in the Diabetes Control and Complications Trial (DCCT Research Group, 1993). This goal was not achieved despite the application of more

flexible and intensive insulin administration protocols, frequent glucose monitoring, and the efforts of a multi-disciplinarian team of health care professionals providing regular check-ups and feedback. Due to the difficulties in maintaining well-controlled glucose levels, two clinically important qualitative states often arise, hypoglycemia (<3.9 mmol/L; e.g., Cox, Donner et al., 1999) and hyperglycemia (>9.9 mmol/L; e.g., DCCT Research Group, 1993). The characteristics, causes, and prevention of these pathologically high and low glucose states has received considerable research attention, and some of the key findings of this body of research will be highlighted in the next two sections.

Hypoglycemia

Hypoglycemia occurs when glucose levels drop to a pathologically low level. Conventional risk factors for hypoglycemia include a general mismatch among food intake, physical activity, and insulin quantity or timing (Clarke et al., 1999a). For example, missing a meal, exercising more vigorously than usual, or taking more insulin than is required can lead to a hypoglycemic episode. Hypoglycemia has received increased research attention, in part due to the recent adoption of more intensive insulin therapy treatment protocols (Gonder-Frederick, Cox, & Ritterband, 2002). These more intensive protocols entail more frequent use of insulin throughout the day. Such protocols aid in the maintenance of lower average glucose levels and delay the development of long-term, complications of diabetes (DCCT Research Group, 1993). Unfortunately, these more intensive treatment approaches may be associated with an increased occurrence of hypoglycemic episodes (e.g., DCCT Research Group, 1993, 1995a).

Diagnosis of hypoglycemia. Although a glucose level of less than 3.9 mmol/L is a common definition for hypoglycemia (Cox, Gonder-Frederick, Polonsky et al., 1995; Gonder-Frederick et al., 1997), more stringent criteria are sometimes used, such as less than 3.3 mmol/L (Johnson, Perwien, & Silverstein, 2000) or 2.8 mmol/L (Wiebe, Alderfer,

Palmer, Lindsay, & Jarrett, 1994). The more stringent diagnostic approach makes use of three criteria: low glucose levels, symptoms compatible with hypoglycemia, and relief of symptoms after treatment (Cryer, Fisher, & Shamoon, 1994). If, however, reduced counter-regulatory responses delay the appearance of hypoglycemic symptoms (see below), then only more serious hypoglycemic episodes will satisfy these diagnostic criteria. In the tightly-controlled, and safer, experimental context of the lab, researchers can rely upon these more extreme and stringent diagnostic criteria. Epidemiological studies also utilize more stringent, lower glucose levels to define hypoglycemia to ensure that incidence and prevalence ratings are not overestimated (Cryer et al., 1994). Field studies, however, often use more lenient, higher glucose levels to define hypoglycemia (Cox, Gonder-Frederick, Julian, & Clarke, 1994; Clarke et al., 1999b; Nurick & Johnson, 1991). This identification and examination of less extreme glucose levels facilitates earlier identification of hypoglycemia and minimizes the occurrence of the more dangerous, very low glucose levels (Cryer et al., 1994).

A matter of severity. To differentiate between less and more severe levels of hypoglycemia, researchers often classify hypoglycemic episodes into three categories, very mild, mild-moderate, and severe (Cryer et al, 1994; Fishbein & Palumbo, 1995). Very mild hypoglycemia has been defined as biochemically recognizable, but asymptomatic behaviourally and psychologically (Cryer et al., 1994). Mild-to-moderate hypoglycemia is generally recognized as causing a variety of symptoms: physical, behavioural, and psychological, but the particular symptoms experienced are often person-specific (Cox et al., 1985a). Severe hypoglycemia (SH) is generally defined as an inability to treat oneself and a need for assistance. Assistance may be needed because the person is so cognitively disoriented that he or she cannot take appropriate treatment action, or because the person has become unconscious (see Clarke, Gonder-Frederick, & Cox, 1996).

The counter-regulatory response. In the healthy individual, hypoglycemia induces a variety of physiological responses with different responses initiated at different glucose levels (for more details see review by Cryer et al., 1994, or Cryer 1997). At the mildest levels of hypoglycemia (4.6 mmol/L) the body inhibits insulin production. If this is not sufficient to elevate glucose levels, the hormone glucagon is released around 3.8 mmol/L of blood glucose followed by epinephrine around 3.7 mmol/L glucose (Cryer et al., 1994). In healthy individuals these hormonal responses are more than sufficient to normalize glucose levels. However, under experimentally-induced hypoglycemia, a variety of additional physiological and behavioural responses may be triggered as glucose levels continue to drop. Other commonly examined physiologically responses to hypoglycemia include: the release of norepinephrine, growth hormone, cortisol, and pancreatic polypeptides into the blood (Bjorgaas et al., 1997; Ovalle et al., 1998). A variety of regulatory systems control these hormonal responses. For example, the release of epinephrine is largely controlled by adrenomedullary activation, norepinephrine release by sympathetic-cholinergic activation, and polypeptides secretion by parasympathetic activation.[2]

Changes in counter-regulatory responses. The specific glucose levels at which physiological responses occur and the magnitude of the responses vary, depending upon prior physiological circumstances. For example, individuals with generally high-glucose levels, as indicated by glycosylated hemoglobin (A_{1C}) levels > 10 %, produce counter-regulatory responses earlier or at higher glucose levels than healthy individuals tested under the same hypoglycemic-induction procedures (Boyle, Schwartz, Shah, Clutter, & Cryer, 1988). Conversely, people with Type 1 diabetes and lower average glucose levels

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[2] Adolescents do not appear to exhibit the norepinephrine counter-regulatory response to hypoglycemia that adults exhibit (Bjorgaas et al., 1997; Gschwend, Ryan, Atchison, Arslanian, & Becker, 1995).

often exhibit delayed and blunted counter-regulatory responses to experimentally-induced hypoglycemia (e.g., Jones et al, 1997; Ovalle et al., 1998).

Impaired hypoglycemic awareness. Among individuals with diabetes, delayed and diminished counter-regulatory responses are of particular concern because they increase the likelihood that more severe and dangerous hypoglycemic episodes will occur (e.g., Clarke, Cox, Gonder-Frederick et al., 1995; Mokan et al., 1994). This is believed to occur for two reasons. First, the typical physiological defenses against hypoglycemia (i.e., release of glucagon and epinephrine) are less effective. Secondly, the behavioural symptoms typically associated with the counter-regulatory response are weaker, if not completely absent (Cryer et al., 1994; Veneman, Mitrakou, Mokan, Cryer, & Gerich, 1993). Without obvious behavioural symptoms, the individual is less likely to recognize and treat their hypoglycemia with interventions such as consuming quick-acting carbohydrates (e.g., fruit juice).

Types of hypoglycemia symptoms. Hypoglycemia typically is associated with a number of negative consequences (see reviews by Gold et al., 1997; Gonder-Frederick et al., 1997). Low glucose levels are correlated with physical symptoms (Deary, Hepburn, MacLeod, & Frier, 1993; Pennebaker et al., 1981), short-term cognitive deficits (Driesen et al., 1995; Maran, Lomas, MacDonald, & Amiel., 1995), impaired driving ability (Cox et al., 2000), and mood or psychological changes (Drozda, Allen, Standiford, Turner, & McCain, 1997; Gold, MacLeod, Deary, & Frier, 1995; Gonder-Frederick et al., 1989; Hendricks & Hendricks, 1998; McCrimmon, Deary, & Frier, 1995a; Ross, McCrimmon, Frier, Kelnar, & Deary, 1998). A subset of hypoglycemic symptoms are often classified as either autonomic or neuroglycopenic in nature (Deary et al., 1993). Autonomic symptoms generally reflect reactions due to either adrenergic hormonal responses, such as a shakiness, pounding heart, or nervousness, or cholinergic hormonal responses, such as sweatiness, hunger, or tingling sensations in the body (Ovalle et al., 1998).

Neuroglycopenic symptoms more directly reflect brain dysfunction due to a lack of glucose, the brain's primary energy source. They include symptoms such as mental confusion, drowsiness, weakness, and odd behaviour (Cryer et al., 1994; Ovalle et al., 1998). Individuals with diabetes tend to detect hypoglycemia because of the presence of autonomic symptoms (Cryer et al., 1994). Family members, friends, and other individuals, however, tend to notice the neuroglycopenic symptoms of hypoglycemia, as reflected in cognitive dysfunctions and altered behaviours (Cryer et al., 1994).

Frequency of hypoglycemia. Hypoglycemia is a common experience among individuals with Type 1 Diabetes Mellitus (Cryer, 1997). The large-scale DCCT of 1441 type 1 diabetes patients found that these participants experienced about 1 to 2 mild-to-moderate hypoglycemic episodes per week over the 3- to 9-year duration of the study (DCCT Research Group, 1995a). Another study of 441 patients with diabetes reported a similar number of hypoglycemic episodes per week of 1.8 (Pramming, Thornsteinsson, Bendtson, & Binder, 1991)[3]. Although some researchers have reported much higher frequency rates of 3.5 to 7.0 per week (Cranston, Lomas, Maran, MacDonald, & Amiel, 1994) and 7.5 to 10.0 per week (Ovalle et al., 1998), most field-studies also produce hypoglycemic frequency estimates of at least 1- to 2-episodes per week for both children (Gonder-Frederick, Snyder, & Clarke, 1991) and adults (e.g., Clarke et al., 1999b; Janssen et al., 2000).

Hypoglycemia frequency rates are important for determining adequate sampling and design procedures in behavioural field studies. To ensure a reasonable number of hypoglycemic episodes (i.e., 10) per participant, field study researchers typically have participants complete 3 to 5 symptom rating trials per day until a total of 50 to 80 trials

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[3] Other prospective studies have reported lower incidence estimates of hypoglycemia (Barkai, Vámosi, & Lukács, 1998; Gold, MacLeod, & Frier, 1994; Wiebe et al., 1994), but the estimates are based upon more restrictive definitions of hypoglycemia.

have been completed (e.g., Cox et al., 1995; see review by Cox et al., 1993). This is equivalent to about 3 to 4 weeks of data collection per participant. Of course these frequency estimates are only rough approximations; some individuals experience many hypoglycemic episodes, others experience very few (see Cryer, 1997).

Hyperglycemia

Hyperglycemia occurs when glucose levels rise to a pathologically high level. As with hypoglycemia, a mismatch among food consumption, exercise, and insulin administration can lead to hyperglycemia. Excessive food, insufficient physical activity, or too little insulin, as well as acute illness and psychosocial stressors can lead to hyperglycemia (Johnson, 1980). Physiological changes during adolescence are also associated with decreased insulin sensitivity (see review by Dunger & Edge, 1994), and both physiological and behavioural factors contribute to the poorer metabolic control found during adolescence (Johnson, 1995; Ruggiero & Javorsky, 1999).

Diagnosis of hyperglycemia. Hyperglycemia is defined as abnormally high blood glucose levels. Among individuals with diabetes, hyperglycemia is often operationally defined as glucose levels 10.0 mmol/L or higher (Cox et al., 1995; DCCT Research Group, 1993; Meltzer, Johnson, Pappachan, & Silverstein, 2003; Nurick & Johnson 1991). Other researchers prefer using a somewhat higher glucose level to operationally define hyperglycemia, such as 13.3 mmol/L (Johnson et al., 2000) or 14.4 mmol/L (Weinger, Jacobson, Draelos, Finkelstein, & Simonson, 1995).

Frequency of hyperglycemia. Even with conscientious and strict self-care activities, normal glucose levels are very difficult to maintain in individuals with diabetes. Abnormally elevated glucose levels are the norm rather than the exception among Type 1 diabetes patients. Although frequency estimates of hyperglycemic glucose tests are not commonly reported, some basic frequency data is available. In one field study of

adolescents an average of 27% of the glucose tests were 13.8 mmol/l or greater, M = 12/45 (Wiebe et al., 1994). A second field study of children reported that approximately 50% of children's glucose tests were greater than 10.0 mmol/l (Gonder-Frederick et al., 1991). Given the inherently difficult nature of maintaining normal glucose levels, hyperglycemia is, and will remain, a common occurrence in the lives of individuals with Type 1 Diabetes Mellitus.

A dualistic view of hyperglycemia. Among individuals with Type 1 diabetes, relative insulin deficiency is a central cause of hyperglycemia. A second physiological cause of hyperglycemia in Type 1 diabetes is gaining recognition, insulin insensitivity (see review by Greenbaum, 2002). Insulin insensitivity is an impairment in glucose uptake or metabolism. In this dissertation, a proposal was put forth that hyperglycemia largely due to insulin insensitivity would be more psychologically symptomatic than hyperglycemia due to insulin deficiency. A description for each type of hyperglycemia and the rationale for expecting different short-term consequences for each is discussed next.

Insulin-deficiency hyperglycemia. A typical example of hyperglycemia due to insulin deficiency would occur when food (carbohydrate) consumption exceeded the amount of short-term insulin administered. Although such hyperglycemia is associated with hormonal changes (e.g., norepinephrine reductions, Gschwend et al., 1995; growth-hormone reductions, Draelos et al., 1995), as long as insulin-mediated glucose uptake is unaffected, a basic amount of glucose is being processed.

Insulin-insensitivity hyperglycemia. Empirical evidence also has accumulated that insulin insensitivity affects and is affected by hyperglycemia (DeFronzo, Hendler, & Simonson, 1982; Makimattila et al., 1996; Vuorinen-Markola, Koivisto, & Yki-Jarvinen, 1992; Yki-Jarvinen & Koivisto, 1986). Insulin insensitivity refers to impaired insulin-mediated glucose uptake or glucose metabolism. If a current hyperglycemic episode is

largely due to insulin insensitivity, then a reasonable assumption is that less glucose is being processed and utilized than when hyperglycemia is due to relative insulin deficiency. Thus, the psychological and behavioural changes associated with hyperglycemia are expected to be more severe for insulin insensitivity hyperglycemia than for insulin deficiency hyperglycemia.[4]

Insulin insensitivity factors. The specific cellular mechanisms linking hyperglycemia and insulin insensitivity are not known currently (Greenbaum, 2002). However, some factors associated with increased insulin resistance include recent episodes of hypoglycemia (Heller & Cryer, 1991), recent periods of hyperglycemia (Vuorinen-Markola et al., 1992), and generally, poorer metabolic control (i.e., higher glucose levels, Makimattila et al., 1996). Prior episodes of hypoglycemia may cause the release of various counter-regulatory hormones that lead to insulin resistance, which lasts for several hours (see review by Bolli, Fanelli, Perriello, & Feo, 1993). At a more macroscopic level, psychosocial stressors also may cause the release of various neurochemicals that lead to insulin resistance (see review by Surwit, Ross, & Feinglos, 1991).

An important distinction. Compared to hyperglycemia due to insulin deficiency, hyperglycemia due to insulin insensitivity is expected to result in more intense and easily identifiable symptoms. Ignoring differences in these two potential underlying causes of hyperglycemia when attempting to identify its symptoms could mask the identification of symptoms that are associated with only one type of hyperglycemia. This may explain why researchers have had difficulty identifying consistent, behavioural symptoms of hyperglycemia (see glucose-symptom relations below). In the current study, rather than conclude that hyperglycemia has no short-term psychological consequences, the dualistic

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[4] The specific physiological mechanisms that may account for the different psychological and behavioural symptoms of these two types of hyperglycemia are not known at this time.

model of hyperglycemia was tested, along with the more traditional unidimensional model of hyperglycemia. In this field study, adolescents' beliefs about the cause of their current hyperglycemic episodes were used to categorize hyperglycemia into the different types of hyperglycemia.

A field-study operationalization of types of hyperglycemia. Although the *gold standard* for measuring *in vivo* insulin action (or insulin sensitivity) is the euglycemic hyperinsulinemic clamp technique, this is a complicated, time consuming, and costly procedure (e.g., Makimattila et al., 1996; Cervenakova, Ksinantova, & Koska, 2002). Other less costly methods include intravenous or oral Glucose Tolerance Test estimates (Cervenakova et al., 2002). These somewhat simpler laboratory methods still typically last 2 hours or more, require multiple blood samples per assessment, and therefore, were not feasible as an ongoing measure of insulin resistance needed multiple times per day over a 3-week field-study. An indirect but crude method of differentiating between the two types of hyperglycemia was based upon the use of self-reported beliefs about the cause of hyperglycemia. For example, hyperglycemia, reported as due to eating more than usual, exercising less than usual, or taking less insulin than usual, probably reflects hyperglycemia due to a relative excess in glucose intake or insulin deficiency. Alternatively, hyperglycemia thought to be due to recent stressors, earlier episodes of *hypoglycemia*, or as unexplainable or unknown causes, may reflect hyperglycemia due to impaired glucose uptake or insulin insensitivity.

A summary of the review on symptoms of hypo- and hyperglycemia. In addition to highlighting the relatively complex physiological underpinnings of glucose aberrations, this review of hypoglycemia and hyperglycemia also reveals that pathological glucose fluctuations are relatively common events in the day-to-day lives of individuals with diabetes. Hypoglycemia has received extensive research attention, research attention that has resulted in fairly precise models that link physiological conditions, behavioural

symptoms, and hypoglycemic awareness. Low-glucose fluctuations have profound influences on individuals' physical and psychological functioning. For hyperglycemia, however, models linking physiological conditions and behavioural consequences are not available. In this study, the proposal that hyperglycemia largely due to insulin insensitivity may be more symptomatic than hyperglycemia due to insulin deficiency was examined. A failure to take into account these underlying physiological differences in hyperglycemia may, in part account for the empirical inconsistencies in finding linkages between hyperglycemia and behavioural or psychological changes. The next section reviews evidence for the psychological and behavioural consequences of both hypoglycemia and hyperglycemia.

Glucose-Related Effects on Moods and Behaviours

This literature review begins with a description of qualitative and anecdotal evidence for the existence of a relation between glucose levels and personal and interpersonal behaviours. It is followed by a description of two relatively unique research designs commonly used among diabetes behavioural researchers: glucose manipulation laboratory studies and short-term longitudinal field studies. This information should help in understanding the diabetes-specific research findings that follow. The review focuses on glucose-related changes in moods and behaviours.

Anecdotal Evidence of Behavioural Effects

Various glucose-related changes in personal and social behaviours have been noted anecdotally and identified through surveys. For example, one interview study of 51 adult couples compared the psychological and social characteristics of people with diabetes and their spouse. The finding of particular interest for the current study was that moodiness was found to be a typical symptom associated with glucose fluctuations (Jensen, 1985). Each member of the dyad rated their own levels of moodiness and that of their spouse.

Moodiness ratings for those with diabetes were higher, based on both their own self-ratings and spousal ratings. Interview responses revealed another important trend. Spouses reported that discriminating between glucose-related moodiness and more naturally occurring moodiness was difficult. For example, one wife, referring to changes in her husband's behaviour, stated that, " I never know if he is just in a bad mood - or if he should go and get some food to increase his blood sugar" (Jensen, 1985, p. 357).

Similar evidence was found in a case study of a family with an 8-year-old daughter with diabetes. The purpose of the case study was to examine how families with a chronically ill child manage day-to-day functioning (Deatrick & Knafl, 1990). One of the father's concerns was that non-family members might misinterpret his daughter's illness related-behaviours. This concern was evident in his statement below.

> We have told a couple of neighbors [that our daughter has diabetes] . . . people who she's around a lot. They have seen her in a fit of rage, really upset and we try to explain it to them. We want them to understand that it's the diabetes and not that she's just being a brat (p. 21).

The father's comment highlights how glucose fluctuations may alter individual's social behaviours and how these behaviours may be misinterpreted or misattributed as due to more stable underlying characteristics such as a person's temperament or personality.

Dashiff (1993) provided a third example of how glucose fluctuations can interfere with the quality of social interactions among people with diabetes. It came from a study of the parents of pre-adolescent and adolescent daughters with diabetes. Although the focus of the study was on parental emotions and functioning, the social consequences of glucose-related changes in behaviour emerged once again. One father was quoted as saying: "One of our struggles is to distinguish her mood [due to] . . . hypoglycemia . . . [from] her anger at what we've done or not done" (p. 366).

In each of the examples above, glucose-related changes were reflected in negative behavioural changes or *bad* behaviour. Glucose fluctuations do not necessarily lead to "bad" behaviour. One clinical researcher noted that "knowing the child's personality and 'normal' behavior will help with the recognition of [low-blood glucose related behavioral changes], e.g., if the child becomes uncharacteristically quiet or disruptive" (Strang, 1994, p. 458). The emphasis is on "uncharacteristic" behaviour, not 'bad' or 'good' behaviour. The various qualitative reports are quite consistent in describing how glucose fluctuations influence people's behaviour. Social behaviours may be altered, but these illness-related behavioural alterations may be quite difficult to differentiate from normal fluctuations in day-to-day social interactions.

Two Basic Research Designs

To study the correlates and consequences of short-term fluctuations in glucose levels, two general research designs have been utilized: laboratory-based, experimental manipulations of glucose levels and longitudinal field studies of naturally occurring glucose fluctuations. Laboratory-based studies have enabled researchers to examine a variety of physiological changes associated with glucose fluctuations while providing the benefits of precision, control, and clarity of interpretation found with experimental designs. Field studies can supplement the lab studies by allowing researchers to test the generalizability of laboratory-based results. Field studies also enable researchers to identify risk factors and symptoms of glucose fluctuations that may occur only in the natural environment of the individual. For example, work- or childcare-related distractions may be risk factors of reduced or delayed hypoglycemic awareness that would not be identified in a typical laboratory study. Similarly, glucose-related changes in social interaction patterns would be difficult to identify in the laboratory setting.

Laboratory Studies

For the typical laboratory study (e.g., Jones et al., 1997; Maran et al., 1995; Ovalle et al., 1998), participants with diabetes usually spend the evening and night before the experiment in hospital. With the use of intravenous insulin- and glucose-infusion and arterialized blood sampling, researchers monitor and control the participants' glucose levels to ensure that each participant has not experienced abnormal glucose levels prior to the initiation of the experiment. This ensures that each participant begins the study with controllable and comparable glucose levels. In order to manipulate glucose levels, the relative rate of glucose infusion is systematically increased to increase glucose levels, and the relative rate of insulin infusion is increased to decrease glucose levels.

These glucose level manipulations are often executed in stages, and once a given glucose stage is reached, it is maintained for a pre-determined amount of time ranging from 10 minutes to 2 hours. During each glucose stage, participants are typically asked to rate how much they are experiencing various symptoms (e.g., weakness, cheerfulness, or annoyance), to perform various cognitive tasks, and to estimate their glucose levels. At each of these glucose stages, the arterial blood is sampled to assess the actual glucose level. At the same time, a variety of the participants' underlying physiological responses, such as epinephrine, norepinephrine, cortisol, and pancreatic polypeptides, are measured.

Field Studies

The typical field study is a short-term longitudinal study. Individuals rate their current symptoms or moods, provide a subjective estimate of their current glucose level, and then record their actual glucose level (e.g., Cox et al., 1993; Freund, Johnson, Rosenbloom, Alexander, & Hansen, 1986). With the introduction and use of hand-held personal computing devices, researchers also have had participants perform brief cognitive tasks prior to each glucose estimate and measurement (Cox, Donner et al., 1999). In order

to collect a sufficient number and range of hyper- and hypoglycemic episodes, participants usually perform at least 40 trials and often more. Current diabetes treatment practices often require individuals to test their glucose levels 3 or more times a day. However, to avoid assessment trials too closely related to each other, researchers typically require that no more than 5 glucose estimates per day be used. Therefore, data collection usually lasts from 2- to 4-weeks per participant in these field studies.

Blood Glucose-Related Symptoms

A central focus of this study is on how glucose levels affect adolescents' moods and social behaviours. Little systematic empirical research is available on glucose-related changes in social behaviours. Fortunately, more data is available on glucose-related effects on moods. Relevant data comes from a variety of sources, laboratory studies, surveys, and field studies. Participants of various ages have been studied, but the majority of data have been collected from adult samples. A number of basic findings and empirical gaps are identified in the review that follows.

Clinical Manifestations of Glucose Abnormalities

Clinical observations, interviews, and surveys have identified a fairly large catalogue of glucose-related symptoms (e.g., Goldgewicht, Slama, Papoz, & Tchobroutsky, 1983; Gonder-Frederick et al., 1989; Hamera et al., 1988; Hepburn, Deary, & Frier, 1992). Table 1 contains a fairly representative sampling of these symptoms compiled from various symptom checklists (Eastman, Johnson, Silverstein, Spillar, & McCallum, 1983; Gonder-Frederick et al., 1989; O'Connell, Hamera, Schorfheide, & Guthrie, 1990; McCrimmon, Kelnar, Gold, Frier, & Deary, 1995b; Pennebaker et al., 1981). This list reflects an aggregation of symptoms reported or observed from various samples of people with diabetes. Each of these symptoms is certainly not experienced each time an individual becomes hypoglycemic or hyperglycemic, rather this represents the

range of symptoms that have been reported by individuals during some of their abnormal glucose fluctuations.

Table 1. *Frequently Examined Symptoms of Blood Glucose Fluctuations*

Physical Symptoms		Psychological Symptoms	
hunger	generally hot or cold	dejected	comfortable
sweating	cold or hot hands	sad or depressed	contented
tremors	increased salivation	afraid or worried	calm, relaxed, & peaceful
dizziness	breathing heavier	nervous-anxious	safe & secure
weakness	palpitations	upset	confident
fatigue	heart pounding	angry	cheerful
sleepiness	blushing	irritable	happy
increased thirst	heartburn	frustrated-annoyed	trouble concentrating
frequent urination	nausea	argumentative	trouble talking
dryness of skin	blurred vision	naughty	reduced orientation
headache	double vision	tense or jittery	nightmares
		energetic or alert	

Note. List of symptom checklist sources: Cox et al., 1985a; Clark & Renfert 1985; Eastman et al., 1983; Freund et al., 1986; Gonder-Frederick et al., 1989; Gonder-Frederick, Snyder & Clarke, 1991; McCrimmon et al., 1995b; Moses & Bradley, 1985; Nurick & Johnson, 1991; Pennebaker et al.,1981.

Many glucose-symptom relation studies have been dominated by physical symptoms with only a few cognitive- or mood-related items included in the symptom checklists (e.g., Boyle et al., 1988; Deary et al., 1993; Freund et al.,1986; Meltzer et al., 2003; Pennebaker et al., 1981; Wiebe et al., 1994). The earliest surveys (Goldgewicht et al., 1983) and field studies (Eastman et al., 1983; Pennebaker et al., 1981) focussed almost exclusively on the physical consequences of diabetes. This focus is understandable in light of the medical nature of diabetes. Systematic studies of glucose-related changes in cognition and mood emerged later (Gonder-Frederick et al., 1989; Weinger et al., 1995), whereas studies of social-behavioural consequences are still rare (see review by Gonder-Frederick et al., 1997).

Empirical Studies Emphasize Hypoglycemic Symptoms

Among the studies of glucose-related symptoms, hypoglycemia generally has shown more reliable symptoms than hyperglycemia. Physical symptoms and cognitive deficits are very reliable consequences of hypoglycemia-induction lab studies (e.g., Boyle et al., 1988; Draelos et al., 1995; George et al., 1995; Hepburn et al., 1991; McCrimmon et al., 2003; Mokan et al., 1994; Weinger et al., 1995; Widom & Simonson, 1992). Hypoglycemia-related changes in moods also are well-established laboratory findings (Hepburn et al., 1991; McCrimmon et al., 1995a; Weinger et al., 1995). In fact, some researchers have used hypoglycemia-induction procedures as a method of investigating the psychometric structure of moods themselves among healthy adults and adults with diabetes (e.g., Gold et al., 1995; Hepburn, Deary, Munoz, & Frier, 1995).

For example, in one laboratory study (McCrimmon et al., 1995a), 16 healthy adults completed two sets of ratings, once when they were euglycemic (5.0 mmol/L) and once when they were hypoglycemic (2.6 mmol/L). Hypoglycemia was associated with reduced happiness, more tension and anger, as well as a greater sense of threat and loss when thinking about the future. In another laboratory study (Gschwend et al., 1995; Weinger et al., 1995), during one visit, glucose levels were lowered from 8.9 mmol/L to 5.6 mmol/L, and then to 2.2 mmol/L. Unlike many of the other laboratory studies, this study utilized an extensive 19-item list of potential glucose-related changes in moods. At each glucose level, individuals rated their moods and physical symptoms, and researchers assessed the participants' cognitive performance. Reliable physical, cognitive, and mood-related changes were observed during reduced glucose. Such experimental studies provide quite strong evidence for a meaningful linkage between hypoglycemia and changes in individuals' physical symptoms, cognitive functioning, and emotions or moods.

Factor analytic studies of these laboratory-based, hypoglycemia-induction studies have identified two main physiologically-based symptom factors. Some of the symptoms can be attributed to an autonomic or counter-regulatory hormonal response, and other symptoms can be attributed to a neuroglycopenic or glucose-related brain-function response (see Cryer, 1997 for details). The laboratory setting, however, necessarily restricts the type of emotional and social behaviours that can be examined. Except for anecdotal reports of atypical, odd social behaviours, such as flirtatiousness or aggressiveness during low-glucose induction-procedures (Gonder-Frederick et al., 1997), participants generally do not recognize or engage in enough "odd behaviour" for it to emerge as a reliable symptom (Hepburn et al., 1991). Hepburn et al. (1992) suggested that the more restricted setting of the laboratory may have limited the expression or detection of certain symptoms.

Symptom Surveys of Hypoglycemia

Interviews or surveys avoid the overly restricted sampling environment of the laboratory. Indeed, in large sample surveys of individuals with Type 1 diabetes "odd behaviour" is identified as a reliable symptom of hypoglycemia (Hepburn et al., 1992). Larger scale, more inclusive survey studies of adults with Type 1 diabetes have identified an additional hypoglycemic symptom factor (Deary et al., 1993; Hepburn et al., 1992). As with the laboratory studies, both autonomic (e.g., sweating, shaking) and neuroglycopenic (e.g., confusion, physical incoordination) symptoms emerge as reliable factors. A third factor that emerges is a general malaise factor representing symptoms such as headache and nausea.

Behavioural disturbances. Survey studies of children's and adolescents' symptoms of hypoglycemia have resulted in a somewhat different factor structure. In a sample of 101 families, parents and children with diabetes (M = 11 years, range of 5 - 17) were separately

and simultaneously interviewed about hypoglycemia-related symptoms (Ross et al., 1998). For children, an additional behavioural disturbance factor emerged that reflected increases in irritable, naughty, aggressive, argumentative, and odd behaviour during hypoglycemia (McCrimmon et al., 1995b; Ross et al., 1998). Therefore, the factor structure of the children's low glucose symptoms consisted of autonomic / neuroglycopenic, behavioural disturbance, and general malaise factors (Ross et al., 1998). Factor analyses of the parents' ratings of their children's symptoms resulted in a slightly different factor structure of neuroglycopenic, autonomic, and behavioural disturbance factors (Ross et al., 1998). Note that children, unlike their parents, did not appear to discriminate between autonomic and neuroglycopenic symptoms of their low glucose episodes.

Although naughtiness is clearly a child-specific reference, other behavioural disturbance symptoms may be evident among older samples. Researchers have offered a couple of different suggestions to explain why a behavioural disturbance factor does not emerge among adult ratings of hypoglycemia-related symptoms. Adults may show little behavioural disturbance because they have learned to suppress overt behavioural symptoms of hypoglycemia (Gold et al., 1997). As well, behavioural symptoms of hypoglycemia may only emerge at the more extreme levels of hypoglycemia among adults (Ross et al., 1998). Therefore, the behavioural symptoms are too rare to emerge as a reliable hypoglycemia-related factor. Another suggestion has been that methodological limitations may account for this empirical difference. More specifically, "[b]ehavioural aspects [or items] of adult hypoglycemic responses may have been under-represented in previous questionnaire-based studies" (p. 842, Ross et al., 1998; Gold et al., 1997).

Although children may be less likely to suppress hypoglycemia-related behavioural disturbances, non-factor analytic evidence suggests that adults also show hypoglycemia-related behavioural disturbances. A survey of marital couples found that partners (e.g., wife or husband) reported increased aggressiveness during their partners' hypoglycemic

episodes (Everett & Kerr, 1995 cited in Gonder-Frederick et al., 1997). Such social-behavioural evidence, however, is quite limited (see review by Gonder-Frederick et al., 1997).

Person-Specific Glucose Effects

Except for social-behavioural evidence, the consequences of hypoglycemia presented so far appear very robust. We might expect that the expression of hypoglycemia-related symptoms is quite consistent across individuals. Empirically, however, specific hypoglycemia-related changes in physical symptoms, cognitive performance, and moods are quite variable from person-to-person (Gonder-Frederick et al., 1997; Gonder-Frederick, Cox, Driesen, Ryan, & Clarke, 1994). For example, in the interview of parents and their children with diabetes (McCrimmon et al., 1995b), some symptoms have been frequently cited by parents (e.g., pallor - 88%, sweating - 77%, tearfulness - 74%, and irritability - 73%), while other potential symptoms have been cited far less often (e.g., blurred vision: 19%, nightmares: 20%, nausea: 33%; naughtiness: 40%, dizziness: 51%). Variability in hypoglycemic symptom ratings also has been evident during hypoglycemic-induction laboratory studies (Gonder-Frederick et al., 1994; Hepburn et al., 1991). Individuals report some symptoms more consistently than others (Gonder-Frederick et al., 1997).

As noted earlier, some of the variability in symptom-glucose relations may be due to variability in the functioning of individuals' physiological counter-regulatory responses. Counter-regulatory responses to glucose level have been shown to change as a function of prior physiological experiences and circumstances. An earlier hypoglycemic episode will impair a later counter-regulatory response. For example, individuals who have temporarily lost the typical counter-regulatory bodily response of releasing epinephrine in response to hypoglycemia will not produce those symptoms typically associated with epinephrine

release (e.g., shakiness, pounding heart, or nervousness) during a later hypoglycemic episode (Heller & Cryer, 1991). Physiological conditions alone could lead to variability in hypoglycemic-related symptoms both within and across individuals with diabetes.

Field-study data also show that hypoglycemia-related symptoms and moods are quite person-specific (see review by Gonder-Frederick et al., 1997). Furthermore, the person-specific nature of glucose-related symptomatology has meant that many symptoms are not reliably classifiable as clearly due to either high-glucose levels or low glucose levels (Cox et al., 1985a). Both hypoglycemia- and hyperglycemia-related symptoms were highly idiosyncratic (Cox et al., 1985a; Freund et al., 1986; Gonder-Frederick et al., 1989; Meltzer et al., 2003; Nurick & Johnson, 1991; Pennebaker et al., 1981; Wiebe et al., 1994). A given symptom may occur during hypoglycemia for one individual, but occur during hyperglycemia for another individual. As one pediatric researcher observed, "[f]luctuating BG [blood glucose] can affect behavior and both very high and very low levels may present similar signs and symptoms which the children themselves can find confusing, [such as] headaches, aggression" (Strang, 1994, p. 460). Evidence that some of the same symptoms can arise from either hypoglycemia or hyperglycemia comes from one of the earliest field studies. In this study, nine of the 19 symptoms assessed were associated with both high and low glucose levels, although not necessarily within the same individuals (Pennebaker et al., 1981).

Researchers also used these field studies to estimate the number of symptoms that individuals typically experience during glucose fluctuations. A sampling of such estimates are presented in Table 2. A symptom was considered reliably associated with glucose levels if symptom ratings correlated with glucose levels. *Correlated* was defined as reliable if it was significant at a given alpha level, such as $p \leq .05$, or if it exceeded a given effect size, such as r's $\geq \pm .30$ (see Table 2 for study specific criteria). Positive correlations indicated that the symptom arose during higher glucose levels, while a negative correlation

indicated that the symptom arose during lower glucose levels.

Symptoms per person. As shown in Table 2, individuals tended to experience three or more symptoms during glucose fluctuations. However, while some individuals' experienced and identified numerous glucose-related symptoms, others only reported a few reliable symptoms. Still others were unable to identify any reliable glucose-related symptoms (Freund et al., 1986; Wiebe et al., 1994). Among those individuals who did reliably experience and identify glucose-related symptoms, the number of symptoms per person has ranged from as few as 1 to as many as 16 (Gonder-Frederick et al., 1989).

With the exception of Studies 8 and 9, the symptom lists used in these field studies were largely composed of physical symptoms. In field studies 8 and 9, the symptom list used by Gonder-Frederick et al. (1989, Study 8) consisted of 14 mood-related items out of 28, while the symptom list used by Moses and Bradley's (1985, Study 9) was composed almost exclusively of mood adjectives. Twenty-six (75%) of the 34 adult participants in Gonder-Frederick et al.'s (1989) study experienced glucose-related changes in mood ratings. Twelve (70%) of the 17 adult participants in the Moses and Bradley (1985) study exhibited significant glucose-related changes in mood ratings. The mean number of significant glucose-related mood changes was 2.3 per participant in the Gonder-Frederick et al. (1989) study, and 2.4 per participant in the Moses and Bradley (1985) study. The mean number of glucose-related changes in mood appears similar to the mean number of glucose-related changes in physical symptoms.

Table 2. *Number of Glucose-Related Symptoms in Individual with Type 1 Diabetes*

	Participants with diabetes		Measurement traits		# of Symptoms	
Study[a]	*N*	Age (Range)	Statistical Cutoff[b]	*M* # of Tests	*M* (Range)	# of items
1	25	[c](12-15)	$r \geq \pm.30$	44	3 (°)	23
2	6	14 (12-17)	$p < .05$	87	3 (0-6)	24
3	78	14 (11-19)	$r \geq \pm.30$	169	~1 (°)	23
4	35	16 (°)	$p < .05$	40	3 (°)	18
5	7	22 (18-33)	$p < .05$	93	6 (1-9)	24
6	30	32 (15-65)	$r \geq \pm.40$	50	3 (°)	19
7	26	35 (16-64)	$r \geq \pm.31$	40	3 (1 to 16)	10
8	33	38 (19-68)	$r \geq \pm.30$	40	5.5 [c]	28
9	17	~35 (23-49)	$p < .025$	35-42	2.4 [c]	30

Note. M # of tests refers to the mean number of glucose-symptoms trials completed. # of items refers to the number of symptoms assessed.

[a] 1. Freund et al., 1986; 2. Nurick & Johnson, 1991; 3. Meltzer et al., 2003; 4.Wiebe et al., 1994; 5. Nurick & Johnson, 1991; 6. Pennebaker et al., 1981; 7. Gonder-Frederick, Cox, Pennebaker, & Bobbitt, 1986: Times 1, 2, & 3; 8. Gonder-Frederick et al., 1989; 9. Moses & Bradley, 1985.

[b] Some studies defined a symptom of glucose using a minimum absolute correlation magnitude. Other studies used a significance test and a given p-value. Some studies used both criteria, but I have only reported the correlation magnitude cutoff for those.

[c] Mean or range not available.

As with the laboratory studies, among the more physically-oriented symptom studies, reliable symptoms of hypoglycemia were much more common than were symptoms of hyperglycemia (Freund et al., 1986; Gonder-Frederick et al., 1986; Nurick & Johnson, 1991; Pennebaker at al., 1981). The more mood-oriented field studies (8 and 9), however, suggest that hyperglycemia is not as asymptomatic as it appears.

Hyperglycemic Symptoms Highlighted

Glucose-related changes in mood do not appear exclusively related to low glucose levels. Mood-related changes were associated with high-glucose levels almost as often as they were with low glucose levels in the Moses and Bradley (1985) study. In the Gonder-Frederick et al. (1989) study, the number of mood-related symptoms experienced during hyperglycemia ($n = 47$) was higher than the number of mood-related symptoms during hypoglycemia ($n = 24$) across all participants.

Gonder-Frederick et al. (1989) also tested whether or not the valence of the mood items (positive or negative) correlated differentially with high or low glucose levels. Some reliable patterns emerged. Low-blood glucose tended to correlate with negative moods, and high glucose tended to correlate with positive moods. Although as Gonder-Frederick et al. pointed out, "high BG was related to positive mood states for some people and to negative mood states for others . . ." (p. 56). Only 6 of the 26 participants experienced both positive and negative moods during low (or high) glucose level.

A lab fly in the ointment. The commonly reported changes in moods during hyperglycemia, however, were not supported in a recent laboratory study (Weinger et al., 1995). In one part of the study of individuals with Type 1 diabetes, glucose levels were raised from 8.9 mmol/L to 14.4 mmol/L. At each glucose level, individuals rated their physical symptoms and 19 moods. Researchers then assessed the participants' cognitive performance. No reliable changes were observed in moods during elevated glucose levels. Similar null effects were found for cognitive and physical symptoms (see Gschwend et al., 1995).

A critique and counter-interpretation. The laboratory protocols of the studies above may have unintentionally limited the researchers' ability to identify physical and behavioural symptoms of hyperglycemia. In the study above, hyperglycemia was induced

through the infusion of excessive levels of glucose; participants' glucose levels were elevated and maintained at different levels of hyperglycemia experimentally (Gschwend et al., 1995; Weinger et al., 1995). The individuals had been receiving a continuous supply of insulin, and additional insulin was needed to induce hyperglycemia. This implies that insulin-mediated glucose metabolism was functioning. As well, hypoglycemia is commonly associated with subsequent insulin resistance, but earlier episodes of hypoglycemia had been strictly avoided prior to the beginning of the experiment. Therefore, it was likely that hyperglycemia was due to insulin deficiency not insulin insensitivity. If, as suggested earlier, the more behaviourally symptomatic form of hyperglycemia is associated with insulin insensitivity, then typical hyperglycemic induction procedures may not provide an effective test of hyperglycemic influences. Thus, the failure to find mood and physical symptoms of hyperglycemia may reflect methodological limitations.

Contextual Triggers

There may be another more general explanation for the difficulty in finding hyperglycemic-related influences on moods and social behaviours in the laboratory. Hyperglycemia may represent a general form of arousal[5] similar to physical exertion. Physical exercise, as a form of physiological arousal, has been shown to amplify either positive or negative reactions in participants, depending upon the contextual triggers (e.g., Foster et al., 1998). So, specific contextual or situational factors may largely determine if, and how, glucose levels effect individual psychological responses. The laboratory settings were probably relatively emotion-free, and so lacked emotional or contextual triggers. Thus, the participants' hyperglycemia-related arousal may have remained relatively unfocussed.

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[5] Based upon anecdotal reports, I suspect that if there is any inherent valence in hyperglycemia-related arousal it would tend to be negative.

Replicate and Extend

In this research project, to avoid the contextual limitations of laboratory studies and to utilize natural contextual triggers in the assessment of hyperglycemic effects on moods and social interactions, a field study design was used. Specifically, the dissertation assessed how glucose levels related to the social interactions and moods of adolescents as they went about their normal daily activities. Previous adolescent field studies assessed only a few mood items (i.e., Freund et al., 1986; Meltzer et al., 2003; Wiebe et al., 1994). To provide a more sensitive and reliable assessment, a broader list of moods was included in the current field-study checklist. Similar evidence of glucose-mood relations found in two early adult field studies (Gonder-Frederick et al., 1989; Moses & Bradley, 1985) was expected in the current sample of adolescents with Type 1 diabetes.

The self-reported quality of adolescents' social interactions also was examined in the current project. If contextual cues are important triggers for the expression of glucose-related arousal-effects, then those effects may be more evident during social interactions. A social interaction is typically ripe with emotional cues. As well, adolescents may be less reticent to acknowledge the occurrence of negative social interactions than negative moods. Individuals do tend to report fewer negative moods than positive moods (Watson, Weise, Vaidya, & Tellegen, 1999). Adolescents may be more willing to report negative social interactions than negative moods because social interactions may be viewed as less reflective of personal difficulties or failings. If glucose levels are associated with the quality of social interactions among adolescents with diabetes, the results will provide the first systematic evidence of such a relation.

Subjective Perceptions of Glucose-Related Effects

As arousal models suggest (e.g., Allen et al., 1989; Cacioppo et al., 1996; Zillman, 1984), a failure to recognize that certain actions or feelings are being altered by current

glucose levels will affect not only the individuals' interpretation of their own actions, but also how they interpret the actions and attitudes of those around them. Therefore, assessing the perception of glucose-related changes in behaviour is essential to fully understand the psychological impact of glucose-related effects. Subjective perception or awareness of glucose-related effects is dependent upon three factors: awareness of one's current glucose levels, awareness of one's current behaviours or social interactions, and awareness that these two factors are linked (Cox et al., 1993). In the following section, some conceptual and practical issues associated with awareness of glucose-related effects are discussed. In particular, those factors that affect recognition of behavioural changes in one's physical or behavioural status are highlighted, as are those factors that affect the recognition that the change is linked to glucose fluctuations. A review of findings on glucose estimation accuracy and symptom belief accuracy follows. Glucose estimation accuracy represents awareness of one's current glucose level, the first basic component of being aware of a glucose-related effect. Symptom belief accuracy represents to what extent people are aware of how glucose levels influence their symptoms, moods, or behaviours.

Awareness and Interpretation

A host of psychological and environmental factors can affect the recognition and interpretation of glucose-related influences (Cox et al., 1993)[6]. Many reasons can account for the failure to recognize that ones' glucose fluctuations are influencing, or are influenced by, one's symptoms, moods, or behaviours. Most of the reasons can be categorized either as factors contributing to the failure to detect the changes or as factors

[6] This section is largely based upon Cox et al.'s (1993) review of hypoglycemic symptom awareness. I believe it applies equally well to hyperglycemic awareness issues.

contributing to the failure to recognize the link between symptoms or moods and changes in glucose levels (Cox et al., 1993).

Symptom detection. Symptom detection depends, in part, upon the salience of the symptom or the change in behaviour (Cox et al., 1993). A more severe glucose fluctuation may result in a very intense or strong symptom, which should be more salient and easier to recognize. Symptom detection, however, is dependent upon more than the intensity of the symptom itself. A symptom of the same intensity might be detected on one occasion, but go undetected the next occasion because of differences in attention processes (Pennebaker, 1982). For example, normally noticeable changes in one's physical, cognitive, or psychological condition might go unnoticed while watching an attention demanding, highly exciting sporting event. On the other hand, during a quiet, somewhat boring lecture, attentional resources might be readily available to notice changes in one's physical condition.

Symptom interpretation. Individuals not only need to detect a change in their behaviour or condition, they also need to attribute that change as due to their current glucose level. To interpret a given change in physical, psychological, or social condition as a symptom of a current glucose level, individuals must understand that such a change is a plausible symptom of glucose fluctuation (Cox et al., 1993). An adolescent, for example, is unlikely to link a change in behaviour to a change in glucose level if that change is not considered plausibly related to their glucose fluctuations. Both detection and plausibility, however, are still not sufficient to ensure the proper identification and interpretation of a glucose-related change in behaviour.

Competing explanations. The same behaviour can be caused by many different circumstances (Cox et al., 1993; Kovatchev, Cox, Gonder-Frederick, Schlundt, & Clarke, 1998). A glucose fluctuation is only one of many plausible causes of changes in symptoms,

moods, and behaviours. A stressful encounter, a hot day, or a late night could explain pounding heart, sweatiness, or drowsiness, respectively. Any of these physical conditions also could be due to glucose fluctuations. Therefore, even if adolescents with diabetes recognize that they can become irritable or anxious during hypoglycemic episodes, they may interpret feelings of irritableness or anxiousness as due to some other cause, such as annoying peers. Consequently, a more salient, but inaccurate, competing explanation may be used rather than the subtler glucose-related explanation.

Circumstantial implausibility. Other circumstances or psychological issues also could interfere with the adolescent's ability to interpret accurately their changes in behaviour or condition (Cox et al., 1993). Recent food consumption might appear inconsistent with feelings of hypoglycemia and so make the attribution of hypoglycemic-related symptoms appear implausible. Similarly, hyperglycemic-related symptoms may not seem very plausible following an exercise workout. In sum, accurate symptom detection and interpretation is not a straightforward task, but, rather a complex psychological process mediated by a variety of physiological, cognitive, and situational factors (Leventhal, 1986; Pennebaker, 1982)

Blood-Glucose Estimation

As indicated earlier, awareness of current glucose levels is a basic prerequisite for recognizing the relation between glucose fluctuations and changes in feelings and behaviours. Glucose awareness has been investigated in various studies, and it is most often referred to as blood glucose estimation accuracy. Much of the impetus for examining glucose estimation accuracy studies seems driven by practical concerns rather than theoretical ones. The central practical benefit of accurate glucose estimation is being able to identify abnormal glucose fluctuations earlier. Early recognition of hypoglycemia and hyperglycemia allow individuals to treat current metabolic control problems and avoid

more serious metabolic problems. For the current research project, glucose estimation accuracy serves as a measure of glucose awareness.

Glucose-estimation accuracy. Data on the glucose estimation accuracy of individuals with Type 1 diabetes is presented in Tables 3 and 4.Table 3 represents general or overall glucose estimation accuracy, while Table 4 represents individual's accuracy in detecting low glucose levels. The data in Tables 3 and 4 come from 14 different samples of individuals with diabetes[7]. These glucose estimation accuracy estimates should be reasonably reliable as most of the estimates are based on 40 or more trials per person, typically collected over a 2- to 4-week period. Overall, accuracy levels are quite poor. After error rates are taken into account, glucose-estimation accuracy is around 50% (see Tables 3 and 4).

Careful examination of Tables 3 and 4 reveal several relevant findings. First, individual differences in glucose estimation accuracy are considerable (see Table 3). Individual accuracy estimates range from -30% for one parent of a child with diabetes to 82% for one adolescent with diabetes. A negative accuracy score indicates that the person is making more incorrect, dangerous estimation errors than correct estimates.

Secondly, clear age differences are evident in glucose estimation accuracy. Estimates of younger children's glucose levels, whether estimated by the parents of the children or the children themselves, are very poor (see Gonder-Frederick et al, 1991, Study 1 in Table 4). Indeed, 50% of parents and 67% of children produced more dangerously incorrect estimates than correct glucose estimates. On the other hand, adults and adolescents show at least some evidence of accurate glucose estimates some of the time.

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[7] Three estimation accuracy studies were excluded. Two studies were based on only a single BG estimation trial (Diamond, Massey, & Covey, 1989; Wing et al., 1984). The third study had only 3 participants (Roales-Nieto, 1988).

A third finding is that glucose estimation accuracy improves as the glucose levels become more extreme. This is illustrated in Study 1 of Table 4. Only 50% of participants recognized that they were hypoglycemic when their glucose levels were 3.3 mmol/L, but when glucose levels were 2.2 mmol/L, 85% of the participants recognized that they were hypoglycemic. Nonetheless, overall glucose estimation accuracy is not good, especially at less extreme, but still pathological levels. Individuals tend to overestimate their glucose levels when they are hypoglycemic and underestimate current glucose levels when they are hyperglycemic.

Table 3. *Field Studies of General Blood Glucose Estimation Accuracy by Age*

Study[a]	*N*	Age	Diabetes duration *M* (Range or *SD*)	# of Trials	Criteria	Accuracy % (Range)
1	19[b]	6.3	2.6 (3/4 to 5)	40	AI	6 (-30 to 58)
	12[c]	7.7	--	- -	- -	0 (-25 to 32)
2	25	~13.5	2.3 (½ to 13)	44	AD	3.8 (1.9 to 5.6)
	ibid	ibid	ibid	ibid	± 20%	55
3	78	14.1	6.0 (1.5 to 15)	169	AI	33%- 41%
4[d]	15	14.1	7.7 (1 to 13)	87	AI	18 (-5 to 48)
5	35	16	6.5 (*SD* = 3.6)	40	AI	38 (-7 to 82)
4[e]	7	23	3.5 (0.1 to 8)	93	AI	32 (-5 to 52)
6	39	33	12.2	40	AI	<45
7	9	34	15.6 (2 to 25)	10-46	AD	5 (2 to 10.7)
8	78	38	19.3 (*SD* = 10.4)	50	AI	20
9	11	41	17.6 (*SD* = 4)	50-80	AI	26
10	36	44	10.3 (2 to 50)	40+	AI	<45

Note: Age is in years. Diabetes duration is in years. # of items refers to the number of glucose estimation trials assessed. Criteria refers to which of the glucose-estimation accuracy measures were used. AI is the Accuracy Index based on the Error Grid Analysis. AD is the absolute deviation in glucose estimates in mmol/L. The ± 20% criteria is the percent of guesses with 20% of the actual glucose level. Glucose estimates are based upon means for all participants, even if the original authors preferred to focus and compare on subgroups of participants. For those studies in which an intervention was used, the above data are based on pre-intervention, baseline measures.

[a] 1. Gonder-Frederick et al., 1991; 2. Freund et al., 1986; 3. Meltzer et al., 2003; 4. Nurick & Johnson, 1991; 5. Wiebe et al., 1994; 6. Cox et al., 1991; 7. Gross, Magalnick, & Delcher, 1985; 8. Cox, Gonder-Frederick, Polonsky et al., 1995 & Clarke, Cox, Gonder-Frederick et al., 1995, 9. Cox et al., 1994, long-term follow-up, control participants only, 10. Cox, Carter, Gonder-Frederick, Clarke, & Pohl, 1988 & Cox et al., 1985b.

[b] Parent estimates for child;

[c] Child self estimates;

[d] Adolescent sample,

[e] Adult sample

Table 4. *Field Studies of Blood Glucose Estimation Accuracy during Hypoglycemia*

Study[a]	*N*	Age	Diabetes duration *M* (Range or *SD*)	# of Trials	% of participants detecting their low BG level (mmol/L)
1	47	34	9 (3 to 15)	70	low BG of < 3.3 detected: 50 low BG of < 2.8 detected: 73 low BG of < 2.2 detected: 85
2	93	36	17 (*SD* = 10.6)	70	low BG of < 3.9 detected: 47
3	27	adult	--	40-80	low BG of < 3.9 detected: 57
4	78	40	20.5 (*SD* = 10.3)	50-70	low BG of < 3.9 detected: 44
5	11	41	17.6 (*SD* = 4)	50-80	low BG of < 2.8 detected: 43

Note: Age is in years. Diabetes duration is in years. # of items refers to the number of glucose estimation trials assessed. % of participants detecting their low BG level refers to the percent of the sample that accurately recognized that they had low glucose levels at each glucose level. Glucose estimates are based upon means for all participants, even if the original authors preferred to focus and compare on subgroups of participants. For those studies in which an intervention was used, the above data are based on pre-intervention, baseline measures.

[a] 1. Kinsley et al., 1999; 2. Clarke, Cox, Gonder-Frederick, & Kovatchev, 1999b & Cox, Gonder-Frederick, Kovatchev et al., 1999a; 3. Cox et al., 1993; 4. Cox, Gonder-Frederick, Polonsky et al., 1995 & Clarke, Cox, Gonder-Frederick et al., 1995; 5. Cox, Gonder-Frederick, Julian, & Clarke, 1994, long-term follow-up, control participants only.

Glucose-estimation accuracy summary. A review of the glucose-estimation accuracy literature of individuals with Type 1 diabetes reveals several empirical findings. Most individual with diabetes make a high proportion of glucose estimation errors.[8] At more extreme glucose levels, glucose-estimation accuracy was better. Children were clearly less accurate than adolescents and adults at estimating their current glucose levels. And finally, individual differences in glucose-estimation accuracy were fairly large.

Glucose-estimation accuracy prediction. According to the *Transfer of Excitation* model, glucose-estimation accuracy, as a measure of glucose awareness, was expected to

[8] In response to this poor BG-estimation ability, a Blood Glucose Awareness Training (BGAT) program was developed to rectify this situation (see Appendix B for more details).

influence how glucose levels related to the moods and social interactions of adolescents in the current study. Specifically, glucose levels were expected to be more strongly related to moods and social interactions when glucose awareness was lower.

Symptom-Belief Studies

Symptom-belief accuracy studies provide another form of glucose-related awareness data. Symptom beliefs can be thought of as an outcome of symptom detection and symptom interpretation that are established over time. Establishing these symptom beliefs is partly a product of regularly testing one's blood glucose levels. If certain feelings, physical or emotional, continually co-occur with particular glucose levels (e.g., lows or highs), a person could recognize the relation and come to understand that these particular feelings are associated with these particular glucose levels. Similarly, false-symptom beliefs should be disproved empirically through regular glucose testing. As glucose-related symptoms can change over time (Gonder-Frederick et al., 1986), this system of regular glucose monitoring should also allow individuals to alter their symptom beliefs. Some evidence, however, suggests that once individuals form symptom beliefs they are resistant to change (Cox et al., 1993).

Symptom-belief accuracy estimates for hypoglycemia among insulin-dependent adolescents (Freund et al., 1986) were very similar to those of insulin-dependent adults (Cox et al., 1993; Diamond et al., 1989; Eastman et al., 1983; Gonder-Frederick et al., 1986). The average hypoglycemia *hit* rate (correct identification of a symptom) was 40 percent, a rate almost identical to that of the adults (Gonder-Frederick et al., 1986). Similarly, the adolescents' average *correct rejection* (correctly identifying a symptom as unrelated to glucose levels) percentage of 78% for low glucose levels was also equivalent to the adults' overall *correct rejection* rate (i.e., 75%). Considerable individual variation in symptom-belief accuracy also was evident for adolescents (Freund et al., 1986), as with

the adults with diabetes adults (Gonder-Frederick et al., 1986). After two weeks of glucose monitoring and symptom identification efforts, only 7 of the 23 adolescents had identified at least one reliable symptom of hypoglycemia (Freund et al., 1986).

Symptom-belief accuracy challenges. These previous symptom belief studies suggest that symptom awareness in adults and adolescents is far from ideal. As indicated earlier, accurate symptom identification requires proper symptom detection and interpretation. Symptom belief accuracy also requires identification of the underlying cause of a symptomatic response from among various competing explanations present in any given situation, and avoiding causal search misdirections because of apparent circumstantial implausibility of glucose effects. Given such requirements, the low levels of symptom belief accuracy are understandable.

Assessment barriers to symptom-belief accuracy. The assessment of symptom belief accuracy, however, is difficult because establishing a reliable glucose-symptom relation is, itself, very difficult logistically speaking. The occurrence rates for individual symptoms and their corresponding glucose aberrations is typically low. For example, assume that grouchiness is associated with high-glucose levels for a given adolescent. In order to statistically identify grouchiness as a reliable consequence of the adolescent's high glucose level, both high glucose episodes and grouchiness must co-occur frequently and distinctly enough to emerge as a reliable association. However, grouchiness sometimes occurs independent of high-glucose levels. Similarly, high glucose episodes will not always lead to grouchiness such as during celebrations where glucose-related exaggerations in mood tendencies would likely be positive in valence. Thus, over the course of a field study, identifying reliable behavioural correlates of glucose aberrations is empirically difficult. In the current study, symptom belief accuracy was not assessed due to limited reliability in individual-item analysis.

Symptom belief ratings, however, were used as a general measure of perceived glucose influence or awareness. A belief that glucose highs or lows influence one's physical symptoms or moods is a subjective indication of increased attention and awareness of glucose-related effects. Thus, symptom belief ratings were used as a general measure of subjective glucose awareness.

Glucose-Related Awareness Predictions

In this research project, two types of glucose-related awareness measures were assessed. Glucose estimation accuracy was assessed as a measure of glucose-related awareness. Perceptions of glucose-related influences was the other measure of glucose awareness. This awareness data was used to test whether or not awareness of glucose-related influences moderated how glucose levels related to participants' moods or social interactions. Based upon the *Transfer of Excitation* and *Arousal-Adjustment* models, higher awareness levels were expected to lead to weaker relations between aberrant glucose levels and moods or social interactions, while lower awareness levels were expected to result in stronger relations between glucose and moods or social interactions. Glucose awareness was not expected to affect glucose-psychological outcome relations under the *Response Facilitation* model or the *Negative-Bias Arousal* model.

Methodological Considerations

To test study hypotheses, the glucose levels, moods, social interaction ratings, and perceptions of glucose-related effects among a sample of adolescents with diabetes were assessed. Several methodological issues need comment. Firstly, I used a short-term, longitudinal field-study design. Secondly, adolescents provided ratings 2 to 4 times per day for a three-week period. Thirdly, data were gathered with handheld computers rather than paper-and-pencil recordings. Fourthly, the mood and social interaction items assessed were empirically or logically derived rather than based upon a pre-existing mood or social

interaction rating scales. Finally, a dualistic model hyperglycemia was used to examine hyperglycemia-related psychological effects. Each of these issues are addressed in turn.

A Field-Study Design

Of the three research designs typically used to study glucose-related physical or psychological changes, laboratory, surveys, and field studies, the field study is the most suitable for this project. In the laboratory setting, social interactions, and even moods, are unnaturally constrained. The drawback to using a survey is that the results depend upon the accuracy of participants' recollection and their subjective recognition that their glucose levels were actually associated with a change in their physical symptoms, moods, or social interactions. The field study approach, however, is not so dependent upon recollection or subjective awareness, nor does it constrain the types of moods and social interactions participants are likely to experience. Furthermore, previous research has shown that glucose-symptom and glucose-mood relations tend to be relatively idiosyncratic, making a within-participant research design most appropriate.

Field studies of glucose-related changes in symptoms, moods, and behaviours utilize real-time *in situ* symptom ratings and glucose measures somewhat similar to the *Experience Sampling Method* other researchers have successfully used with older children and adolescents (Csikszentmihalyi & Larson, 1987; Larson, 1989). In glucose-related field studies, participants are asked to rate their *current* symptoms, moods, and/or recent social behaviours and measure and record their current glucose levels multiple times per day. Statistical techniques then are used to identify those symptoms, moods, or behaviours that covary with the participants' glucose levels.

This type of repeated-measures field study allows an assessment of a broad range of symptoms, moods, and behaviours as potential consequences (or causes) of aberrant glucose fluctuations. As well, any relations identified have an inherent ecological validity.

This data-collection procedure also enables the collection of a relatively large number of repeated observations (e.g., Whalen, Jamner, Henker, Delfino, & Lozano, 2002).

Computer-based data collection. The use of a compact, electronic diary, or computer-based recording device brings with it a number of advantages. Each data entry is date-time stamped, unlike paper-and-pencil data collection methods. This temporal data can then be used to check how well adolescents are following data-collection sequence instructions (i.e., estimating their glucose levels before testing them). Once entered, the data is secure and cannot be read or modified by the participant or other individuals. Finally, a recent study reported that adolescents learned how to use these devices quickly and with no difficulty (Whalen et al., 2002).

Item Selection

Empirical-logical criteria was used to select the moods and social-interaction items to be rated by the adolescents. An initial pool of social-behavioural examples was extracted from anecdotal reports (Gonder-Frederick et al., 1997) and from previously used psychologically-oriented symptom checklists (Gonder-Frederick et al., 1989; McCrimmon et al., 1995b; Ross et al., 1998; Weinger et al., 1995). From this pool of items, further selection was based upon: 1) items that a reasonable number of participants had previously endorsed, 2) physical symptoms of both hypoglycemia and hyperglycemia, and, 3) an approximately equal number of positive and negative psychological items.

Moods. Discrete mood items are meant to represent specific feeling states, which can be combined for reliability into a larger mood factor. This measurement approach reflects a well-developed and well-established, hierarchical mood assessment approach (see review by Watson & Clark, 1997).

Moods over emotions. From my perspective, glucose-related influences are more akin to moods than emotions. Emotions are generally considered short in duration and

intense, while moods are viewed as somewhat milder and longer lasting (Matthews, 1992; Thayer, 1989). Thayer's (1989) definition of mood parallels my view of how glucose levels are associated with or influence people's moods and behaviours. Thayer defined mood "as a tendency to act a particular way under certain circumstances" (p.15). Thayer (1989) also emphasized that mood does not control behaviour. Instead, mood increases the likelihood that certain mood-related behaviors will occur. This describes how blood glucose fluctuations were expected to relate to the moods and behaviours of adolescents with diabetes.

Hypoglycemia and Hyperglycemia Defined

The relations between glucose levels and moods and social interactions were evaluated separately for hypoglycemia and hyperglycemia because various physiological and empirical differences have been identified between these two aberrant glucose states. Hypoglycemia was defined as any glucose level less than 4.0 mmol/L and hyperglycemia as any glucose level greater than 9.9 mmol/L.

A new qualitative definition of hyperglycemia also was examined. That is, hyperglycemic episodes were classified as either due to relative insulin deficiency (excessive glucose intake), or due to insulin insensitivity (impaired insulin utilization). The classification was based upon the participants' beliefs about why they were currently hyperglycemic. Hyperglycemia was classified as due to excessive glucose intake if one of the following trial choices were selected: *had extra food or drinks*[9], *less activity or*

[9] Note, I have assumed that *extra* was interpreted as the consumption of more carbohydrates than planned for based on the amount of insulin administered. Adolescents are educated in the role and importance of carbohydrates in the management of their diabetes. Thus, I assumed that adolescents would recognize extra food or drink consumption as due either to 1) a larger total volume of food or drink intake or 2) the consumption of food or drinks that are more carbohydrate intensive than their regular meals.

exercise, forgot or delayed taking insulin. Hyperglycemia was classified as due to impaired insulin utilization if one of the following trial choices were selected: *high stress or high excitement, am sick (like a cold)*, or *not sure*. The relation between stress and poorer metabolic control is thought to be due to a link between stress and impaired insulin sensitivity (Aikens, Wallander, Bell, & Cole, 1992; Halford, Cuddily, & Mortimer, 1990). Common illnesses, for example, generally lead to greater insulin requirements independent of glucose intake. Impaired-insulin-utilization is thought to be associated with non-conventional causes of high-glucose levels, and so, the adolescents are more likely to be unsure why their current glucose levels are high.

General Research Hypotheses and Questions

Arousal-awareness assessment. In this study, I have adopted an arousal-related theoretical perspective on how glucose-related effects might influence the moods and social interactions of adolescents with Type 1 diabetes. Extreme glucose levels were expected to be associated with more extreme mood and social interaction ratings. Awareness of glucose-related effects were assessed as potential moderators of the glucose-behaviour relations. Greater levels of awareness were expected to lessen the relation between glucose levels and the moods and social interactions of the adolescents.

Systematic assessment of social interactions and moods. In the current study, the relation between adolescent's social interactions and their glucose levels were assessed. This previously unexamined relation was expected to provide a relatively sensitive assessment of the psychological effects of hyperglycemia. Social interactions may provide the contextual triggers needed to activate the latent arousal-based, reactivity associated with hyperglycemia. General anecdotal evidence suggests that high-glucose levels are more likely to be associated with negative, rather than positive, social interactions. However, systematic data is needed before any firm conclusions can be drawn. A broad sampling of

moods also was investigated, as little evidence is available on the relation between hyperglycemia and mood ratings among adolescents.

A dualistic model of hyperglycemic effects. A proposed, dualistic model of hyperglycemic effects also was examined. Hyperglycemia was conceptualized as either due to insulin insensitivity or to insulin deficiency. Insulin-insensitivity hyperglycemia (that due to impaired insulin utilization) was expected to be most psychologically symptomatic.

Covariates. In examining the various research questions, background characteristics of the participants were evaluated to determine if any of the resulting short-term glucose-related relations were moderated by demographic characteristics or diabetes-related characteristics. Specific details about these measures and the more central measures of interest are described next.

METHOD

The initial data-collection session included reviewing the purpose and procedures of the study, implementing informed consent procedures, gathering family and adolescent demographic and health-related information, and demonstrating how the handheld computers work. For the field-study component of data collection, adolescents completed symptom ratings, glucose estimations, and glucose measurements over a three-week period. Following completion of data collection, feedback was mailed to the adolescents and their families. Recruitment and data collection followed approval of the project by the Human Subject Research Review Ethics Board of the University of Manitoba.

Participant Eligibility and Recruitment

Exclusion criteria. Participation in this study was relatively cognitively demanding, requiring proficient reading ability, learning to use a personal handheld computer, and the ability to provide relatively subtle subjective ratings. Therefore, children less than 12 years of age were not eligible to participate. Similarly, adolescents with cognitive impairments

(e.g., Downs Syndrome) were not eligible to participate. As well, adolescents using medications that are likely to exert a serious or variable influence on their moods or behaviours (e.g., psychotropic) were not eligible to participate. Other systemic illnesses (e.g., asthma), however, did not necessitate exclusion. A chronic illness with a mild, but constant influence on an adolescents' moods or behaviours would not effect the identification of within-person glucose-behaviour relations over time.

Inclusion criteria. Eligibility was restricted to those adolescents who had Type 1 Diabetes Mellitus for at least 6 months. After six months with diabetes, residual insulin production is minimal, the initial psychological disruption associated with the onset of the diabetes should have lessened, and adolescents have had time to adust to the day-to-day requirements of this very demanding disease. As a field study, a central aim of the study was to evaluate how glucose levels relate to adolescents' moods and behaviours in their natural day-to-day contexts. Therefore, no other exclusion or inclusion criteria were used.

Population size. In Manitoba, a general age-related increase in the prevalence rates of Type 1 diabetes is evident. On March 31, 1993, the prevalence rates were 21.0, 107.7, and 239.5 per 100,000 for the birth- to 4-year-olds, 5- to 9-year-olds, and 10- to 14-year-olds (Blanchard et al., 1997). From a practical recruitment perspective, the Diabetes Education Resource for Children and Adolescents (DER-CA) has a current case load of approximately 200 adolescents falling within the eligible age range of 12- to 17-years of age for this study. Of these adolescents, 97 lived in the city of Winnipeg and were eligible to participate.

Recruitment procedure. Recruitment letters were mailed to eligible families. As well, posters describing the study were posted in the DER-CA (see Appendix C for details). Initially, recruitment letters were mailed to adolescents living within the city. A second set of recruitment letters was mailed to families living outside the city within a 200

km radius from the city to recruit more participants. Family members telephoned to indicated their interest in participating. These families were given additional information, questioned to ensure that the adolescents were eligible, and, if the families were eligible and interested, a data collection appointment was scheduled. To facilitate recruitment and lower the participation drop-out rate, each adolescent was given three participation rewards over the course of the data-collection period. The rewards included two miniature golf passes, two bowling passes, and finally, a $10 movie certificate (see Appendix D for more details).

Sample Size

Sample size determination. In this study, data were sampled from two different hierarchical levels, adolescents and observations within adolescents. Sample size determination for this stratified sampling method required the usual sample size determination information of the Type I error rate, the desired statistical power ($1-\beta$), and the estimated effect sizes. It also required the estimation of the inter-correlations among the various predictors (variance / covariance matrices), the percent of variance explained in the outcome variable, how this outcome variance was distributed between observations within adolescents (occasions or Level 1) and between adolescents (Level 2), and the minimum number of observations per adolescent to be sampled for reliability or cost efficiency purposes (for details see Bosker, Snijders, & Guldemond, 1999; Snijders & Bosker, 1993). The specific statistical procedures and estimates used are presented in Appendix E. Sample-size determination calculations indicated that 20 adolescents who provided 45 sets of ratings would provide sufficient statistical power, with an 80% chance to detect the hypothesized relations between glucose levels, awareness of glucose-related effects, and moods and social interaction ratings.

The sample. Twenty adolescents participated in the study. Ten of them were female. The mean age of the participants was 14.3 years and ranged from 12- to 18-years of age. All participants were attending school and grade levels ranged from 6 to 12 (see Table 6 for other sample characteristics). The median number of observations per adolescent was 51, ranged from 28 to 83, and resulted in a total of 1028 observations.

Measures

Demographic and Diabetes-related Characteristics

One form was used to collect basic socioeconomic status information from a parent of the adolescent (see Appendix F) and another form was given to the adolescents themselves to determine the birthdate (and age), gender, current grade, how long they have had diabetes (age of onset), the frequency and type of insulin used, glucose testing frequency, and the glucose level they considered high in their daily management of diabetes (see Appendix G). A summary of this information is presented in Tables 5 and 6.

Glycosylated hemoglobin. With the permission of each adolescent and their parent (see Consent form under Appendix C), the staff at the DER-CA provided two A_{1C} estimates through medical chart audits, one A_{1C} prior to the start of the study and the next available one. A_{1C} values represent a person's average glucose values over the last 2 to 3 months. Glycosylated hemoglobin, "as a short-lived protein which is structurally altered by the attachment of glucose molecules . . . [is] a biological marker of hyperglycemia" (Cox & Gonder-Frederick, 1992, p. 628). Psychometrically, the A_{1C} is both a reliable and accurate measure of metabolic control (Nathan, Singer, Hurxthal, & Goodson, 1984).It is not appropriate for evaluating short-term blood glucose effects that are assumed to be precise and short-lived. Nonetheless, the A_{1C} does provide a reliable measure of the adolescents' general metabolic control, and it is very useful in characterizing the general metabolic control of the sample.

In addition to these basic background characteristics of the sample, the adolescents completed questionnaires on their attitudes and feelings associated with having Type I diabetes. Specifically, the adolescents completed the Diabetes Quality Of Life (Ingersoll & Marrero, 1991) and the Hypoglycemia Fear Survey surveys (Cox , Irvine, Gonder-Frederick, Nowacek, & Butterfield, 1987).

Diabetes Quality-of-Life: Youth scale. The Diabetes Quality of Life for Youths (DQOLY) questionnaire assesses the perceived impact of diabetes on one's life, diabetes-related worries, and diabetes treatment-related life satisfaction as well as general life satisfaction (Ingersoll & Marrero, 1991). There are a total of 52 items, 23 items for the Impact scale, 11 items for the Worries scale, and 17 items for the Life Satisfaction scale (see Appendix H). Items are scored on a 1- to 5-point Likert scale. For the Impact and Worries scales, items were rated on frequency in which a 1 reflects *never* and a 5 reflects *all the time*. The Life Satisfaction scale was rated on degree of satisfaction in which a 1 reflects *very dissatisfied* and a 5 reflects *very satisfied.* Summing the individual responses (assuming no missing items) leads to raw scores ranging from 23 to 115, 11 to 55, and 17 to 85, for the Impact, Worries, and Life Satisfaction, respectively.

DQOLY psychometrics. The psychometric properties of the modified DQOL for youth are reasonably good. In one sample of 74 older children and adolescents with diabetes, internal reliability estimates (Cronbach's alphas) were .83, .82, and .85 for Impact, Worries, and Life Satisfaction, respectively (Ingersoll & Marrero, 1991). In another sample of 69 adolescents with Type 1 diabetes, Cronbach's alphas were .88, .82, and .88 for the Impact, Worries, and Life Satisfaction scales, respectively (Guttmann-Bauman, Stugger, Flaherty, & McEvoy, 1998). The DQOLY questionnaire also appears to show evidence of construct validity in that it is significantly related to diabetes-specific

health status indicators[10] (metabolic control: Guttmann-Bauman et al., 1998; severe hypoglycemic problems: Marrero, Guare, Vandagriff, & Fineberg, 1997), other psychological and social functioning outcomes (Grey, Boland, Yu, Sullivan-Bolyai, & Tamborlane, 1998), and treatment interventions that improve both metabolic control and psychological well-being (Grey, Boland, Davidson, Li, & Tamborlane, 2000).

Hypoglycemic Fear Survey. The Hypoglycemic Fear Survey (HFS) was developed to assess individuals' behavioural and emotional responses to hypoglycemia (Cox , Irvine, et al., 1987). The HFS assesses "events precipitating fear, the phenomenological experiences of the fear response, behavioural reactions to hypoglycemia (both adaptive and maladaptive), and physiological outcomes" (Irvine, Cox, & Gonder-Frederick, 1994, p. 123). The HFS is made up of 23 individual items with 10 items representing behavioral consequences and 13 items representing fears or worries (see Appendix I). Each item is rated on a 1- to 5-point scale with 1 representing Never and 5 representing Always. Therefore, the behavioural scale scores could range from 10 to 50, the worries scale could range from 13 to 65, and the total fear of hypoglycemia score could range from 23 to 115. This survey has been used with a variety of samples, including people with Type 1 and II Diabetes Mellitus, and a variety of ages, from adolescence to old age, (see review by Irvine et al., 1994).

HFS reliability. Irvine et al. (1994) provided a review of the psychometric characteristics of the HFS based on seven different studies. Internal reliability for the Worry subscale was very good with Cronbach alphas of .89, .90, and .96 (see Irvine et al., 1994). The internal reliability for the Behaviour subscale was fair with alphas of .60, .69, and .84 (see Irvine et al., 1994). Test-retest correlations were reasonably good for both the

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[10] Although some studies have failed to find a relation between metabolic control (glycosylated hemoglobin) and the DQOLY (Grey et al., 1998; Ingersoll & Marrero, 1991).

Worry and Behaviour subscales: the test-retest correlations, over an interval of six weeks, were .76 and .59 for the Worry and Behaviour subscales, respectively. Over a three-month interval, test-retest correlations were .64 and .68 for the Worry and Behaviour subscales, respectively.

HFS validity. Construct validity was evident in the significant relations between the Worry and Behaviour subscales with general measures of anxiety and fearfulness. In these same studies (see Irvine et al., 1994), some support for discriminant validity was found in the lack of (or lesser) relations between the HFS subscales and other constructs (e.g., anger / hostility). Validity for the HFS was also evident in the relations between Worry subscale scores and metabolic control measures and the number of hypoglycemic episodes. One of the studies in this review, includes a study of children and adolescents, 9 years and older (Green, Wysocki, & Reineck, 1990). The psychometric characteristics in this sample were similar to that found with adults. A more recent study also has used the HFS successfully with adolescents (Marrero et al., 1997). In this study, participants with a history of hypoglycemic-related loss of consciousness reported higher HFS scores. This evidence is consistent with the construct validity of the HFS.

The administration sequence of the HFS and DQOLY questionnaires was counterbalanced, with 10 participants completing the HFS prior to the DQOLY, and 10 participants completing the DQOLY prior to completing the HFS. Fear of hypoglycemia, DQOLY scores, the questionnaire administration sequences, and the various other characteristics of the adolescents were examined as potential covariates in the statistical models of mood and social interaction ratings.

Glucose Assessments

Glucose Measurement. Occasion-specific glucose level is the main predictor in the current study. Portable glucose monitoring devices, first introduced in the mid-1970's,

allow individuals to monitor their glucose levels in their natural context and make treatment adjustments based upon these glucose assessments (Skeie, Thue, Nerhus, & Sandberg, 2002). From a medical-device assessment perspective, the accuracy of glucose monitors is not ideal when compared with laboratory based glucose assessments (Poirier et al., 1998; Skeie et al., 2002). For example, in one recent study, only 86% of glucose assessments met suggested standards rather than the 95% expected (see Skeie et al., 2002).[11] Similarly, when using glucose laboratory assessments as the reference criteria, the accuracy of 5 different glucose monitors were 82%, 87%, 91%, 97%, and 100% with criteria based on being within ± 20% and identifying the same hypoglycemia episodes (Poirier et al., 1998). From a behavioural assessment perspective, the accuracy and precision of glucose monitors are quite sufficient (Clarke, Cox, Gonder-Frederick, Carter, & Pohl, 1987). Glucose levels as assessed by the glucose monitors are on a continuous scale from approximately 2 to 40 mmol/L.

Continuous glucose-level measures. In addition to examining raw glucose levels, other forms of continuous glucose levels were assessed as potential predictors of moods and social interactions. The mean of each adolescent's glucose was substracted from their raw glucose score (i.e., person-centred) to simplify the interpretation of regression parameters. I also created a normal-to-high glucose measure (excluding the low levels) and a low-to-normal glucose measure (excluding the high levels).These latter glucose measures avoid confounding low glucose effects with high glucose effects within the same analyses. Both of these glucose measures were adolescent median-centred.

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[11] The International Organization for Standardization (ISO) has suggested that 95% of glucose monitor assessments should fall within ±20% of laboratory tests or, when glucose levels are ≤ 4.2 mmol/L, ±.83 mmol/L of laboratory tests (see Skeie et al., , 2002).

Categorical glucose levels. Glucose-related effects may be threshhold-dependent. Therefore, glucose levels were also categorized. Hypoglycemia was defined as any glucose level less than 4.0 mmol/L. Normal glucose levels were defined as glucose levels greater than 3.9 mmol/l and less than 10.0 mmol/L. Hyperglycemia was defined as any glucose level greater than 9.9 mmol/L (Gonder-Frederick et al., 1989)[12]. Using these criteria, two dichotomous variables were created. The hypoglycemic dichotomous predictor was created with low glucose equal to 1 and normal equal glucose levels equal to 0, and the hyperglycemic dichotomous predictor reflected high glucose equal to 1 and normal glucose levels equal to 0.

Hyperglycemia follow-up questions. An alternative definition of hyperglycemia also was created. This definition is based upon the dualistic model of hyperglycemia which proposes that there are qualitatively different reasons for the presence of high-glucose levels. To assess this qualitative aspect of hyperglycemia, adolescents were asked to identify reasons they might be experiencing high-glucose levels (levels > 10 mmol/L). Specifically, they were asked to check off the most likely reason(s) from the list below: *forgot to take my insulin*, *delayed taking my insulin*, *ate extra food*, *overate due to an earlier low BG*, *did less exercise than expected*, *am sick* (like having a cold), *things have been stressful*, or *not sure*. Impaired insulin utilization (or insulin insensitivity) is thought to be associated with non-conventional causes of high-glucose levels, and so, the adolescents are more likely to be unsure why their glucose levels are high. This list was generated from previous reports on likely reasons for hyperglycemia, as well as from basic glucose management factors (e.g., Johnson, 1980, 1995).

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[12] Alternative, more extreme definitions of dichotomous hyperglycemia were assessed, but they did not provide any new information over-and-above that found with the typical hyperglycemia definition used throughout the current study.

Qualitative hyperglycemia defined. The alternative, semi-qualitative definition of hyperglycemia was based upon the hypothesis that two types of hyperglycemia exist: 1) that due to excessive-glucose intake or relative insulin deficiency, and 2) that due to impaired insulin-utilization or insulin insensitivity. Excessive glucose intake was inferred if any of the following reasons for the presence of high glucose level were selected on any given trial: *forgot to take my insulin, delayed taking my insulin, ate extra food, overate due to an earlier low BG, or did less exercise than expected.* Impaired insulin-utilization was inferred if the reasons selected included *am sick* (like having a cold), *things have been stressful*, or *not sure*. A mixed type of hyperglycemia also was defined as high-glucose levels in which adolescents reported at least one excessive-glucose intake reason and one impaired-utilization reason. Three dichotomous hyperglycemia variables also were created: 1) to represent impaired insulin utilization hyperglycemia (= 1) versus normal glucose level (= 0), 2) to represent excessive-glucose hyperglycemia (= 1) versus normal glucose level (= 0), and 3) to represent a mixed set of reasons (= 1) versus normal glucose level (= 0).

Blood-Glucose Estimation Accuracy

Two types of glucose estimation accuracy were calculated: occasion-specific and adolescent-specific. Each of these measures was assumed to reflect some form of psychological awareness of glucose-related influences on their behaviours, feelings, or cognitions. From the multilevel analysis perspective, the occasion-specific measure was a Level 1 predictor, and the adolescent-specific measure was a Level 2 predictor.

Occasion-specific glucose-estimation accuracy. Occasion-specific blood glucose estimation accuracy was based upon two types of accuracy measures, continuous and categorical. The continuous estimation accuracy measures were based upon the similarity between the adolescent's numerical glucose guess and their actual numerical glucose level (in mmol/L)at each trial. For the numerical accuracy estimate, an absolute difference score

was calculated (absolute value of (estimate - actual)*100). This value measured the extent to which each estimate reflected a lack of glucose-level awareness. The categorical estimation accuracy measure was based upon the consistency between adolescent's categorical guess (low, normal, or high) during the trial and their actual glucose levels, also categorized as low, medium, or high for each trial.

Person-specific glucose-estimation accuracy. Adolescent-specific measures of glucose awareness were also calculated. A mean of each adolescent's set of absolute deviation accuracy scores was calculated. As well, the number of correct categorical estimates for each adolescent was summed and divided by the total number of estimates they provided. This ratio was multiplied by 100, and resulted in a percent-correct score for the categorical estimates for each adolescent.

Perceived Glucose Influences

Belief ratings. The adolescents' reported beliefs that a high or low glucose episodes influenced their physical symptoms or moods was interpreted as evidence of heightened awareness of glucose-related influences. To identify symptom beliefs, adolescents were asked to rate 36 items (3 of the items were fake items) on a seven-point scale, ranging from 0 (*not at all*) to 6 (*very much*) (Freund et al., 1986; Gonder-Frederick et al., 1986; O'Connell et al., 1990; McCrimmon et al., 1995b). To identify symptom beliefs for hyperglycemia, adolescents were asked, *When you are high, how much do you feel...* each symptom? A parallel set of symptom beliefs were completed for hypoglycemia. Administration of the symptom belief checklist was counter-balanced with half of the participants completing the hypoglycemia symptom-belief checklist first, and the other half completing the hyperglycemia symptom-belief checklist first. Using a criteria similar to Wiebe et al. (1994), those items that received a rating of 4 or greater were classified as a glucose-related belief. The total number of glucose-related beliefs were summed for each

participant as a general measure of perceived glucose-related influence on their feelings, behaviours, and moods.

The belief list. The 33 items (plus 3 fake items) used in the belief rating scale (see Appendix J) reflect commonly associated physical symptoms and moods of glucose-related changes (Freund et al., 1986; Gonder-Frederick et al., 1986; O'Connell et al., 1990; McCrimmon et al., 1995b). Moods and behavioural items were selected from both social-behavioural examples found in anecdotal reports (Gonder-Frederick et al., 1997) and from previously used psychologically-oriented symptom checklists (Gonder-Frederick, et al., 1989; McCrimmon et al., 1995b; Ross et al., 1998; Weinger et al., 1995). The specific selection of items was based upon: 1) items that a reasonable number of participants had previously endorsed, 2) physical symptoms of both hypoglycemic and hyperglycemic, and 3) an approximately equal number of positive and negative psychological items.

Moods and Social Interactions

Mood and social interaction ratings were the two main outcomes in this research project. With 20 adolescents and an average of 51 sets of ratings per adolescent, a total of 1028 sets of mood and social interaction ratings were obtained. A description of each outcome follows, as well as any relevant psychometric information.

Moods and symptoms. Participants were asked to rate how much they experienced 11 physical symptoms and 11 moods on a rating scale from 0 (*not at all*) to 6 (*a whole lot*) (see Appendix K). This represents a subset of the items assessed with the 36-item symptom-belief questionnaire described earlier. Items were eliminated that appeared to be alternative wordings of the same symptom or behaviour (compare Appendix J with Appendix K; see Deary et al., 1993 for a similar approach).

Psychometric characteristics of items. Little data were available on the psychometric characteristics of the individual mood and social interaction items. An early

study examining the test-retest reliability of glucose-symptoms relations compared 23 glucose-symptom ratings from three data-collection phases (Cox, Gonder-Frederick, Pohl, & Pennebaker, 1983). Within-participant reliability estimates were most reliable over the first two data-collection phases, a 6-month period. The average within-participant Pearson correlation was +.51 across 23 people between the first two phases. The average within-participant correlation was +.28 between phases 2 and 3, a 2-month period, and +.27 between phases 1 and 3, an 8-month period. There was considerable individual variability in the reliability estimates, ranging from -.09 to +.91 between phases 1 and 2. Such reliability data were far from ideal, but should be consistent enough to identify reasonably strong relations between glucose levels and mood ratings.

Social Interaction ratings. To assess the quality of adolescents' social interactions, on each trial they were asked to rate to what extent they experienced each of the following social events in the last ½ hour: *laughed and joked, acted silly, had a caring or affectionate interaction, had a stressful interaction, had an upsetting or saddening interaction, had an annoying meeting with someone*, or *argued.* A rating scale of 0 (*not at all*) to 6 (*very much*) was used (see Appendix L). A rating of zero indicated that no social interaction occurred.

Social item selection. This list of potential social interactions represented both positive and negative social interactions. The specific items used reflected the types of social interactions described in survey and anecdotal reports of glucose associations. For example, the *acted silly* item was meant to represent a form of *odd behaviour* often associated with hypoglycemia. Similarly, negative interactions were described as occurring with both high and low glucose levels, so a variety of types of negative social interactions were included. Finally, the *caring or affectionate interaction* item reflected a measure of interpersonal liking or attraction. This was useful as a indirect measure of interpersonal liking or attraction, a measure which has been shown to be susceptible to arousal effects

(see earlier review). As these items were designed specifically for the current study, no psychometric data were available for this social interaction measure.

Aggregation. Mood ratings can be grouped into positive and negative factors to improve reliability (Watson & Clarke, 1997). Researchers have shown that glucose-related moods can be grouped into positive and negative categories (Gonder-Frederick et al., 1989). Based upon the above empirical results and to improve the reliability and variability of the outcomes, on each trial occasion mood ratings were summed into an overall negative mood score and an overall positive mood score. A similar negative-positive grouping procedure was used to combine social interaction ratings into negative and positive summed scores. Sums, rather than means, were used because of the high frequency of zero-rating responses.

Data-Collection Procedure

The initial data-collection session included a review of the purpose and procedures of the study, and the signing and collecting of the consent forms. Next, socioeconomic, demographic, and health-related information was collected from the parents and the adolescents. Diabetes-related psychological concerns were measured using the Fear of Hypoglycemia (Cox, Irvine et al., 1987) and Diabetes Quality Of Life (Ingersoll & Marrero, 1991). This was follow by an assessment of the adolescents' glucose-related symptom- and mood-beliefs. Note, diabetes-related questionnaires and symptom and mood beliefs interviews were conducted by a naive research assistant to minimize the likelihood of the results being due to experimenter expectancy effects. Finally the use of the handheld computer (PDA) was demonstrated and tested with the participation of the adolescents.

For the field-study component of the data-collection period, adolescents completed physical symptom, mood, and social interaction ratings, glucose estimates, and glucose measurements over a three-week period. Adolescents were asked to perform these ratings

and estimates approximately 3 times per day for the next 3 weeks. During the field-study portion of the project, one or two brief meetings occurred to download the PDA data, provide gift certificates, and ensure that things were going well. These meetings usually took place at the University of Manitoba, although some meetings took place at the DER-CA, some at the adolescents' homes, and some at coffee shops for greater convenience for the adolescent or their parents.

Following completion of the field-study data-collection period, a final meeting occurred at which time handheld computers were returned, the movie certificate was given out, and families were thanked for their participation. Each participating family was mailed personalized feedback including a personal list of the adolescents' glucose-related physical symptoms, moods, and social interactions and a summary of their glucose estimation accuracy (see Appendix M feedback information). At the conclusion of the project, adolescents were mailed a summary of the overall study findings.

Specific Research Questions

In this dissertation project, three unique glucose-related research issues were examined.

Arousal-awareness assessment. In this study, the different theoretical models of arousal-related influences were compared using glucose levels as a measure of arousal. Extreme glucose levels were expected to be associated with more extreme mood and social interaction ratings. Specifically, these ratings were expected to be either more negative or more positive during either low or high-glucose levels compared to ratings during normal glucose levels. Both continuous and dichotomous, threshold-dependent glucose measures were assessed. Among the different psychological models of arousal, awareness is a central issue. To test for the effects of awareness, several measures of glucose-related awareness were tested as potential moderators of the glucose-outcome

relations. The measures included occasion-specific glucose-estimation accuracy, aggregated adolescent-specific measures of glucose-estimation accuracy, and adolescent-specific perceptions of glucose-related influences. Greater levels of awareness were expected to lessen the relation between glucose levels and the mood and social interaction ratings of the adolescents.

Systematic assessment of social interactions and moods. Previous researchers have had difficulty identifying reliable association between high-glucose states and moods. Social interactions were expected to provide a more sensitive assessment of the psychological effects of hyperglycemia. The emotionally evocative nature of many social interactions may offer the triggers and focus needed to activate underlying hyperglycemic arousal-related responses. In this first systematic field study of glucose influences on the social interactions of individuals with Type 1 diabetes, adolescents provided ratings of both their positive and negative social interactions. Adolescents also rated a broad sampling of both positive and negative moods over the duration of the field study.

A dualistic model of hyperglycemic effects. The proposed, dualistic model of hyperglycemic effects stated that hyperglycemia may be due either to insulin insensitivity or to insulin deficiency. Each adolescent checked off the probable reasons why they were experiencing high-glucose levels (>10 mmol/L) on each high-glucose occasion. Based upon the list of selected reasons, hyperglycemic episodes were classified as due either to a relative insulin deficiency, to insulin insensitivity, or to mixed reasons. Insulin-insensitivity hyperglycemia (that due to impaired insulin utilization) was expected to be most psychologically symptomatic.

Covariates. In examining the various research questions, background characteristics of the participants were evaluated as potential covariates of the mood and social interaction ratings. The covariates assessed included demographic characteristics

and diabetes-related characteristics. Potential demographic moderators included age, gender, grade, and socioeconomic status. The diabetes-specific characteristics evaluated included duration of diabetes, insulin-treatment protocols, and general metabolic control (glycosylated hemoglobin), and diabetes-related psychological concerns (such as diabetes quality of life and fear of hypoglycemia ratings). The results of these research investigations are described below.

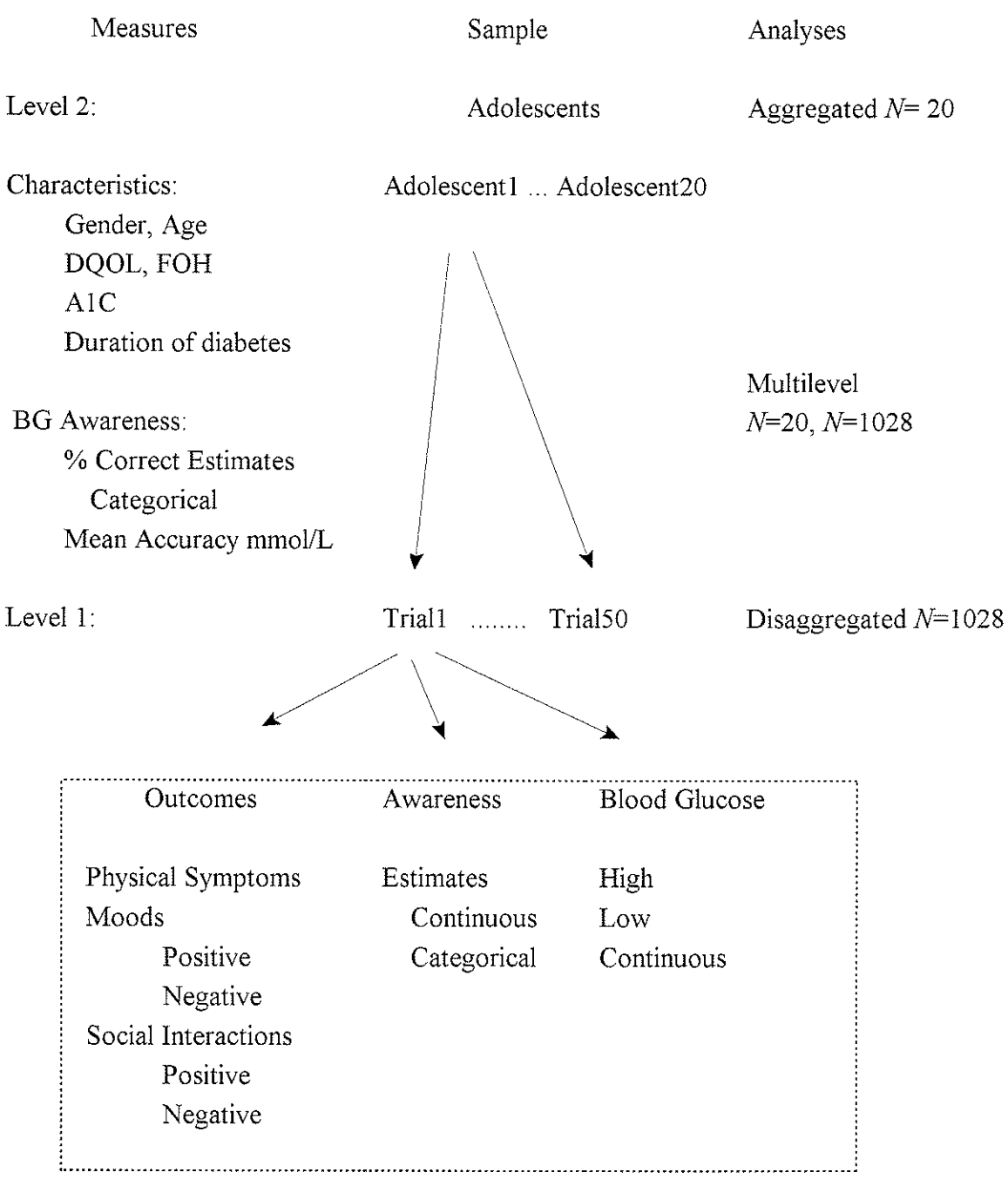
RESULTS

Prior to statistical testing of the specific research questions, the distributional characteristics of the data were evaluated and described below. Basic descriptive information about the sample and the study measures follow. Next within-adolescent correlations, which ignore the dependencies among the data, are presented to provide an initial description of the relations between glucose levels, and moods and social interactions. Finally, the specific research questions were tested using multilevel statistical regression modeling. These models are presented last. A schematic overview of the study design presents the main measures, the sample, and the analyses conducted at each level (see Figure 1).

Analytic Issues

Initial data evaluations. The frequency and distributional properties of the data were examined. Outliers were checked for data-entry errors, and if they were true outliers, they were eliminated so as to prevent them from having an undue influence on the results. As well, observations identified as having an unduly large influence on regression parameter estimates, via examination of extreme Cook's D values (> 3 *SD*s), were corrected in one of two ways. Either the observations were eliminated, or a dichotomous predictor was created to represent a set of these influential observations. This predictor was then included as a covariate in the regression analyses to remove the variance

Figure 1. *Schematic Summary of Design, Data Structure, and Analysis of Study*



associated with these influential observations (see Tabachnick & Fidell, 2001, Chapter 4). Individual rating items were combined into aggregate scores. The normality and linearity of the data were evaluated using various univariate and bivariate graphical plots (see Friendly, 1991). For non-normal distributions, the data was re-expressed or transformed using square root and log transformations to improve the normality and linearity of the data.

Covariates. To control for potential methodological confounds, two occasion-specific covariates were used for each outcome: physical symptom ratings and the parallel outcome measure of the opposite valence. For positive moods, negative moods ratings were used as a covariate, while for negative moods, positive moods ratings were used as a covariate. Similarly, for positive social interactions, negative social interactions ratings were used as a covariate, while for negative social interactions, positive social interactions ratings were used as a covariate. Occasion-specific covariates were rated at the same time of day using the same scale. These occasion-specific covariates control for potential confounds such as a tendency to use only one part of the rating scale, time-of-day effects, feeling physically unwell, or other influences that applied generally to the outcome ratings. In addition to these occasion-specific covariates, any other adolescent or occasion-specific characteristic identified as a significant predictor of the outcome were included in the multilevel regression models.

Outcomes: Distributions. Positive-mood ratings were normally distributed and analyzed using SAS Proc Mixed. For the other three outcomes -- negative moods, negative social interactions, and positive social interactions -- the distributions were positively skewed. None of the typical transformations on data (square root, log, and inverse) produced reasonably normal distributions in the data. This was due to the relatively high frequency of 0-value ratings. These outcome ratings reflected a count-like response pattern, and such data are better modeled assuming that responses reflect an

underlying Poisson distribution. Under a Poisson distribution, predicted response values cannot be less than zero, and the variability in response patterns depends to some extent upon the mean-response pattern evident in the data. Therefore, for negative moods, and both social-interaction ratings, multilevel regression modeling was based on an assumed underlying Poisson distribution. An extra-dispersion scale parameter estimate was used to estimate the variance in ratings (for details see the SAS GLIMMIX macro, Littell, Milliken, Stroup, & Wolfinger, 1996). Evaluation of residual values for these regression models indicated that the assumed underlying distributions were reasonable. No obvious systematic patterns were evident visually in the resulting residual plots.

Sample Characteristics and Descriptive Statistics

Family background. Family characteristics of the twenty participating adolescents indicate that they were from relatively homogeneous backgrounds (see Table 5 for details). All came from two-parent families, most parents worked at least part-time, and 19 of the 20 families labeled themselves as white in race. Variability was evident in family incomes and occupations.

Table 5. *Qualitative Description of Family Demographic Data*

Variable	Members	Typical Status	Range
Marital Status	Family	all 2-parent families	--
Income	Family	47% $40,000-$80,000	<$20,000->$80,000
Education	Parent 1	50% 2-4 yrs post High School	9-18 years of school
	Parent 2	46% 2-4 yrs post High School	12-18 years of school
Work Status	Parent 1	18/20 working, 72% full time	2 homemakers
	Parent 2	19/20 working	1 no response
Race	Parent 1	19/20 White	1 Native

Note. Parent 1 was usually the mother and parent 2 the father.

Adolescent characteristics. The adolescents themselves ranged in age from 12 to 18 with a mean age of 14.3 years. Ten females and ten males participated in the study. Grade level ranged from 6 to 12 with a modal grade level of 9. Additional details about the adolescents are presented in Table 6, including diabetes-specific medical background information. The adolescents' general metabolic control with a mean glycosylated hemoglobin levels (HbA_{1C}) of 9.1% (*SD*=1.5) was similar to other adolescent samples (e.g., HbA_{1C} of 9.3%, *SD*=1.6 (Leonard, Jang, Savik, Plumbo, & Christensen, 2002) in one sample and HbA_{1C} of 8.9%, SD=1.6 in another (Holl et al., 2003). The upper end of the normal range is about 6.2%. The mean number of typical glucose tests per day was reported to be 4 and the modal number of insulin injections was 3. Glucose levels from 8 to 12 mmol/L were considered high "for them" by most of the adolescents. Among these various adolescent characteristics, two significant correlations were identified. Older adolescents had diabetes longer than younger adolescents, $r = .56$, $p < .01$, and those who had diabetes longer had higher mean glycosylated hemoglobin levels, $r = .42$, $p < .07$.

Table 6. *Description of Adolescent Demographic and Diabetes History Data*

Variable	N	Mean or Description	Range
Age	20	*M* = 14.3 years, *SD* = 1.7	12 - 18 years
Gender	20	10 Males, 10 Females	--
Education	19	Mode in Grade 9	Grade 6 - Grade 12
Duration of Diabetes	20	*M* = 6.1 years, *SD* = 3.9	0.9 - 13 years
BG Tests / Day	15	4	2 - 8 tests
Method of Injection	19	13 pen, 5 syringe, 1 pump	3 methods
HbA_{1C}			
Before	20	*M* = 9.2%, *SD* = 1.4	5.8% - 12.2%
After	19	*M* = 9.1%, *SD* = 1.6	6.2% - 12.7%
High BG "for me"	18	8 mmol/l for 44%	8 - 13 mmol/l
Insulin Type			
Slow Acting	19	14 BID, 5 OD	1- 2 / Day
Fast Acting	19	1 OD, 9 BID, 7 TID, 2 QID	1 - 4 / Day

Note. *N* = number of adolescents responding to each item. HbA_{1C} = Glycosylated hemoglobin, a laboratory-based test of the adolescents' mean blood-glucose levels (mmol/l) over the previous 3-4 months. *Before* refers to the last HbA_{1C} collected before the first interview of the study. *After* refers to the first HbA_{1C} collected after the interview. OD = 1 a day. BID = 2 a day. TID = 3 a day. QID= 4 a day. *High BG for me* is the response to the question asking adolescents about the blood glucose level they consider high.

Handheld computer use. The handheld computer data-collection format functioned very well. The software for the data collection was designed specifically for the project by the author. Unfortunately, 5 system crashes resulted in some data loss. In one case, a participant generously extended his period of participation to provide additional observations. In other cases, data losses ranged from two days to a week-and-a-half of observations. Almost all of these difficulties occurred during the first half of the study. In response to these difficulties, the software program was re-created with a newer, more robust version of the programming software (PDAToolbox) when it became available, and few problems occurred afterwards. All adolescents quickly learned how to use the

equipment and none reported difficulty using it. The overall mean time taken to complete a trial was 3 minutes (*SD* = 2 minutes). The modal response time between estimating glucose levels and entering actual glucose levels was less than 1 minute. This was reasonable given current testing speeds associated with glucose monitor testing equipment. The mean number of days adolescent participated in the field study portion of the data-collection period was 21 (*SD*=3) and the mean number of trials completed per day was 3 (*SD* = 1, see Table 7 for more details).

Table 7. *Frequency of Handheld-Computer Use per Adolescent*

Time Dimension	Median	*M*	*SD*	Min	Max
Number of Days Completed	21	21	3	14	27
Number of Trials / Day	3	3	1	1	6

Note. $N = 20$. Frequencies were rounded to the nearest integer.

Diabetes Quality of Life. The Diabetes Quality of Life (DQOL) scales assessed the adolescents' *satisfaction* with diabetes-related aspects of their lives, *worry* about having diabetes, and how diabetes directly *impacts* their lives (see Table 8). The internal consistency of the scales was reasonable, ranging from .75 to .81. These reliability coefficients were similar to previous uses of the DQOL for youth, in which coefficients have ranged from .82 to .85 (Ingersoll & Marrero, 1991; Grey et al., 1998). Mean scale scores of Impact, 52.5, and Worry, 18.7, also were very similar to previous adolescent studies (e.g., Faro, 1999; Grey et al. 1998; Ingersoll & Marrero, 1991). Mean DQOL Satisfaction ratings have varied considerably from study-to-study, ranging from 35.9 (*SD*=12.0, Faro, 1999) to 83.9 (*SD*=11.3, Ingersoll & Marrero, 1991). The present sample's mean Satisfaction rating of 67.6 fell in middle of these two extremes and was very similar to that reported by Grey et al. (1998) of 65.2, *SD*=12.4. Impact scores were significantly correlated with higher Worry scale scores, $r = .49$, $p < .03$, and lower

Satisfaction scores, $r = -.49$, $p < .03$. The Satisfaction and Worry scales were not significantly correlated with each other, $r = -.11$, $p < .65$.

Fear of Hypoglycemia. The Fear of Hypoglycemia (FOH) questionnaire assessed how hypoglycemic episodes affect the thoughts and behaviours of individuals with diabetes. Specifically, *worry*-related thoughts about experiencing hypoglycemic episodes and *behaviours* that individuals take in order to avoid having a hypoglycemic episode were assessed. Internal consistency for the two subscales, Worry and Behavioural Avoidance, and the Total scale score were reasonable (see Table 8) and comparable to previous applications of the FOH questionnaire (see review by Irvine et al., 1994). Previous alphas have ranged from .60 to .84 for the Behavioural Avoid subscale and .89 to .96 for the Worry subscale (see Irvine et al., 1994). Current sample mean scale scores were somewhat lower than scores reported in a previous review (Irvine et al., 1994). In that review the sample was generally older, with the Behavioural Avoid score ranging from 26.1 to 28, SD= 6.3, and the Worry score ranging from 32 to 38, SD=12. Worry subscale scores were not significantly correlated with the Behavioural Avoid subscale, $r = -.14$, $p < .60$, in the current study.

Table 8. *Descriptive Statistics for Quality of Life and Fear of Hypoglycemia Questionnaires.*

Variables	*N* items	*M*	*SD*	Min	Max	Range	Alpha
DQOL scales							
Impact	23	52.5	10.6	34	72	23-115	.81
Worry	11	18.7	5.3	12	33	11-55	.75
Satisfaction	17	67.6	8.1	54	80	17-85	.78
FOH scales							
Avoidance	10	19.3	7	9	30	0-40	.73
Worry	13	17.5	9.8	0	38	0-52	.88
Total Fears	23	36.8	12.8	13	58	0-92	.84

Note. Minimum = minimum value. Max = Maximum value. Range = possible range of scores. Alpha = Cronbach's Alpha. DQOL = Diabetes Quality of Life scale (Ingersoll & Marrero, 1991). FOH scale = Fear of Hypoglycemia scale (Cox , Irvine et al., 1987). BG = Blood glucose levels. $N = 20$.

Glucose Levels

Participant glucose levels. A total of 1036 glucose measurements were recorded by the 20 adolescents with Type 1 diabetes in this study. Eight extreme glucose scores 2.5 *SD*s or higher above a participant's mean glucose level were deleted as very abnormal and so as to prevent these observations from exerting an excessive influence on subsequent glucose-relation analyses. For the remaining 1028 observations, the grand mean glucose level was 11.2 mmol/L, *SD* =6.0, with a minimum of 1.9 and a maximum of 34.6 mmol/L. Table 9 lists the descriptive statistics for the glucose levels of each adolescent.

Table 9. *Summary Glucose Levels for Each Participant*

		Blood Glucose Information					
ID	*n*	*M*	*SD*	Min	Max	Lows	High
1	58	7.9	3.5	2.7	16.4	7	14
2	29	18.1	8.2	5.1	34.6	0	24
3	70	7.1	1.8	3.2	11.9	2	6
4	78	8.5	4.6	2	18.9	10	26
5	73	11.6	5.7	2.4	24.4	7	43
6	55	11.9	5.7	3.8	25.9	1	29
7	56	12.5	6.4	3.6	27.2	1	30
8	31	10.6	5.1	2.8	21.9	2	14
9	43	10.4	4.3	2.9	21.1	3	22
10	28	15.9	8.4	1.9	31.8	2	21
11	36	16.8	8.2	2.1	32.5	2	24
12	55	10.5	5	3.6	21.8	1	24
13	46	12.4	5.7	3.5	23.8	1	28
14	51	14.5	6.4	3.2	29	3	38
15	42	14.1	5.4	5.4	25.3	0	32
16	39	7.4	3.6	2.3	13.9	10	12
17	40	12.1	7	2.5	30	3	21
18	54	13.9	5.9	2.9	26.4	1	38
19	61	9.9	4.1	2.9	20.9	6	31
20	83	8.5	3.5	3	17.3	7	29
Mean	51	11.7	5.4	3.1	23.7	3.4	25

Note. ID refers to the ID of each participant. The *n* refers to the number of trial completed per adolescent. *M* refers to the mean glucose level for each adolescent across trials. Min refers to the lowest and Max to the highest glucose level experienced by each adolescent. Lows = number of glucose reports < 4.0 mmol/L. Highs = number of glucose reports > 9.9 mmol/L.

Low glucose levels. Among the 1028 glucose observations recorded, 69 glucose levels (6.7%) were less than 4.0 mmol/L or classifiable as hypoglycemic. The modal number of hypoglycemic episodes per adolescent was 1 and ranged from 0 to 10 (see Table 9). As a percentage of the trials each adolescent completed, the mean number of lows was 6% and ranged from 0% to 26%. Generally, this sample of adolescents exhibited few hypoglycemic episodes over the 3-week data-collection period.

High-glucose levels. Among the 1028 glucose observations, 506 (49%) of the glucose recordings were greater than 9.9 mmol/L[13]. Table 9 includes the number of hyperglycemic episode of each participant as well as the mean frequencies across the 20 participants. The number of hyperglycemic episodes ranged from 6 to 43 per adolescent with a mean and median of 25 and a standard deviation of 9. As a percentage of the trials each adolescent completed, the mean number of highs was 52% and range from 8% to 83%.

Qualitative types of hyperglycemic. Of the 506 hyperglycemic episodes, 153 were classified as due to excessive glucose intake, 192 were classified as due to impaired-insulin function, and 114 were classified as due to some mix of both excessive glucose and reduced insulin function. Excessive-glucose classifications were most often based on the adolescents reporting the "had extra food or drinks" causal explanation. Impaired-insulin classifications were most often based on the adolescents reporting the "not sure" causal explanations. The frequencies of specific reason given for these 3 types of hyperglycemia are presented in Part A of Table 10. Of the remaining episodes, 27 were missing causal explanations, and 20 were labeled as *not high* for the participant. Basic statistical

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[13] An alternative definition of hyperglycemia also was tested. Hyperglycemic epsidoes were defined as glucose levels 1 standard deviation above the adolescent's mean glucose level or greater than 15 mmol/L whichever was the lower criteria. Using this more stringent hyperglycemia definition was not associated with more significant relations.

information for the three types of hyperglycemic episodes, after aggregating trials within adolescents, are presented in Part B of Table 10. Most adolescents experienced some episodes of each type of hyperglycemia. Adolescent-to-adolescent variation, however, is clearly evident with the variation in the number of episodes (i.e., 1 *SD*) as large as the mean number of episodes.

Table 10. *Perceived Causes and Number of Types of Hyperglycemia*

A.	Types of Hyperglycemia		
	153 Excessive	192 Impaired	114 Mixed
Reported Causal Beliefs	n	n	n
forgot or delayed insulin	39	--	34
had extra food or drinks	118	--	51
less activity or exercise	52	--	77
high stress or excitement	--	10	75
am sick	--	34	34
not sure	--	161	64

B. Adolescent Level	Median	*M*	*SD*	Min	Max	% of trials
Excessive glucose Intake	7.5	7.6	5.8	0	25	28
Impaired-insulin function	7	9.6	8.9	0	34	29
Mixed Reasons	3	5.7	6.9	0	26	20

Note. Types of Hyperglycemia were defined by glucose levels > 10 mmol/L along with the reported reason for their hyperglycemia. Percent of trials = (number of hyperglycemic episodes /number of trials)*100. $N = 20$.

Correlations among glucose measures. Adolescent-level intercorrelations were examined to assess the relations between the various glucose measures. As expected, continuous glucose levels were correlated with the dichotomous glucose measures above. The positive correlations with between continuous glucose levels and the dichotomous hyperglycemia measures ranged from .44, $p < .05$, to .93, $p < .0001$. The correlation between continuous glucose levels and the percent of hypoglycemic episodes was $r = -.55$, $p < .02$. The three qualitative dichotomous measures of hyperglycemia were independent

from each other, even after aggregation to the adolescent level, with *r*s ranging from -.15 to +.15 and *p*s > .50.

Glucose Awareness

Two general types of glucose-awareness measures were examined: glucose-estimation accuracy and the number of perceived symptoms of glucose highs and lows. Glucose-estimation accuracy estimates were available for every observation, and aggregate scores of these occasion-specific estimates for each adolescent were calculated. An adolescent-specific measure of the overall perception of glucose-related influence was based upon the adolescents symptom-belief ratings. At the adolescent-level, these two types of awareness measures were uncorrelated. The correlation between the total symptom-belief score and percent correct categorical guesses was $r = -.17$, $p < .50$, and the correlation between the total symptom-belief score and the mean absolute deviations of estimates was $r = +.28$, $p < .25$.

Occasion-specific glucose estimates. There were 1019 absolute-difference scores out of the 1028 glucose scores. The grand-mean of occasion-specific estimation error was 3.8 mmol/L (*SD*=3.7) and ranged from 0 mmol/L, an exactly correct estimate, to 22.9 mmol/L, a large relative difference. Of the 1028 categorical glucose estimates, 666 or 64.8% were correctly identified as low, normal, or high. Of these correct guesses, 6% (42 /666) were low-low matches, 56% were normal-normal matches, and 38% (251/666) were high-high matches. Neither of these glucose awareness measures showed evidence of changing over the course of the field study, $r = .04$ ($n = 1019$) and $r = -.04$, $p < .17$ ($n = 1028$) for absolute deviations and categorical estimates, respectively.

Adolescent-specific glucose estimates. Adolescents provided a mean number of 51 (*SD* = 16) occasion-specific glucose estimates and the number of estimates ranged from 28 to 83. Across the 20 adolescents, the mean of within-person mean absolute difference

scores was 3.9 mmol/L and ranged from 1.0 to 6.5 mmol/L. The mean amount of variability in absolute difference scores, as measured via the standard deviation among absolute difference scores, was 3.4 mmol/L and ranged from 0.9 to 6.0. For within-adolescent categorical estimates, the mean percent accurate was 65.2% (*SD*=14.3) and ranged from 37.3% to 97.8%. Among these within-adolescent correct categorical estimates, 8% were low-low categorical matches, 53% were normal-normal matches, and 40% were high-high matches. The adolescent-level correlation between the categorical measure of glucose awareness and the continuous measure of unawareness was significantly negative, $r = -.75$, $p < .0001$. More categorically correct estimates were associated with smaller continuous estimation errors.

Item-specific perceived impact of glucose-related highs and lows. If adolescents rated a potential symptom or mood as 4 or higher on the 0 (not at all) to 6 (very much) point scale, then that item was classified as a symptom belief. Each physical symptom and the percent of adolescents who selected it as a glucose-related symptom are listed in Table 11. All but one adolescent reported that weakness and shakiness were symptoms of low glucose levels. Dizziness, hunger, and difficulty thinking were the next most commonly reported symptoms of low glucose episodes. For high glucose episodes, thirstiness and dry skin were the most commonly reported symptoms (see Table 11). Interestingly, half of the participants also reported having difficulty thinking during high-glucose episodes. For glucose-related mood beliefs, behaving oddly and having negative aggressive moods were reported most often for both low and high glucose episodes (see Table 12). Aggressive mood beliefs did appear somewhat more common for high-glucose levels than low-glucose levels.

Table 11. *Physical Symptom Glucose Beliefs: Percent of Adolescents Reporting Each*

Physical Symptoms	Low BG	High BG
Weak	**95**	20
Hard to Think	**55**	50
Shaky	**95**	5
Dizzy	**65**	30
Hungry	**60**	20
Thirsty	10	**85**
Dry Skin, Mouth	10	**65**
Sleepy	50	35
Blurry Vision	45	25
Queasy	30	30
Sweaty	40	20
Cold Hands	35	20
Headache	20	20
Hot Face	15	25
Tingling	10	10

Note. Values represent the percent of adolescents reporting each physical symptom belief when they experience high and low-blood glucose (BG) levels. Values > 50% are bolded. $N = 20$.

Table 12. *Mood Glucose Beliefs. Percent of Adolescents Reporting Each*

Mood Symptoms	Low BG	High BG
Acting Oddly	**60**	**60**
Frustrated	45	**65**
Restless	40	**65**
Grouchy	30	**60**
Argumentative	45	**60**
Alert	20	45
Energetic	15	40
Silly	20	35
Depressed	30	25
Teary	20	25
Worried	25	20
Sad	10	15
Happy	10	20
Confident	10	20
Excited	5	25
Relaxed	20	5
Calm	15	5
Caring, affectionate	10	10

Note. Values represent the percent of adolescents reporting each mood symptom of high and low glucose (BG) levels. Values > 50% are bolded. $N = 20$.

General perceived impact of glucose abnormalities. The symptom belief awareness measure used was the total number of symptoms and moods believed to be associated with glucose highs and lows. The internal consistency of these sums was quite good, ranging from .85 to .92 (see Table 13). For both high and low glucose episodes, adolescents reported means of 10 symptoms and 10 mood beliefs. The mean of the total symptom beliefs was 19.5. The total number of symptom beliefs ranged from 3 to 41

across adolescents, indicating that the perception of glucose-related influences varied considerably from adolescent-to-adolescent.

Table 13. *Descriptive Statistics for Adolescent Beliefs about Symptoms of High and Low Blood-Sugar Levels*

Variables	*N* items	*M*	*SD*	Min	Max	Range	Alpha
Adolescent Beliefs: Number of Symptoms							
Low BG	33	10.4	5.9	1	27	0-31	0.87
High BG	33	10	5.7	2	24	0-31	0.85
Total BG	66	19.5	9.5	3	41	0-61	0.92

Note. Minimum = minimum value. Max = Maximum value. Range = possible range of scores. Alpha = Cronbach's Alpha. Adolescent Beliefs questionnaires were constructed for the dissertation and are based on a sampling of typical symptoms found in the literature. BG = Blood glucose levels. $N = 20$.

Level 1 Occasion-Specific Ratings

The variability in ratings of individual physical symptoms, moods, and social interactions was quite limited. Therefore, sets of individual item ratings were grouped and summed at each occasion. These grouped rating scores were used to assess the central research questions of this dissertation. To provide basic descriptive information, preliminary, item-by-glucose correlations and a disaggregated analysis of item-by-glucose relations are presented below. These preliminary results represent basic trends and should be considered tentative. The main research questions were analyzed using grouped item ratings.

Level 1 Covariate: Physical Symptoms. Across the 1027 physical symptom ratings, the grand mean was 11.5 ($SD = 5.7$) and ranged from 0 to 34. The mean of mean physical symptom ratings within adolescents was 12.1 and ranged from 6.6 to 20.4. Mean variation of physical ratings within adolescents, as measured by standard deviations in adolescent scores, was 4.2, and ranged from 1.9 to 5.9. Again considerable variability from adolescent-to-adolescent was evident in reports of physical symptom ratings. Physical

symptom ratings were used as a covariate for all multilevel analyses. As a covariate, physical symptoms, in part, controlled for adolescent-to-adolescent and occasion-to-occasion differences in rating tendencies.

Positive mood descriptive statistics. The grand mean positive mood rating sum was 9.8, *SD* = 5.7, ranging from 0 to 24. Within-adolescent descriptive statistics for positive mood ratings are presented in Table 14. The mean of adolescent mean positive mood ratings was 9.8, and ranged from 2.9 to 19.9. Within-adolescent variability in positive-mood ratings, as measured by the standard deviation among ratings, was 3.4, and ranged from 1.7 to 5.0.

Availability of Social Interactions and Negative Moods. Generally, adolescents reported far more positive moods than the other 3 outcomes: negative moods, positive social interactions, and negative social interactions (see Table 14 and the ratings differences paragraph below). One participant was excluded because he provided almost no ratings greater than zero for negative moods, positive social interactions, and negative social. Therefore, the total number of available ratings was 976 for negative moods and 977 for the social-interaction ratings.

Negative mood descriptive statistics. The grand mean negative mood rating sum was 3.0, *SD* =3.7, ranging from 0 to 23. Within-adolescent descriptive statistics for negative mood ratings are presented in Table 14. The mean of within-adolescent mean negative mood ratings was 3.2, and ranged from 0.2 to 9.5. Within-adolescent variability, as measured by the standard deviation of negative mood ratings, had a mean of 3.0 with a range of 0.5 to 4.1.

Table 14. *Adolescent-Aggregated Statistics of the Mood and Social Interaction Ratings*

		Across Adolescents			
Outcomes	Statistic	*M*	*SD*	Min	Max
Positive Moods	*n* Trials	51	16	28	83
	M of Rating	9.8[a]	4.4	2.9	19.9
	SD of Rating	3.4[y]	1	1.7	5
Negative Moods	*n* Trials	49	20	0	82
	M of Rating	3.2[b]	2.2	0.2	9.5
	SD of Rating	3[y]	0.9	0.5	4.1
Positive Social Interactions	*n* Trials	49	20	0	83
	M of Rating	4.9[c]	2.1	0.7	9
	SD of Rating	4.2[z]	1.6	1.6	7.7
Negative Social Interactions	*n* Trials	49	20	0	83
	M of Rating	3.3[b]	1.8	0.6	6
	SD of Rating	4.7[z]	1.5	1.2	7.6

Note. For the Statistic column, *n* trials refers to the number of trials completed. *M* of Rating refers to the Mean adolescent rating. *SD* refers to the *SD* (variability) in adolescent ratings. The values of the statistics presented are those aggregated across all adolescents. Superscripts that differ within Mean ratings and within *SD* ratings indicate that values differed significantly from each other at $p < .05$, $N = 19$-20.

Social interaction descriptive statistics. The grand mean, social-interaction rating sum for positive ratings was 4.8 (*SD* = 4.7) with a range of 0 to 23, and for negative ratings, was 3.2, *SD* =5.1, with a range of 0 to 32. Within-adolescent descriptive statistics for both positive and negative social-interaction ratings are presented in Table 14. The mean of within-adolescent means were 4.9 and 3.3 for positive and negative social interactions, respectively. Within-adolescent variability, as measured by the standard deviation of ratings, was 4.2 and 4.7 for positive and negative interactions, respectively (see Table 14 for details).

Within-adolescent rating differences. Comparisons of mean adolescent outcome ratings showed a number of significant differences. Mean positive ratings were higher than

the other three types of outcome ratings. As well, mean positive social interaction ratings were higher than both negative mood and negative social interaction ratings. Mean variability of the within-adolescent outcomes ratings showed a different pattern. Both positive and negative social interaction ratings were significantly more variable than positive and negative mood ratings. Mean variability in positive social interaction ratings did not differ significantly from the variability in negative social interaction ratings. As well, no differences in mean variability in ratings were found between positive and negative moods. Thus, positive ratings are generally higher than negative ratings, and social interaction ratings are more variable than mood ratings.

Relations Among Adolescent-Level Covariates and Predictors

Few significant relations were evident among the various predictors and covariates. DQOL Satisfaction scores were higher for females, $M = 71.5$, than for males, $M = 63.6$, $t(1,18) = -2.45$, $p < .03$. Poorer metabolic control, that is higher glycosylated hemoglobin levels, was associated with higher continuous glucose levels, $r = .77$, $p < .0001$, more episodes of hyperglycemia, $r = .45$, and a higher number of symptom beliefs, $r = .45$, $p < .05$. The sample size of 20 was relatively small for such statistical comparisons.

Within-Adolescent Glucose-Item Rating Relations

Within-adolescent correlations between individual item ratings and hypoglycemia and hyperglycemia are presented in Tables 15 to 17. The correlations were based upon few occurrences for many of the adolescents. Therefore, the results represent tentative findings.

Within-adolescent individual physical symptom glucose relations. Within-adolescent correlations between individual physical symptom ratings and dichotomous glucose levels were summarized in Table 15. The physical symptoms of shakiness, having difficulty thinking, hunger, and sweatiness were most commonly associated with low-

glucose episodes. High-glucose episodes appeared to be associated with increased thirst and decreased shakiness.

Within-adolescent individual mood-glucose relations. Within-adolescent correlations between individual mood ratings and the occurrence of high- and low-glucose episodes were summarized in Table 16. This table was organized conceptually with negative moods followed by the positive moods. Generally, the results showed that high- and low-glucose levels were associated with more negative and aggressive moods, specifically grouchiness, feeling like arguing, and frustration. Low-glucose episodes also were more often associated with feelings of worry and unusual or odd behaviours. Less contentedness also appeared to be associated with high and low glucose levels.

Within-adolescent individual social interaction-glucose relations. Within-adolescent correlations between individual social-interaction ratings and the occurrence of high- and low-glucose episodes were summarized in Table 17. This table was organized conceptually with negative social interactions followed by the positive social interactions. Arguments, stressful social interactions, or upsetting social interactions were associated more often with high-glucose levels. An increased likelihood of having had a caring social interaction also was evident in the pattern of correlations. Few significant associations were evident between social interactions and low-glucose level.

Table 15. *Significant ($p < .05$) Within-Person Spearman Correlations Between Discrete Physical Symptoms and High and Low Glucose Levels: Counts out of 20*

Physical Symptoms		Blood Glucose Levels	
		High BG	Low BG
Shaky	Continuous	-----	++++++++++
	Dichotomous	---	++++++++
Hard to think	Continuous	--+	+++++
	Dichotomous	--	++++
Hungry	Continuous	----	+++-
	Dichotomous	--+	+
Sweaty	Continuous	+	++
	Dichotomous		++
Sleepy	Continuous		--+
	Dichotomous		–+
Headache	Continuous	++	+
	Dichotomous	++	+
Thirst	Continuous	++	
	Dichotomous	+++	
Dry Skin	Continuous	++-	
	Dichotomous	-	-
Queasy	Continuous	+	
	Dichotomous	+	
Tingling	Continuous		
	Dichotomous		
Itchy	Continuous		+

Note. Continuous refers to symptoms rated from 0 (not at all) to 6 (very much). Dichotomous refers to physical symptoms dichotomized (0 to 3 = 0, 4+ = 1). High BG was defined as glucose levels => 10 mmol/L. BG Low is defined as < 4 mmol/L. Symbols refer to participant-level counts of significant relations $p < .05$, + is one significant positive relation, and - is one significant negative relation with blood glucose. $N = 20$.

Table 16. *Significant ($p < .05$) Within-Person Spearman Correlations Between Discrete Moods and High and Low Glucose Levels: Counts out of 20*

Moods		Blood Glucose Levels	
		High BG	Low BG
Grouchy	Continuous	++	++
	Dichotomous	++	++-
Arguing	Continuous	+-	++
	Dichotomous	+-	++-
Frustration	Continuous	++--	+
	Dichotomous	++-	--
Odd	Continuous	--	+++
	Dichotomous	--	+++
Worried	Continuous		++
	Dichotomous		+++
Sadness	Continuous		
	Dichotomous		
Content	Continuous	---+	--
	Dichotomous	---+	--
Cheerful	Continuous	--++	-
	Dichotomous	--++	-
Energy	Continuous	-	--
	Dichotomous	-	--
Giddy	Continuous	-	-++
	Dichotomous	-	+
Relaxed	Continuous	+	-
	Dichotomous	+	-

Note. Continuous refers to symptoms rated from 0 (not at all) to 6 (very much). Dichotomous refers to physical symptoms dichotomized (0 to 3 = 0, 4+ = 1). High BG was defined as glucose levels => 10 mmol/L. BG Low is defined as < 4 mmol/L. Symbols refer to participant-level counts of significant relations, + is one significant positive relation, and - is one significant negative relation with blood glucose. $N = 20$.

Table 17. *Significant ($p < .05$) Within-Person Spearman Correlations between Discrete Social Interactions and High and Low Glucose Levels: Counts out of 20*

Social Interactions		Blood Glucose Levels	
		High BG	Low BG
Arguing	Continuous	++++	-+
	Dichotomous		
Stressed	Continuous	++++	+
	Dichotomous	+	
Upset	Continuous	+++	++
	Dichotomous		
Annoyed	Continuous	+++	+
	Dichotomous		
Fighting	Continuous	++	++
	Dichotomous		+
Alone	Continuous	-	
	Dichotomous	+-	+
Caring	Continuous	+++--	
	Dichotomous		
Laughing	Continuous	-	
	Dichotomous		++
Silly	Continuous	-	
	Dichotomous		+
Chatty	Continuous	-	
	Dichotomous		

Note. Continuous refers to symptoms rated from 0 (not at all) to 6 (very much). Dichotomous refers to physical symptoms dichotomized (0 to 3 = 0, 4+ = 1). High BG was defined as glucose levels => 10 mmol/L. BG Low is defined as < 4 mmol/L. Symbols refer to participant-level counts of significant relations, + is one significant positive relation, and - is one significant negative relation with blood glucose. $N = 20$.

Within-adolescent correlations summary. Except for low-glucose related shakiness, the frequency of significant correlations between glucose levels and individual items was relatively low (see Tables 15 to 17). The limited variability in physical symptom, mood, or social interaction ratings within each adolescent probably accounts for the relatively low frequency of significant correlations. In the main multilevel regression analyses, individual items were grouped in positive and negative factors to provide a more variable and reliable measure of moods and social interactions. But first, disaggregated analyses were conducted to examine how low and high glucose level episodes related to individual item ratings at the observation level.

A Disaggregated, Individual-Item Analysis

Logistic analyses of the bivariate glucose-items relations were summarized in Table 18. The within-adolescent dependencies among the ratings was ignored and all scores were pooled for a single-level analysis. The results represented the relations between glucose levels and individual, dichotomized item ratings at the occasion-level. By ignoring the adolescent-specific dependencies among the ratings, the *p*-values were larger than .05, and so the statistical significance of the results were overly liberal. The magnitude and direction of the presented relations, however, should be reasonably valid.

Individual item ratings. Among physical symptoms, high-glucose levels were consistently related to more thirstiness, more dry skin, more itchiness, less tingling of the lips, and less odd behaviour (see Table 18). Low-glucose episodes were associated with more shakiness and more sweatiness among the physical symptoms. Few significant relations were evident among the moods and social interaction ratings. One reliable relation was that both high- and low-glucose episodes were associated with more argumentativeness.

Table 18. *Logistic Analyses of the Relations between Physical, Mood, and Social Interaction Symptoms and High- and Low-blood glucose Levels*

Symptoms	High BG *n*		High BG		Low BG *n*		Low BG	
Physical	*n1*	*n0*	Beta	*SE*	*n1*	*n0*	Beta	*SE*
Sleepy	825	86						
Queasy	328	583	.24 $^{+}$	0.14				
Headache	259	652	.28 $^{+}$	0.15				
Act Oddly	228	683	-.38 *	0.15				
Itchy	202	709	.44 **	0.16				
Thirsty, Pee	649	262	.49 ***	0.15				
Dry Skin	540	371	.36 **	0.14	271	238	-.50^{+}	0.27
Tingling	116	795	-.80 ****	0.21	81	428	-.93^{+}	0.48
Think Prob	338	573			194	315	.49^{+}	0.26
Shaky					187	322	1.68***	0.29
Sweaty					129	380	.61*	0.28
Moods and Social Interactions								
Arguing	231	680	.40**	0.15	117	392	.60*	0.28
Fighting	11	900	1.46^{+}	0.78	4	504	1.93^{+}	1
Grouchy	268	643	.24^{+}	0.15				

Note. Outcomes were dichotomized with ratings of 0 to 3 = 0 and ratings of 4+ = 1. Some symptoms (Tingling, Dry Skin, and Thinking Problems) occurred on both High and Low BG occasions. High BG was defined glucose levels => 10 mmol/L. Columns defined as *n1* refer to the number of observations when the symptom was present, and *n0* is the number of observations when it was not present.

$^{+}p < .10$. $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$. $^{****}p < .0001$.

Multi-Level Regressions

The data set was multilevel in structure with multiple ratings coming from each person. The mean set size was 51 ratings per adolescent. The amount of non-independence was estimated via intra-class correlation estimates. This correlation represents the extent to which total variance in the 1028 or 977 ratings scores was attributable to differences

among adolescents. The intra-class correlation also "can be interpreted as the expected correlation between two randomly chosen [observations] within the same [adolescents]" (Hox, 2002, p.31). Multilevel statistical procedures incorporate into the analyses the statistical dependencies among the ratings when testing the various research questions.

In each set of multilevel regression analyses, physical symptom ratings and the opposite-valence mood or social-interaction ratings were used as covariates. Other adolescent- or occasion-specific characteristics significantly related to an outcome were also used as covariates. The occasion-specific covariates minimize the likelihood that glucose-related results were due to some *general* occasion-specific methodological confound such as a tendency to use one part of the rating scale or time-of-day effects. To simplify interpretation of regression results, all covariates were centred at their grand mean. This means that the resulting parameter estimates were based upon covariates set to their mean levels rather than set to an unrealistic value of zero.

Positive Moods

Positive-mood covariates. The fixed effects covariates for the positive mood ratings model are presented in Table 19. The intercept is the mean positive mood rating score conditional upon the other predictors in the model. Both occasion-level covariates, physical symptoms and negative mood ratings, were highly associated with positive mood ratings. More physical symptoms and higher negative mood ratings were associated with lower positive mood ratings. The originally significant Fear of Hypoglycemia Worry subscale was of borderline significance after the other predictors of positive moods were in the regression model. General metabolic control was dichotomized and operationalized as the upper (> 9.3%) and lower (≤9.3%) 50% of glycosylated hemoglobin values. A median split of glycosylated hemoglobin (A_{1C}) levels was used in the glucose by metabolic control

interaction (see below) to ensure a sufficient number of adolescents were represented in each cell of the interaction.

Glucose and positive moods. A significant interaction between the dichotomous hyperglycemia predictor and general metabolic control was found for positive mood ratings (see Table 19). High glucose episodes were associated with fewer positive mood ratings for adolescents with better general metabolic control, but high glucose episodes were not significantly related to positive mood ratings of adolescents with poorer general metabolic control (see Table 20). The negative relation between hyperglycemia and positive moods in this study may be evidence that hyperglycemia, as a form of arousal, is a negatively biased influence rather than a valence-free influence. The failure to find a relation between high glucose episodes and positive moods for those adolescents with generally poor metabolic control may reflect a reduced psychological sensitivity to high-glucose levels among these adolescents.

Table 19. *Interactions of Blood Glucose (Category) and Glucose Control on Positive Moods*

Effects	Beta Estimate	*SE*	*df*	*p*
Average Positive Mood	9.66	1.30	15	0.0001
Physical Symptoms	-0.14	0.04	887	0.0006
Negative Moods	-0.36	0.10	887	0.0002
FOH Worry	0.21	0.10	15	0.06
Adolescent Median BG Level	-0.30	0.30	15	0.32
Glucose Control: A_{1C}	-0.58	2.18	15	0.79
BG Category	-0.53	0.26	887	0.04
BG Category by A_{1C}	1.05	0.48	887	0.03

Note. Average Positive Mood is the model intercept. Physical symptoms, negative moods, and FOH (Fear of Hypoglycemia) Worry scale represent the average sum of each effect and are grand centred. Median BG level is also grand centred. A_{1C} is dichotomized on a median split for each adolescent. BG Category is dichotomized and defined as Normal, < 10 mmol/L, or High, => 10 mmol/L for each observation. *N* (Adolescents) = 19. *N* (Observations) = 910.

Table 20. *Post Hoc Analysis of Blood Glucose and Glucose Control on Positive Moods*

	Beta Estimate	*SE*	*df*	*p*
Adolescents with Low A_{1C}s:				
BG Category	-0.53	0.26	887	0.04
Adolescents with High A_{1C}s:				
BG Category	0.52	0.40	887	0.19

Note. Adolescents were categorized as having either Low A_{1C}s, $n = 11$, or High A_{1C}s, $n = 8$ based on a median split. BG category is a dichotomous variable, defined for each observation as Normal, < 10 mmol/L, $n = 619$, or High, => 10 mmol/L, $n = 291$. *N* (Adolescents) = 19. *N* (Observations) = 910.

The nesting of positive mood ratings. The intra-class correlation among positive mood ratings was .60. This indicates that 60% of the variability in positive moods ratings was attributable to differences among adolescents, and 40% was attributable to differences between occasions. Thus, the pool of positive mood ratings was not independent and

depended quite strongly upon which adolescent was providing a given rating. This study is mainly focussed on differences between occasions. The nesting of positive mood ratings emphasizes the need to use a multilevel analytic approach to control for differences among adolescents.

Positive moods variance components. Statistically, some of the adolescent-to-adolescent differences in the relations between glucose levels and positive mood ratings were taken into account through the estimation of random effects. The intercept (or mean positive mood rating) was estimated as a random effect, and so a separate mean positive mood ratings score was calculated for each adolescent. Physical symptom ratings and negative mood ratings were estimated as random slopes. In other words, how physical symptom ratings and negative mood ratings covaried with positive mood ratings was allowed to vary from adolescent to adolescent. This is equivalent to estimating the heteroscedasticity of slopes for the covariates, rather than assuming homoscedasticity of slopes as with the traditional ANCOVA analysis. As well, the random effects themselves were allowed to covary with each other. A comparison of model fits (-2 times the log likelihood) suggested that all of these components should be set as random and allowed to covary with each other. The significance and substantive conclusions of the glucose level by A_{1C} interaction, however, was not altered if these covariates were treated as fixed effects.

Positive-mood model goodness. A summary of the overall quality of the model was calculated as the estimated proportional reduction in prediction error (see Chapter 7 of Snijders & Bosker, 1999). The proportional reduction in prediction error at the occasion-specific level for positive moods was 24%. The proportional reduction in prediction error at the adolescent-specific level for mean positive moods was 20%.

Negative moods. No significant regression-based, high-glucose-relations were found for the negative mood ratings. Therefore, no results are presented for this outcome.

Positive social interactions

Positive social interaction covariates. This model was based upon a multilevel generalized linear model that assumed an underlying poisson distribution of the errors. The final model of fixed effects for positive social interaction ratings are presented in Table 21. The intercept is the mean positive social interaction rating conditional upon the other predictors in the model. Higher negative social interaction ratings were associated with lower positive social interaction ratings. The mean effect for physical symptoms was not significant, but physical symptoms had a significant random effect on positive social interactions (see below), and so was retained in the model. A glucose-related awareness effect also was found. Adolescents with a higher percent of correct categorical glucose estimates (accurate low, normal, or high estimates) reported more positive social interactions[14].

Glucose and positive social interactions. Hyperglycemic episodes due to impaired-insulin function were associated with fewer positive social interaction ratings see Table 21). Hyperglycemia classified as due to excessive glucose intake was not significantly related to the adolescents' positive social interactions, $beta = 0.12$, $SE = 0.08$, $df = 572$, $p < 0.17$. This is the first empirical evidence that different types of hyperglycemia might have different psychological or social consequences. This finding is consistent with the proposed dualistic view of hyperglycemia, that hyperglycemia due to insulin-insensitivity would be more symptomatic than hyperglycemia due to relative insulin deficiency. This type of

[14] Note, a smaller sample size was available because only observations where glucose levels were either normal or classified as due to impaired-insulin function were used. The main effect for glucose awareness and the other covariates were also significant when all observations were included in the analyses.

hyperglycemia also seems to represent a negatively valenced form of arousal rather than valence-free form of arousal because hyperglycemia was associated with fewer positive social interactions.

Table 21. *Main Effects of Blood Glucose Awareness on Positive Social Interactions*

Effects	Beta Estimate	*SE*	*df*	*p*
Avg Positive Social Interactions	1.81	0.16	17	0.0001
Physical Symptoms	-0.03	0.02	578	0.10
Negative Social Interactions	-0.02	0.01	578	0.02
BG Awareness	0.03	0.01	17	0.01
High BG (Impaired)	-0.23	0.10	578	0.02

Note. Average Positive Social Interactions is the model intercept. Physical symptoms and Negative Social Interactions represent the average sum of each effect and are grand centred. BG Awareness is the percent of correct blood-glucose guesses (categorized as Low, Normal, High) per adolescent, grand centred. High BG (Impaired) is the Normal vs High BG observations, interpreted as due to impaired-insulin function. All adolescents except one (n = 18/19) contributed to the n = 158 High BG (Impaired) episodes, and 443 observations are from Normal BG episodes. Fit Statistics: Log Likelihood = 1677.1, AIC = 1683.1, BIC = 1685.9.

N (Adolescents) = 19. N (Observations) = 601.

The nesting of positive social interaction ratings. As a generalized linear model, variance parameter estimates were not directly usable. The intra-class correlation among positive social interaction ratings was crudely estimated as .17, using the assumed normal distribution model of the multilevel Proc Mixed SAS procedure. This indicates that 17% of the variability in positive social interaction ratings was attributable to differences among adolescents, and 83% was attributable to differences between occasions.[15] Thus, the positive social interaction ratings were not independent, and depended upon which adolescent provided a given rating. Again, the focus of the current study was on

[15] Note that the estimate of variance associated with adolescent differences was likely smaller due to the generally low number of social interaction that were reported. If social interactions were more common in this sample, the adolescent-specific variance in social interactions would probably be larger.

differences between occasions. The nesting of scores within adolescents suggested that a multilevel analytic approach was necessary to control for rating differences among adolescents.

Positive social interactions variance components. To control for adolescent-to-adolescent differences among the positive social interaction ratings, adolescent-specific random effects were used in the statistical model. A random intercept was estimated so that a separate mean positive social interaction score was calculated for each adolescent. Physical symptom ratings also were estimated as random to calculate a different slope for each adolescent. The negative social interaction rating covariate was treated as a fixed effect because how negative social interactions relate to positive social interactions was similar across adolescents. The decisions to use fixed or random effects were based upon parsimony and a comparisons of model fit (-2 times the log likelihood) statistics. The significance and conclusions of how hyperglycemia due to impaired-insulin function relates to the positive social interaction ratings were unaltered if all covariates were fixed, or if all were treated as random and allowed to covary with each other. Given the complexity associated with variance estimates in multilevel generalized linear models, reductions in prediction-error variance were not calculated.

Negative Social Interactions

Negative social interactions covariates. This social interaction model was based upon a multilevel generalized linear model analysis that assumed an underlying poisson distribution of the errors. The fixed effects of the final model for negative social interactions are presented in Table 22. The intercept is the mean negative social interaction rating conditional upon the other predictors in the model. The positive social interaction rating covariate was significantly correlated with negative social interaction ratings. The physical symptom score was not significant as a fixed effect, but the score was a significant

random effect for negative social interactions (see variance component description below), and so was retained in the model. Three adolescent-level characteristics were also significant covariates of negative social interaction ratings. Higher Satisfaction scale scores of the Diabetes Quality of Life were associated with fewer negative social interaction ratings. Higher Worry scale scores of Diabetes Quality of Life were associated with more negative social interaction ratings. The Fear of Hypoglycemia Behavioural Avoidance subscale was associated with fewer reported negative social interactions ratings.

Table 22. *Interactions of Blood Glucose and Glucose Awareness on Negative Social Interactions*

Effects	Beta Estimate	*SE*	*df*	*p*
Avg Negative Social Interaction	0.89	0.13	14	0.0001
Physical Symptoms	0.03	0.02	886	0.17
Positive Social Interactions	-0.04	0.01	886	0.03
DQOL Satisfaction	0.00	0.00	14	0.02
DQOL Worry	2.46	0.44	14	0.0001
FOH Avoidance	-0.72	0.12	14	0.0001
BG High (All types)	-0.02	0.10	886	0.82
BG Awareness	0.00	0.01	14	0.51
BG High x BG Awareness	0.02	0.01	886	0.007

Note. Average Negative Social Interaction was the model intercept. Physical symptoms, Positive Social Interactions, DQOL subscales, and FOH subscale represent the average sum of each effect and were grand centred. BG High referred to a dichotomized variable with normal glucose levels =0 and all types of High glucose => 10 mmol/L. BG Awareness is the percent of correct categorical guesses per person, grand centred. *N* (Adolescents) = 19. *N* (Observations) = 910.

Glucose and negative social interactions. A significant glucose-awareness by glucose effect was found for negative social interactions (see Table 22). Post-hoc analyses showed that among adolescents with a higher percent of correct categorical glucose estimates, all types of high-glucose episodes (i.e., glucose levels > 10 mmol/L) were

associated with more negative social interaction ratings (see Table 23). For those adolescents with fewer percent correct categorical estimates, glucose was not related to negative social interactions. For those adolescents with high levels of glucose awareness, hyperglycemia is associated with more negative social interactions. Thus, hyperglycemia acted as a negatively biased form of arousal rather than a valence-free form of arousal. Opposite to that predicted by the arousal-awareness models, greater glucose-awareness was associated with a stronger relation, rather than a weaker relation, between high-glucose levels and negative social outcomes.

Table 23. *Post Hoc Analysis of Blood Glucose and Glucose Awareness on Negative Social Interactions*

	Beta Estimate	*SE*	*df*	*p*
Adolescents with Low Awareness:				
BG High Category	-0.20	0.13	886	0.13
Adolescents with High Awareness:				
BG High Category	0.25	0.12	886	0.04

Note. Awareness is the percent of correct blood-glucose guesses with low levels equal to 1 *SD* below the grand mean level and high levels equal to 1 *SD* above the grand mean. BG category is a dichotomous variable, defined for each observation as Normal, < 10 mmol/L, $n = 619$, or High, => 10 mmol/L, $n = 291$. All adolescents contributed to the $n = 467$ High BG episodes, and 443 observations are from Normal BG episodes. Log Likelihood = 3499.2, AIC = 3513.2, BIC = 3519.8. BG High is not significant. N (Adolescents) = 19. N (Observations) = 910.

The nesting of negative social interactions. As a generalized linear model, variance parameter estimates were not directly usable. Instead, the estimated intra-class correlation among negative social interaction ratings was estimated at .10 using the normal distribution model of the multilevel Proc Mixed SAS procedure. Thus, 10% of the variability in negative social interaction ratings was attributable to differences among

adolescents, and 90% was attributable to differences between occasions [16]. The focus of this study was on differences between occasions. This lack of independence among occasion-specific negative social interaction ratings pointed to the need for a multilevel analytic approach.

Negative social interactions variance components. Adolescent-specific random effects were used in the statistical model to control for adolescent-to-adolescent differences in the negative social interaction ratings. The intercept, or mean negative social interaction rating, was estimated as a random effect, so that a separate mean rating score was calculated for each adolescent. As well, both physical symptom and positive social interaction ratings were estimated as random slopes. Thus, how physical symptoms and positive social interactions related with negative social interaction ratings was allowed to vary from adolescent-to-adolescent. As well, the random effects for the intercept and both occasion-specific covariates were allowed to covary with each other. These decisions were based on a comparisons of model fit (-2 times the log likelihood) statistics. The post-hoc comparison became non-significance when the random effects were fixed. The pattern of relations between hyperglycemia and negative social interactions, however, was the same. Again, given the complexity associated with variance estimates in multilevel generalized linear models, reductions in prediction-error variance were not calculated.

DISCUSSION

This dissertation research examined how aberrant glucose levels influence the moods and interpersonal interactions of adolescents with Type 1 diabetes. From a theoretical perspective, among the various psychological models of arousal, glucose-related influences are consistent with an automatic and negatively biased model of arousal.

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[16] As with positive social interactions, the estimate of variance associated with adolescent differences was likely smaller due to the generally low number of social interaction that were reported.

In the field of glucose-related influences on individual's behaviours, the current study assessed two new issues. This initial study provides the first systematic field data of how high glucose levels relate to the social interactions of adolescents with Type 1 diabetes. The evidence suggests that high-glucose levels alter the quality of adolescents' social interactions by decreasing their positive social interactions and increasing their negative social interactions, given certain moderating factors. The second issue investigated how a dualistic view of hyperglycemia may be helpful in better assessing the psychological impact of abnormally high-glucose levels. The specific hypothesis was that insulin-insensitivity hyperglycemia is more symptomatic than insulin-deficiency hyperglycemia. Hyperglycemia, classified as due to impaired-insulin function, was uniquely associated with lower positive social interaction ratings. However, insulin-insensitivity hyperglycemia was not significantly related to positive mood and negative social interaction ratings. Thus, the evidence for the proposed dualistic model of hyperglycemia should be viewed as preliminary. The overall findings, how they related to the extant literature, and how future studies can build upon these findings are discussed below.

Arousal Models and Glucose Effects

An arousal based model for how abnormal fluctuations in glucose levels affects people's moods and social interactions appears quite reasonable. Abnormal glucose levels are associated with various indicators of physiological arousal (Cryer, 1997; Zillman & Zillman, 1996). Furthermore, the physiological effects of glucose fluctuations represent a relatively general, unfocussed form of physiological arousal (Zillman & Zillman, 1996) similar to other forms of general physiological arousal such as exercise (Bunce et al., 1993; Sinclair et al., 1994) and external temperature increases (Anderson et al., 2000).

In three of the four outcomes, abnormally high-glucose levels are, in some form, associated with changes in mood and social interaction ratings. For positive moods,

hyperglycemia is associated with lower positive mood ratings for those adolescents with better metabolic control. Similarly, fewer positive social interaction ratings are associated with hyperglycemia that was classified as due to impaired-insulin function. Finally, more negative social interactions are associated with high glucose episodes for those adolescents who exhibited relatively high levels of glucose awareness.

How the current findings relate to psychological models of arousal depends largely on the evidence for glucose-related awareness effects. The psychological models of arousal mainly differ in the importance assigned to awareness or ambiguity of the underlying source of arousal. For example, the *Transfer of Excitation* model proposes that awareness of arousal is a critical component in determining the effect general physiological arousal has on the behaviours of individuals. Specifically, under the *Transfer of Excitation* model, awareness that one's current arousal is due to a previous event or due to a cause unrelated to the current event will negate its amplifying effect on a current interaction. Other arousal models suggest that awareness of arousal does not necessarily negate the influence of arousal, but can adjust or weaken its amplifying effects (Cacioppo et al., 1996; Foster et al., 1998). Finally, other models of arousal propose that awareness has no substantial effect on how arousal influences individuals' interpersonal behaviours and perceptions (Allen et al., 1989).

In this study, two types of awareness were evaluated as potential moderators of glucose-related influences. The perception of glucose-related effects as measured by the total number of physical symptoms and moods believed to be influenced by low and high glucose episodes was one measure of awareness. Glucose-estimation accuracy represented the other type of glucose-awareness measure. Four different versions of glucose-estimation accuracy were assessed. Each measure represented how well adolescents were able to estimate their glucose levels. At each observation, adolescents' estimated their current glucose level as a categorical guess (low, normal, or high) and as a continuous

numerical guess (in mmol/L). For each adolescent, the percent of accurate categorical glucose estimates and the mean absolute deviations in continuous glucose estimation accuracy was calculated.

In the current study, there is no evidence that awareness of glucose-related effects dampens the strength of the relation between glucose levels and moods and social interactions among adolescents with Type 1 diabetes. This finding is consistent with an early study of glucose levels and moods (Moses & Bradley, 1985). In their study of adults with Type 1 diabetes, glucose estimation accuracy did not differ between those participants with significant glucose-mood relations compared to those participants without any significant glucose-mood relations.

The current results are not consistent with either the *Transfer of Excitation* model or the *Arousal-Adjustment* models. The findings are more consistent with the *Response Facilitation* model where high-glucose levels exhibit a fairly direct influence on moods and social interactions. As well, in all three outcomes, higher glucose levels (or greater arousal) were associated with less positive or more negative psychological outcomes. Thus, the results are consistent with the Negatively Biased model of arousal rather than a valence-free model of arousal. High-glucose levels appear to function as a form of negatively valenced arousal.

Cautionary Notes

No awareness effect. The general lack of evidence for awareness-related effects may have arisen due to methodological short-comings of the study. As always, a larger sample size would be preferable to strengthen confidence in a null result. Better measures of awareness may be needed and better variability in outcome ratings also would have been preferable. As well, the relation between glucose levels and moods and social interactions themselves are not overwhelming strong, and so, not a lot of variance is available to be

moderated. Nonetheless, no reliable evidence is available that glucose awareness dampened how hyperglycemia relates to the moods and social interactions of the adolescents in this study.

Specific to hyperglycemia. In the current study, glucose appears to function as arousal that enhances the likelihood of experiencing negative social interactions and reduces the likelihood of experiencing positive moods or social interactions. Previous studies, however, suggested that arousal can function as a valence-free form of arousal that magnifies whatever mood or activity (positive or negative) is prevalent at the moment including aggression, prosocial behaviour, interpersonal liking, or romantic attraction (see reviews by Anderson, 1989; Cacioppo et al., 1996; Cotton, 1981; Reisenzein, 1983; Zillman, 1984). The main difference between the current study findings and the other studies may be that high-glucose levels are based upon a pathological health condition. In previous studies, sources of arousal included elevated external temperatures (Anderson, 2002), exercise (Bunce et al., 1993; Sinclair et al. 1994), or emotionally evocative psychological materials or interpersonal interactions (Foster et al. 1998). These are not pathological states of arousal. Under these less pathological conditions, arousal effects may be valence-free (Allen et al., 1989; Zillman & Zillman, 1996).

A glucose by awareness interaction. A significant glucose level by awareness interaction was present for negative social interaction ratings. The post-hoc analyses revealed an empirical pattern directly opposite to that which was expected under the arousal-awareness models (Cacioppo et al., 1996; Zillman, 1984). Among those adolescents with high levels of glucose awareness (higher percent of categorically correct glucose estimates), hyperglycemia is associated with more negative social interactions. Those adolescents with average or lower glucose awareness levels do not show evidence of a significant relation between hyperglycemia and negative social interactions. One interpretation of this unexpected finding may be that a reliable relation between glucose

levels and negative social interactions may lead to improved glucose estimation awareness and accuracy. Although no evidence of such an effect was found for positive moods or positive social interactions, negative social interactions may be particularly salient and encourage more cognitive reflection and thought. Some research suggests that negative emotions and moods initiate a more thorough cognitive attributional investigation of events (Forgas, 1995, 1998). Under this interpretation, increased glucose awareness is an outcome rather than a moderator of the glucose-negative social interaction relation. Negative social interactions may act as a signal that glucose levels are currently high. Another potential interpretation is that awareness that one is currently hyperglycemic could lead to negative feelings that, in turn, lead to a greater likelihood of having negative social interactions.

Hypoglycemic Effects

Although low glucose levels also may function as a form of physiological arousal, in this sample, hypoglycemia was quite rare. Only 69 or 6.7% of the 1028 recorded glucose levels were below 4.0 mmol/L. Given this limited database, rather than assess the larger project questions, simpler individual item analyses were conducted to compare with previous empirical findings. Within-adolescent analyses showed that low glucose levels appear to be associated with shakiness, hunger, sweatiness, and difficulty thinking, as well as an increased likelihood of experiencing negative moods, such as feeling grouchy, argumentative, frustrated, worried, or acting oddly. When all the observations are pooled and within-adolescent nesting of observations is ignored, low-glucose levels are associated with shakiness, sweatiness, and increased likelihood of being in an argumentative mood. Although the specific low glucose findings of this study must be considered as very tentative given the limited data upon which they are based, the findings are very consistent with a much larger field of empirical evidence.

Laboratory studies, field studies, and larger sample surveys reveal consistent evidence of low glucose-related physical symptoms: cognitive deficits, negative mood changes, and a greater likelihood of behaving oddly (e.g., Boyle et al., 1988; Draelos et al., 1995; George et al., 1995; Hepburn et al., 1991; McCrimmon et al., 1995a; McCrimmon et al., 1995b; Mokan et al., 1994; Ross et al., 1998; Weinger et al., 1995; Widom & Simonson, 1992; Wiebe et al., 1994). These findings are based upon studies of adults, adolescents, and children. The person-to-person variability in low-glucose reactions common in field studies (Cox et al., 1985a; Freund et al., 1986, Gonder-Frederick et al., 1989; Nurick & Johnson, 1991) may partly explain the limited number of significant correlations in Tables 15-17. Such variability may be due to a variety of factors, including the less extreme hypoglycemic levels typically encountered in the field and less systematic monitoring of low-glucose reactions than takes place in a lab setting. Systematic evidence concerning social interactions, which are not amenable to lab studies, however, is still limited (see reviews by Gold et al., 1997 or Gonder-Frederick et al.,1997).

Hyperglycemia: Social Interactions, Moods, and Valence

Systematic evidence for hyperglycemic influences on the short-term psychological functioning of individuals is limited. Hyperglycemic effects may be generally less obvious than hypoglycemia effects. Yet, ample anecdotal evidence is available on how high-glucose levels are associated with changes in the moods and social interactions of people with diabetes (e.g., Dashiff, 1993; Deatrick & Knafl, 1990; Jensen, 1985; Strang, 1994). Thus, a discrepancy seems to exist in everyday observations and results from systematic studies of hyperglycemia. Methodological limitations were proposed to account for some of these empirical differences.

Social interactions highlighted. One of the motivations for examining social interactions was that they represent how two or more individuals behaved towards each

other. Moods, in contrast, only reflect feeling states which may or may not be linked to how an individual is currently behaving. Furthermore, many psychological studies of arousal show that contextual clues frequently trigger the behaviours magnified by the general physiological arousal (Foster et al., 1998; Reisenzein, 1983; Schachter & Singer, 1962; Zillman, 1984). Social interactions are filled with contextual cues and stimuli, and so may be more likely to trigger arousal-based changes in behaviour. Empirical differences in moods and social interactions were evident in the current study. Both positive and negative social interaction ratings show more within-adolescent variability than moods ratings (see Table 14).

More importantly, the significant relations between hyperglycemia and positive and negative social interactions provide the first systematic, and preliminary, evidence for hyperglycemic effects on the social interactions of adolescents with Type 1 diabetes. The association between glucose levels and positive social interactions was restricted to hyperglycemic episodes classified as due to insulin insensitivity. The association between glucose levels and negative social interactions was restricted to those with better metabolic control. High glucose levels are not related to negative mood ratings in the current study. This result may imply that negative social interactions are more susceptible to hyperglycemic effects than negative moods.

Two earlier field studies, however, did show systematic evidence of hyperglycemia-related changes in both positive and negative moods (Gonder-Frederick et al., 1989; Moses and Bradley, 1985). The current sample of adolescents reported fairly restricted levels of negative mood ratings. This may account for the failure to find a relation between hyperglycemia and negative moods. Previous research shows that adolescence is a period of emotional volatility and increases in negative moods are more common than increases in positive moods (Arnett, 1999; Buchanan et al., 1992; Larson & Richards, 1994). The relatively restricted range of negative mood ratings may be sample

specific. This restriction in ratings also may relate to the mood-sampling method used. Mood ratings were requested just prior to glucose testing. Semi-random mood sampling procedures used in other adolescent studies may be preferable in future studies (e.g., Larson & Richards, 1994).

Positive versus Negative. Similar to other studies (e.g., Watson et al., 1999), individuals in this study tended to report more positive moods or social interactions than negative moods or social interactions (see Table 14). Little systematic data is available on the relation between hyperglycemia and moods, but the data that is available suggests that relations between glucose-levels and moods tend to be very idiosyncratic. One study did report that positive moods were more consistently associated with hyperglycemia than hypoglycemia (Gonder-Frederick et al., 1989).

Glucose sensitivity effects on positive moods. In the current study, the relation between positive moods and hyperglycemia was restricted to those adolescents with better metabolic control (values ≤9.3%). Higher glycosylated hemoglobin levels represent poorer metabolic control generally. Among those adolescents with better metabolic control, that is glycosylated hemoglobin levels (A_{1C}s) in the lower 50% of the sample, high-glucose levels were associated with fewer positive moods (see Table 20). Adolescents with higher glycosylated hemoglobin (A_{1C}s) levels did not show a relation between hyperglycemia and positive moods. Living with continuously elevated glucose levels may result in psychological adaptations, so that hyperglycemia does not exert as strong an influence on an adolescents' moods and social interactions.

The earlier adult studies of glucose-mood relations (Gonder-Frederick, 1989; Moses & Bradley, 1985) reported that hyperglycemic (and hypoglycemic) relations with mood ratings are very idiosyncratic. For example, one person might exhibit a positive correlation between calmness and hyperglycemia, while another exhibits a positive

correlations between dejection and hyperglycemia (Moses & Bradley, 1985). The metabolic control differences found in the present study may contribute to the idiosyncratic nature of glucose-relations frequently reported (e.g., Cox et al., 1985a; Freund et al., 1986; Gonder-Frederick et al., 1989; Nurick & Johnson, 1991; Pennebaker et al., 1981; Wiebe et al., 1994).

Dualistic Model of Hyperglycemia

An alternative conceptualization of the symptomatic effects of hyperglycemia also was proposed and tested in this research project. Basic physiological evidence is accumulating that insulin insensitivity, as well as insulin deficiency, plays an important role in metabolic control and hyperglycemia (DeFronzo et al., 1982; Mäkimattila et al., 1996; Vuorinen-Markola et al., 1992; Yki-Jarvinen & Koivisto, 1986, see Greenbaum, 2002 for a review). The first proposition in this dualistic model of hyperglycemia was that hyperglycemic episodes can be classified as largely due to either 1) relative insulin deficiency, or 2) relative insulin insensitivity. Relative insulin deficiency was defined as a relative excess of glucose intake, not an impairment in glucose uptake. Insulin insensitivity, on the other hand, was defined as impaired glucose uptake. The second proposition, and the hypothesis tested in this study, was that hyperglycemia due to insulin insensitivity is more psychologically or behaviourally symptomatic than hyperglycemia due to insulin deficiency. This insulin-insensitivity hypothesis was based upon the logical expectation that insulin-insensitivity represents a more extreme physiological state than that of insulin-deficiency among individuals with Type 1 diabetes receiving daily insulin treatments.

Empirically, the results of the current study provided, at best, tentative support for the proposed dualistic model of hyperglycemia effects. Consistent with this hypothesis was the finding that positive social interaction ratings were significantly and uniquely related to the insulin-insensitivity hyperglycemia. Contrary to the hypothesis, unique associations

between insulin-insensitivity and the other outcomes was not evident. Much more evidence and research is needed before conclusive statements can be made about this dualistic model of hyperglycemia.

Physiological Speculations

A thorough evaluation of the potential physiological mechanisms by which hyperglycemia may alter social and emotional outcomes is well-beyond the scope of this research project. However, below is a non-systematic sampling of potentially relevant physiological findings on how hyperglycemia may relate to the cognitive-emotional functioning of adolescents with Type 1 diabetes mellitus.

The role of insulin function on glucose metabolism in the brain is somewhat controversial. The dominant position is that insulin does not play a significant role in glucose uptake in the brain. For example, recent researchers using functional brain imaging studies concluded that neither hyperglycemia (Gruetter, Uğurbil, Seaquist, 2000; Hasselbach, Knudsen, Capaldo, Postiglione, & Paulson, 2001) nor insulin (Hasselbach et al., 1999; Seaquist, Damberg, Tkac, & Gruetter, 2001) have any substantial effect on glucose metabolism or blood brain barrier glucose transport in the brain. In contrast, Bingham et al. (2002), based upon their functional brain imaging results, concluded that "basal insulin has a role in regulating global brain glucose uptake in humans, mostly marked in cortical areas" (p.3384).

Earlier *in vitro* research investigations suggested that insulin *per se* may influence brain function. Increased levels of circulating insulin, associated with insulin resistance, has been associated with reduced hippocampal function (Palovcik, Phillips, Kappy, & Raizada, 1984) and reduced acetylcholine synthesis (Brass, Nonner, & Barrett, 1992). Neural and neurochemical changes that would be expected to alter brain function. Peripheral hormonal responses including changes in epinephrine and cortisol responses were also associated

with elevated glucose levels (Zillman & Zillman, 1996). Such hormones changes are frequently associated with cognitive-emotional changes in individuals (Cacioppo et al., 1996; Zillman & Zillman, 1996). These physiological findings represent, at most, vague possibilities of how hyperglycemia may explain the associations between moods and social interactions found among adolescents with Type 1 diabetes.

Strengths and Limitations

The current study possessed a number of strengths and limitations. A review of these characteristics should help in evaluating the current study results.

Sample Sizes. An initial, multilevel power analysis suggested that 20 participants each providing 45 observations should provide sufficient statistical power to identify underlying correlations of .30 between glucose levels and ratings of mood and social interactions. The power-analysis estimates, however, were necessarily based upon numerous tentative estimates. With 20 adolescents providing a mean of 51 observations per adolescent, the sample sizes in this study should have been adequate. Although several significant relations did emerge among glucose levels and outcome ratings in the present study, larger samples are always desirable (Cohen, 1990). The population from which this sample was recruited is relatively rare. A total of 97 eligible adolescents are known to live within the city limits. Thus, from a practical perspective, a sample size of 20 was a definite success.

Data variability. The conclusions rest not just upon the size of the sample and the number of observations collected, but upon the variability in responses. In the current study, negative mood and social interaction ratings were somewhat limited in variability. As well, few hypoglycemic episodes were present in the dataset. As a result, no conclusive examination of hypoglycemia-related influences on moods and social interactions was possible. Hypoglycemic-related influences, however, do not represent the central

contribution of this study. Considerable information was available on the consequences of hypoglycemia on moods, if not social interactions. In the current research study, a sufficient number of hyperglycemic episodes was available to provide a reasonable assessment of their effects on moods and social interactions. As with sample size, more data and variability would be beneficial.

Statistical approach. A relatively new statistical approach, multilevel regression modelling, was used in this study (for more details on this approach see Hox, 2002; Raudenbush & Bryk, 2002; Snijders & Boskers, 1999). As a new statistical approach, it provided a number of statistical benefits and a few limitations commonly associated with new developments. With the use of this multilevel analytic approach, a number of typical assumptions were relaxed to provide a more realistic representation of the underlying relations among the variables. The resulting regression models included the calculation of separate means (intercepts) for each adolescent and the estimation of slopes between covariates and outcomes that were free to vary from person-to-person. With the use of occasion-specific covariates in all the regression models, the likelihood that the results were due to methodological confounds, such as a tendency to use only one part of the rating scale were largely eliminated. Similarly, time-of-day effects, feeling physically unwell, or any other number of influences that might apply generally to outcome ratings were statistically removed from the model. One statistical limitation encountered was that a standardized method for estimating the amount of variance explained is not yet available for analyses based upon generalized linear regression models.

Handheld computer data collection pros. The use of handheld computers for data collection was also noteworthy. The use of handheld computers appealed to the adolescents and appeared to enhance recruitment and continued-participation throughout the duration of the study. No participating adolescents dropped out the study, and all adolescents provided data throughout the 3-week period of data collection. This

computer-based data collection method also provided enhanced privacy and security of the adolescents data. Once a trial was completed the data were no longer accessible. This also provided assurance that the adolescents, themselves, did not try to change their responses after the fact. Furthermore, all observations were date- and time-stamped. This enables additional checks on the data to ensure a reasonable passage of time has occurred between trials and within trials. Such benefits of using hand-held computer technologies have been noted by other researchers as well (e.g., Whalen et al., 2002).

Handheld computer data collection cons. Computer-based data collection is not without potential pitfalls. Equipment failure lead to lost field study data. And although time-date stamping provides an important check on the temporal sequencing of data entry, a participant could circumvent within-trial sequence checks if motivated. Glucose-entry validity checks were not available because the adolescents' glucose monitor records were not available. To encourage proper data collection entry, the importance of completing item ratings prior to glucose testing was emphasized. The level of glucose estimation accuracy, which was not particularly high, suggests that the data collection procedures were followed as instructed.

Differentiating types of hyperglycemia. To test the dualistic model of hyperglycemia, a measure of the primary cause of hyperglycemia was needed for every episode of hyperglycemia reported. An indirect, crude classification method was developed based upon the adolescents' beliefs about the cause of their current hyperglycemic episode. A classification system based on perceived causes of high glucose levels was necessarily crude.

One empirical limitation in this classification system was that most of the reported causes for insulin insensitivity episodes were based upon *not sure* responses rather than specific responses such as *am sick* or *high stress.* Another limitation was that prior

episodes of hypoglycemia, which can induced insulin insensitivity, were not linked to subsequent hyperglycemic episodes. Such an examination would have required more data than was available in the current study. A third limitation was that the list of possible causes of hyperglycemic episodes could have been more extensive. For example, although *forgetting or delaying insulin* administration were options, *taking less insulin than usual* was not included in the hyperglycemia list of potential reasons. However, a general assumption in this study was that the adolescents understood that the goal of these hyperglycemia follow-up questions. The goal was to identify the most likely reason(s) for experiencing a hyperglycemic episode. With such an understanding, I would expect that adolescents would select the causal response options most consistent with their perceived cause of hyperglycemia. So, in the case of taking less insulin than usual, the adolescent could select the parallel causal response option of having had extra foods or drinks (relative to the amount of insulin administered). If this was the case, the same hyperglycemia classification of relative insulin deficiency would be selected.

Future Study Modifications

Practical suggestions on how future studies may be improved also arise from the present findings. Longer sampling durations and bigger samples would certainly be preferable. Rating responses, however, tended to drop off somewhat in the last week of participation. Three continuous weeks of multiple ratings per day was probably more demanding than necessary. If one-week data collection intervals were used every 2- to 4-weeks, this would likely decrease participant fatigue and increase participant motivation. Requesting ratings about just moods or just social interactions rather than physical symptoms, moods, and social interactions also would make the demands of participation more reasonable. Although the mean time to complete a given set of ratings was only 3 minutes, a more focussed assessment might be preferable. Random sampling of moods or social interaction ratings throughout the day using a beeper-like method (see

Csikszentmihalyi & Larson, 1987; Larson, 1989) would likely provide more variability in the ratings and range of social interactions encountered. Finally, gathering close-other observer ratings, such as from a parent or sibling, in addition to self-report ratings would provide very valuable information.

Conclusion

The study results provide an unique test of the arousal and arousal-awareness models of moods and social interactions among of adolescents with Type 1 Diabetes Mellitus. The results of this field study represent how the everyday moods and social interaction of adolescents' with diabetes relate to their hyperglycemic episodes. The evidence is generally consistent with the proposal that high-glucose levels function as a form of negatively valenced physiological arousal to reduce positive moods and social interactions and increase negative social interactions. Furthermore, tentative evidence is found that there may be different forms of hyperglycemia with different psychological and behavioural implications. Generally, the study highlights how subtle physiological conditions may influence personal and interpersonal psychological states.

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APPENDICES

Appendix A Details of Type 1 Diabetes Mellitus

Type 1 diabetes mellitus (T1DM) is a chronic endocrinological disease. It is characterized by a low or a complete absence of insulin production. The Latin phrase *diabetes mellitus* describes one of the typical symptoms associated with the onset of T1DM. *Diabetes* denotes "to run through" and *mellitus* denotes "sweet like honey". Thus, diabetes mellitus signifies excessive urination (polyuria) containing unprocessed glucose. Other typical symptoms of T1DM include excessive thirst (polydipsia), fatigue, and weight loss. People with newly diagnosed Type 1 diabetes also often have islet-cell specific antibodies in their plasma and evidence of an abnormal autoimmune response (Brink, 1994). If left untreated, T1DM will lead to death.

Diagnosis. Clinical diagnosis of T1DM is usually made through a patient symptom-report and a fasting or random blood glucose assessment. The diagnosis of diabetes is confirmed when fasting blood glucose levels are greater than 7.7 mmol/L (140mg/dl), when a random blood glucose level is greater than 11.1 mmol/L (200mg/dl), and when the classic symptoms of hyperglycemia (e.g., excessive: thirst, urination, weight loss, fatigue) are present (M. Harris, 1995). If the fasting or random blood glucose tests are inconclusive, an oral glucose tolerance test is administered to determine the patient's ability to process a rapid influx of glucose. Poor performance on this test is diagnostic of diabetes mellitus (M. Harris, 1995).

Type 1 vs Type 2. Type 1 diabetes was previously labeled Insulin Dependent Diabetes Mellitus (IDDM) or juvenile diabetes because the disease often develops during childhood and adolescence (Dorman, O'Leary, & Koehler, 1994). Type 1 diabetes, however, also can develop during adulthood. The onset of Type 1 diabetes among adults is most common among those 30 years or younger and those with lower Body Mass Index scores (BMI < 25 for females and <27 for males; M. Harris, 1995). Type 2 diabetes mellitus (T2DM) is the other major, much more common type of diabetes mellitus, and, until recently, was almost exclusively present in adults (ADA, 2000). With T2DM, individuals are still producing insulin. However, their insulin is not functioning effectively (M. Harris, 1995). Not surprisingly, T2DM symptoms are not as acute as T1DM symptoms initially. As a results, many people suffering from T2DM remain undiagnosed for long periods of time (M. Harris, 1995). By the time, T2DM is diagnosed the condition may have worsened so that these T2DM adults have become dependent on exogenous insulin supplements or insulin replacements (M. Harris, 1995). Thus, although Type 1 and Type 2 diabetes are etiologically distinct, among adults, Type 1 diabetes can be difficult to differentiate from Type 2 diabetes.

Physiological Basis. Individuals with T1DM, unlike those with T2DM, lose the ability to produce insulin, aside from some residual production in the initial stages of the disease. Insulin is a hormone produced by the beta cells of the islets of Langerhans in the pancreas. Insulin plays a crucial role in metabolism. Insulin is responsible for the uptake of glucose from the bloodstream to the metabolizing cells of the body (Dreary, 1992). Glucose is a basic energy source of the human body, with the brain depending largely on glucose as a direct energy source. Both genetic and environmental factors are known to be responsible for the destruction of the insulin producing beta cells (Field, 2002).

Genetic Etiological Influences. Evidence for the genetic basis of T1DM comes from twin and family studies and molecular and biochemical investigations. Twin and pedigree analysis studies show that closely related genetic relatives of diabetics have a higher probability of becoming insulin dependent than more distance genetic relatives (Connor, 1994; Field, 2002). For example, among caucasians, an identical twin has a 1 in 3

risk of becoming diabetic, a sibling has a 1 in 16 risk, while the risk in the general population is 1 in 500 (Connor, 1994, p. 166). A recent review of genetic linkage studies (within families) and population association studies point to more than 20 putative diabetes predisposing genes (Field, 2002). The presence of common antibodies and biochemical markers in genetic relatives adds further convergent evidence regarding the genetic basis of T1DM (Connor, 1994). However, concordance rates among monzygotic twins are not 100%, environmental factors also are part of the etiological story of T1DM.

Environmental Etiological Influences. Researchers have identified several probable environmental risk factors for T1DM: viral agents, particular nutrients and nutritional practices, and psychological stress (Dorman, McCarthy, O'Leary, & Koehler, 1995). The early use of cow's milk instead of human breast milk provides an interesting illustration of how an environmental agent in genetically susceptible individuals may lead to the onset of T1DM. One of the amino acid sections of bovine milk protein (bovine serum albumin) is similar to human beta cell protein (p69) of the pancreas. The immature digestive system of the infant allows the large bovine protein to pass directly into the blood stream and be identified as a foreign agent. The antibodies for this bovine protein may later mistake the human beta cell (p69) as the foreign agent and attack it. The p69 human beta cell, however, only surfaces during periods of physical stress. So, multiple stress episodes and multiple antibodies assaults may be needed before enough pancreatic beta cell damage has occurred before T1DM results among genetically susceptible populations (Dorman et al., 1995). Despite the multifactorial etiological basis of T1DM requiring both genetic predispositions and environmental agents, this is relatively common disease.

Prevalence and Incidence. T1DM is one of the most prevalent chronic diseases in childhood (La Porte, Masato, & Chang, 1995). Incidence rates across age are somewhat bimodal with boys showing a peak around five years of age, and later both boys' and girls' incidence rates increasing around the onset of puberty (Dorman et. al., 1995). The peak at five years for boys may be due to the increase exposure to infectious agents associated with beginning school. While sudden changes in growth and / or hormones are likely candidates for the increase in incidence during puberty (Dorman et al., 1995). For the most part incidence rates do not differ by gender (Dorman et al., 1995). As T1DM is a chronic disease that occurs early in life with no available cure, long term-consequences can pose a serious problem.

Incidence. The number of new cases per year in Manitoba, or the incidence rate, was 20.4 per 100,000 from 1985-1993. Again age-related increases were evident, with incidence rates of 11.1, 21.5, and 28.8 per 100,000 for the birth- to 4-year-olds, 5- to 9-year-olds, and 10- to 14-year-olds, respectively. In the DER-CA, the number of new cases per year is approximately 52 (or one new case per week) with 58 percent of these new patients falling with the 11- to 17-year age range.

Long-term Consequences. Even among individuals who closely adhere to their treatment regimen, diabetes leads to long-term complications and premature death (DCCT Research Group, 1993). Diabetes is associated with microvascular, neurologic, and macrovascular complications. Such complications are associated with an increased risk of blindness, kidney failure, premature cardiovascular disease, stroke, and necessary amputations. However, intensive insulin treatment and close monitoring can reduce the likelihood of suffering from these long-term consequences (DCCT Research Group, 1993).

Appendix B Glucose Estimation Accuracy and Awareness Training

Glucose estimation accuracy may have important health care treatment implications. Although this is not the focus of the current study, I have presented the basic blood glucose estimation accuracy estimates for the sample below. This information may then be used by other researchers using quantitative meta-analytic techniques. I also have included a description of program that was developed to improve brief glucose estimation accuracy.

Sample Estimation Accuracy. The mean percent of correct estimates was 43% (*SD*=16) ranging from 27% to 84%. Correct was defined as guesses within 20% of the actual glucose level and estimated to be hypoglycemic when hypoglycemic. Another more clinically oriented measure of glucose estimation accuracy, the Error Grid Analysis Accuracy Index (AI, see Cox et al., 1985b) also was estimated. The Mean AI score was 19% with a standard deviation of 26, and individual AI scores ranged from -8% to 83%. A negative score means that the adolescent made more clinically problematic guesses than accurate guesses. In the current sample, AI scores were generally quite low and indicate fairly poor glucose estimation accuracy. Both glucose estimation measures indicate that adolescent-to-adolescent variability in glucose estimation accuracy is quite high.

Blood Glucose Awareness Training. In response to the relatively poor glucose estimation accuracy of individual with diabetes, researchers have developed a Blood Glucose Awareness Training (BGAT) program to enhance glucose awareness among adults with Type 1 diabetes (Cox, Gonder-Frederick, Julian, & Clarke, 1995). This BGAT program has proven itself to be quite effective. It has been shown to improve general BG estimation accuracy as well as increase hypoglycemic and hyperglycemic specific detection rates (Cox, Carter, et al., 1988; Cox, Gonder-Frederick, Julian, et al., 1991; Nurick & Johnson, 1991). The benefits of BGAT are particularly good for those showing the poorest BG estimation accuracy (Cox, Gonder-Frederick, Julian, et al., 1991; Cox, Gonder-Frederick, Polonsky, et al., 1995). Longitudinal follow-up studies have shown that these BG specific benefits are relatively enduring and that other positive outcomes, such as reductions in traffic accidents, improved quality of life ratings, and fewer worries about hypoglycemia, also are evident over time (Cox, Gonder-Frederick, Julian, et al., 1994).

BGAT III is the one of the latest version of the BGAT program (Cox, Gonder-Frederick, Julian, & Clarke, 1995). It consists of 8 classes, one class per week, over 8-week period. The first class is an overview of the BGAT program. The next three classes focus on teaching individuals how to identify BG-related changes in physical sensations, cognitive performance, and moodiness or social interactions. The next three content classes focus on improving individuals' understanding and prediction of the effects of insulin, food, and exercise on BG levels, respectively (see Cox, Gonder-Frederick, Julian, & Clarke, 1995 for more details). The eighth, and final class, provides suggestions on what to expect, and how to respond to, future changes in BG-related consequences.

Appendix C Recruitment-Related Forms

1. Mail-Out Recruitment Letter

2. Poster Advertisement for Diabetes Education Resource for Children and Adolescents

3. Consent / Assent Form

4. Telephone Protocol

Mail-Out Recruitment Letters

Dr. Heather Dean's Cover Letter

(It was typed on DERCA Letter Head)

Dear adolescent and parents,

I have enclosed a letter of introduction to a study that Darren Campbell, a doctoral PhD student in psychology at the University of Manitoba, has proposed to evaluate how glucose levels relate to moods and social interactions in adolescents with type 1 diabetes mellitus. I am a member of his thesis committee and Dr Warren Eaton, Professor of Psychology, is his supervisor. Darren approached me to request help in recruiting subjects who might be interested in participating in the study. He has provided me with copies of an introductory letter that outlines his study and stamped blank envelopes enough for all adolescents with type 1 diabetes (for more than 6 months) who are living in or near Winnipeg. Your address label has been added confidentially by the DER-CA secretary and the letter has been mailed from the DER-CA office. If your family is interested in participating in this study or need further information, you can call Darren at 474-9338 or myself at 787-3011 ext# 2 and leave a message with Rowena.

Yours sincerely,

Heather Dean

Medical Director,

Manitoba Diabetes Education Resource for Children & Adolescents

Professor of Pediatrics

University of Manitoba

The Primary Recruitment Letter

Dear Adolescents and Parents,

I am writing to invite you to participate in a new study of adolescents with Type 1 Diabetes. This study is examining how glucose levels relate to the physical symptoms, moods, and social interactions of 12- to 17-year-olds who have diabetes.

Adolescents will use a HandSpring Visor (handheld computer) to rate their symptoms, moods, and social interactions as they go about their daily activities. The study will take about 3 weeks to complete and adolescents will meet 3-4 times with a researcher during the study.

Personal benefits:

I believe that by participating you will become more aware of how your sugar levels relate to your physical feelings, your moods, and your social interactions. Based on the data you provide, you will

1. be told **how accurate** you were at **guessing your sugar levels,** and what **types of errors you tended to make**, and
2. **receive a list** of those **physical symptoms, moods, and social interactions** that were related to **your high and low sugar levels**.

In appreciation, you will receive an **entertainment** pass (miniature golf, bowling, & movie) for each week of data collection. As well, for your volunteer research participation, you also will receive a **Letter of Thanks** that you could include on your resume.

To be **Eligible** you

1. must live in or near Winnipeg,
2. should **be able to read** and **understand English as well as other kids your age**,
3. must NOT be taking any **medications** or **have any other illnesses** that **interfere with your ability to think,**
4. must NOT be taking **any medications** or **have any illnesses that effect your moods**, or how you interact with others, and
5. must have **had diabetes for 6 months or longer**.

More study details are listed below.

Session 1: (about 1½ hours). You and your parent / guardian will provide some basic information about yourself and your family. Adolescents also will get instructions how to use the Handspring Visors.

Parents, you will be asked to

1. provide contact information
2. provide ethnic, education, and income-related family information, and
3. rate how your son or daughter's physical symptoms and moods relate to their sugar levels.

Adolescents, you will be asked about

1. your age, gender, school grade, and how long you have had diabetes,
2. your day-to-day insulin and sugar-testing activities,
3. how having diabetes and experiencing low sugar levels effects you, and
4. what types of *physical symptoms* (e.g., shaky, headache) and *moods* (e.g., irritable, energetic) you often experience when your sugar levels are high and low.

Both you and your parent will be asked for permission to obtain two A_{1C} values from your medical file.

Session 2: (2 ½ to 3 weeks duration) For this part of the study, I will be lending you a **HandSpring** handheld computer.

Using the HandSpring, **each time you test your blood,** you will complete a set of ratings. For reliable data, you need to complete about 50 sets of ratings. Each time you test your blood, you will be asked to

1. rate your physical feelings, moods, and recent social interactions,
2. guess your sugar level and record both your guess and your actual glucose levels, and,
3. if your glucose levels are unusually high or low, identify likely reasons for it.

After about 1½ weeks, a researcher will meet with you to check how things are going and check on the battery needs of the HandSprings.

Session 3: (Final session, about 30 minutes)

Adolescents, you will again be asked about what types of *physical symptoms* and *moods* you experience when your sugar levels are high and low.

The first and last sessions will take place either at the Diabetes Education Resource centre at 685 William Avenue or at the Duff Roblin Building, University of Manitoba, whichever is more convenient.

By participating, you will help us better understand how diabetes affects adolescents' lives. More specifically, you will tell us how social interactions may affect glucose levels or how glucose levels may affect social behaviours. The study will also show us if these sugar-related changes in moods and social behaviours are noticeable, and give us basic information that may help improve the detection of high and low glucose levels.

If you have any questions about this study or would like to join our study, please call us at 474-9338. To talk to DER-CA staff about this project, please call 787-3011 ext. #2.

Note that your participation is strictly voluntary and that your medical treatment will in no way be affected if you decide not to participate.

Sincerely,

Darren Campbell, PhD Candidate

P.S. This research project is for my PhD. degree in the Developmental Psychology , University of Manitoba. I chose this research topic, in part, because I have Type 1 Diabetes. I would like to know how glucose levels relates to day-to-day physical and psychological well-being.

Poster Advertisement

(size and font modified)

Adolescents with Type 1 Diabetes Mellitus

Join a Research Study!

12- to 17-Year-Old Adolescents

Question: How do your blood sugar levels relate to your moods and interactions with others?

What you will do . . .

- Provide some basic information about yourself and tell us how having diabetes affects you.

- Use a Handspring (Palm-like) handheld computer to keep track of your physical feelings, moods, and social interactions for 3 weeks.

Benefits for you

At the end of the study, you will . . .

1. get a list of the physical symptoms, moods, and social interactions that were related to your high and low sugar levels

2. find out how accurate you are at estimating your blood sugar level

3. receive entertainment passes (miniature golf, bowling, and a movie pass)

General Benefits

By participating, you will help us better understand how diabetes affects the lives of adolescents.

Specifically, you will help us understand . . .

a. how well adolescents can detect changes in their glucose levels

b. how high or low sugar levels relate to the moods of adolescents

c. how social interactions affect sugar levels or how sugar levels may affect social interactions

If you wish to find out more or participate, please call 474-9933 Ext. 2 and leave a message.

Sincerely,

Darren Campbell, PhD Candidate

Psychology Department

University of Manitoba

Consent / Assent Form

(compressed format)

Project: Glucose Levels, Symptoms, and Social Interactions Among Adolescents with Type 1 Diabetes

Principal Researcher: Darren W. Campbell, Ph.D. Candidate, Psychology, U.of Manitoba

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

Purpose of this study

1. Learn how your high and low-blood glucose (sugar) levels are related to the short-term physical health, moods, and social behaviours

2. Find out how noticeable these glucose-related changes are to adolescents with Type 1 diabetes

Participation includes 3 sessions

Session 1 (about 1 hour)

You tell us

1. your age, gender, school grade, and how long you have had diabetes,
2. your insulin treatment (*when, how, and how much insulin you use*),
3. give us access to your recent A_{1C} values ($A_{1C's}$ just *before*, and just *after* the study),
4. how having diabetes and experiencing low sugar levels affects your quality of life, and
5. what types of *physical symptoms* (e.g., shaky, headache), *moods* (e.g., irritable, energetic), and / or *social interactions* (behaving silly) you experience when your sugar levels are high and low.

A parent or guardian also will be asked to tell us how they think your sugar levels are related to your physical symptoms, moods, and social interactions.

Session 2 (3 weeks)

Each time before you test your sugar level, you will use a Handspring handheld computer to

1. rate how you feel from a list of symptoms and moods,
2. tell us about any social interactions you had in the last hour
3. guess your current sugar level and record your actual current sugar level, and
4. check off the reasons you are high or low, if your sugar levels are very high or low

You will be asked to do this about 3 times per day until you have completed 50 trials or 3 weeks of data collection.

5. meet with a researcher after a week or so to download your data and check the battery

Session 3 (about 1 hour)

To see if your feelings have changed, tell us

1. how having diabetes affects your quality of life
2. rate the *physical symptoms*, *moods*, and *social interactions* you experience during highs and low sugar levels

For your safety

We do not believe that taking part in this study is harmful to you or increases your risk of harm. In fact, the increased attention to your sugar levels throughout the day, which is required to take part in this study, should reduce your chances of experiencing problems related to high and low sugar levels.

Note. Although we are asking you to do ratings each time you test your sugar levels, if you feel low, we want you to test and treat yourself as needed before you do any ratings. When you feel better, you can describe how you felt and what you were doing before you treated yourself.

For your privacy

In order to send you personal feedback and stay in contact with you throughout the study, we will need to link your name with your personal information. However, your personal data will always be kept confidential. Each person in the study will be given their own ID number and this number will be used in the study. We will keep computer information in a secure, computer directory and we will store personal information in a secure, locked room.

Feedback and Gifts of Appreciation

Personal feedback

After the study, we will tell you

1. how good you were at guessing your sugar levels and what types of errors you end to make
2. which physical symptoms, moods, and social interactions that were linked to your high and low sugar levels

General feedback

After the study is done, we will send you an overall summary of the study results, and we will also present the results at the next annual DERCA research day.

Gifts of Appreciation

We will give you

1. bowling and miniature golf passes for each week of data collection you complete
2. a letter thanks that you can include in your resume for your volunteer research participation

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to

participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Your signature also indicates that you will return the equipment (a Handspring Visor) loaned to you for data collection purposes at the end of the data collection period, and you will ensure, to the best of your ability, that the equipment is in the same condition it was in, when it was lent to you.

Principal Researcher: Darren W. Campbell, Phone: 474-9338

Supervisor: Dr. Warren O. Eaton, Phone: 474-9739

Committee Member: Dr. Heather Dean, Phone: 787-3011

Note that your participation is strictly voluntary and that your medical treatment will in no way be affected by not agreeing to participate.

This research has been approved by the Psychology / Sociology Review Ethics Board. **If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Secretariat at 474-7122. A copy of this consent form has been given to you to keep for your records and reference.**

_____

Participant's Signature Date

I have witnessed my son / daughter read and sign the above consent form. As well, I have read the consent form myself and agree with my son's / daughter's decision to participate in this study. I also consent to participate myself as requested above.

_____

Parent's or Guardian's Signature Date

_____

Researcher and/or Delegate's Signature Date

Glycosylated Hemoglobin (A_{1C}) Information Request

I would like your permission to have a staff member of the Diabetes Education Resource for Children and Adolescents record and give to me two glycosylated hemoglobin (A_{1C}) estimates from your (and your son's or daughter's) medical chart.

The 2 A_{1C} measures, I am requesting are:

1) the last A_{1C} measure available just before the start of data collection, and

2) the first A_{1C} measure available just following the data collection.

Because this is Personal Health Information, it falls under the Personal Health Information Act, and so is given special attention. You do not need to approve this request in order to remain in the study.

I ask for access to this information because A_{1C} estimates are necessary to assess the comparability of this sample of adolescents with other samples. The reporting of A_{1C} sample averages is standard practice in studies of individuals with Type 1 Diabetes Mellitus.

As with the other data gathered in this study, the data will

be kept *confidential* and *secure*,

be stripped of any *personal markers* at the earliest possible occasion,

Not be personally identifiable in any presentations or publications, and

will only be used to characterize the sample or related to the other information gathered in the study.

If you understand and agree this request, please print and sign your names below.

Sincerely, Darren Campbell

I, _____, give permission for a designated staff member of the Diabetes Education Resource for Children and Adolescents to record and give to Darren Campbell two glycosylated hemoglobin estimates (see 1 and 2 above for the specific estimates) from my medical chart.

_____

Participant's Signature Date

I, _____, give permission for a designated staff member of the Diabetes Education Resource for Children and Adolescents to record and give to Darren Campbell, or a designate, two glycosylated hemoglobin estimates (see 1 and 2 above for the specific estimates) from

the medical chart of my son / daughter, _____,.

_____

Parent's or Guardian's Signature Date

Telephone Protocol

Hi, this is *name goes here* from the University of Manitoba phoning about the Diabetes adolescent study.

Name? _____ M or F

Do you have any new questions about the study? Yes / No

(see Recruitment Letter for study details).

So, would you still like to participate? Yes /No

If yes, great!

Before scheduling the first appointment, we should go over the eligibility checklist.

0. Can you tell me your birthdate (the age check)? _____ (dd/mm/yyyy)

1. You live in or nearby Winnipeg? Yes /No

2. Have you **had diabetes** for **6 months or longer**? Yes /No

3. Are you **able to read and understand English** as well as other kids your age. Yes /No

4. Are you taking any **medications or have any other illnesses** that **interfere with your ability to think.** Yes /No

5. Are you taking **any medications or have any illnesses that effect your moods**, or how you interact with others. Yes /No

Is there any reasons you can think of that would keep you from being able to understand and complete this study? Yes / No

If YES, what is it? ... Based on the reason, should the person be EXCLUDED? Yes / No

If YES, then say, "Given your specific situations, joining this study is probably not a good idea. But, thank you very much for calling and checking with us."

If NO, then . . .

Let's try a find a good time for you and your parent/son/daughter to meet at the DER.

For the first meeting takes place at_____ . The first meeting will take about an hour.

We have some questions for you and we will have a Handspring HHC for you to borrow for the next part of the study. We'll show you how to use it before you go.

The first week available for you to start the field study is _____.

Could you start participating on that week? Yes / No

So, could we meet on *day goes here* ? If no, what would be the first day you are available that week?

On weekdays: How about at 4:30 pm? 6 pm? 7:30 pm?

Alright, I'll see you on _____ *day & date* at _____ *time* at _____.

Thanks. See you then.

Appendix D Donation Solicitation Forms

1. Telephone Request Protocol

2. Letter of Request

3. Thank You Letter

Telephone Request Protocol

Telephone request:

Hello. May I speak to the manager?

Hi. My name is Darren Campbell. I'm a doctoral student at the U. of Manitoba conducting a study on teenagers with diabetes. I was phoning to ask for donations that I could use to encourage the teenagers to participate in the study and to keep participating throughout the study. Could I tell you a bit more about the study?

To get reliable data, I need the participants to participate for about 3 weeks. The study is about how blood sugar levels affect teenagers moods and social relationships. I would like to be able to give them something to join the study and keep participating for the whole 3 weeks. Do you think you could help out with some passes?

Note.

For those businesses that agreed to donate something over the telephone, they often requested a letter describing the study, and how the donations would be used. I gave delivered the *letter of thanks* (see below) when picking up the donations Some business managers required a *written request*, the written request form also is included below.

Donation Request Letter

FIELD(Business)
FIELD(Address)

Dear FIELD(Contact Person),

I am a doctoral student in Developmental Psychology at the University of Manitoba. I am conducting a study with teenagers with Type 1 (or juvenile) diabetes. I am writing this letter to request donations of FIELD(donated item). These will be used as an incentive to get the teenagers to join the study in the first place and as a reward for the teenagers to keep participating until the end of the study.

Below is a brief description of the study, what the teenagers will be asked to do for the study, and how your donation would help with this study.

Diabetes background information

People with Type 1 diabetes must take insulin and measure their blood sugar levels every day (often 3 or more times per day). However, keeping their blood sugar levels in the normal range is very difficult. So, people with Type 1 diabetes tend to have blood sugar levels that are more extreme and change more often than healthy people. We already know that low blood sugar levels can cause physical symptoms, like shakiness and tiredness, and cognitive problems, like trouble concentrating. At very low sugar levels, a person may start behaving very oddly or even pass out.

The Project

In my research project, I will be examining how changes in blood sugar levels affect teenagers' moods and social relationships. To do this, I will be asking the teenagers to rate their moods and their social interactions 3 to 4 times per day for 3 weeks. The teenagers will be asked to complete these ratings each time they test their blood sugar level. The teenagers' ratings will be entered into handheld computers (refurbished HandSprings). In order to get reliable results, I need about 50 teenagers to participate in my study.

Practical Benefits of the Study

By participating in the study, the teenagers are giving extra attention to how sugar levels affects their feelings and behaviour. The personalized feedback which they will receive should help teenagers better understand how diabetes affects their day-to-day social relationships. As well, knowing how sugar levels effect their moods or social interactions, the teenagers have another way of detecting when their blood sugar levels might be high or low.

The importance of your donation

Participation in this study is fairly demanding because it requires 3 to 4 ratings per day and lasts for 3 weeks. This is where your donation is so important. With generous donations from businesses, like yours, FIELD(Business), I can tell the teenagers that they

will receive FIELD(donated item) and similar donations each week to thank them for their effort and time in taking part in my study.

Thank you very much for considering this donation request of FIELD(# of passes) FIELD(donated item). Please feel free to contact me if you want further information.

Sincerely,

Darren Campbell

Donation Thank You Letter

FIELD(Business)

FIELD(Address)

Dear FIELD(Contact Person),

I am a doctoral student in Developmental Psychology at the University of Manitoba. As I mentioned on the phone the other day, I am conducting a study with teenagers with Type 1 (or juvenile) diabetes. You have generously offered to donate some FIELD(donated item).

Below is a brief description of the study, what the teenagers will be asked to do for the study, and how your donation helps in this study.

Diabetes background information

People with Type 1 diabetes must take insulin and measure their blood sugar levels every day (often 3 or more times per day). However, keeping their blood sugar levels in the normal range is very difficult. So, people with Type 1 diabetes tend to have blood sugar levels that are more extreme and change more often than healthy people. We already know that low blood sugar levels can cause physical symptoms, like shakiness and tiredness, and cognitive problems, like trouble concentrating. At very low sugar levels, a person may start behaving oddly or even pass out.

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Thank you very much for your generous donation.

Sincerely,

Darren Campbell

Appendix E Sample Size Determination

Reliability. Reliability considerations were important in determining the number of Level 1 units to collect from each participant. The number of glucose-related assessments per person (Level 1) was determine by how reliable the various mood and social interaction ratings would be when testing the association between ratings and glucose levels. As the focus of this study was on the relation between abnormal glucose levels and the various ratings, the minimum number of abnormal glucose levels to collect is the central consideration. Thus, I began by estimating the minimum number of glucose-related assessments of hypoglycemic and /or hyperglycemic episodes.

Base rate considerations. Based on a review of hypoglycemic and hyperglycemic occurrences, the estimated base rates are 12 to 20 % for hypoglycemia[17] and 27 to 50% for hyperglycemia. A 20% base rate was used to calculate the minimum total number of assessments per person. Therefore, if *n* is the minimum number of hypoglycemic assessments needed, the total number of glucose-related assessments needed will be 5 times *n*.

The formula (1) for calculating the minimum number of assessments per person is

$$n_{min} = \lambda_p (1 - \rho_o) / (1- \lambda_p) \rho_o \text{ where}$$

λ_p is the average assessment reliability per person

ρ_o is the average reliability per assessment (Snijders & Boskers, 1999).

I wanted a minimum average reliability per person (λ_p) of .75. To use Formula 1, I needed an estimate of the occasion-specific reliability (i.e., ρ_o). The occasion-specific reliability estimate reflects the internal consistency of the item-ratings over time. Without such information available, a proxy was used, the estimated consistency of individual mood items.

Unfortunately, item-specific reliabilities were not available so item-specific intercorrelations or reliabilities were estimated using a reliability formula from Brown (1983, p.82). The formula (2) is

$$r_{kk} = k\, r_{ij} / 1 + (k\text{-}1)\, r_{ij} \text{ where}$$

r_{kk} is the overall internal consistency of the scale

k is the number of items in the scale, and

r_{ij} is the estimated average intercorrelation among the items.

Due to a lack of information, the occasion-specific reliability estimates associated with mood ratings were also used for the social interaction ratings.The two internal consistency estimates of mood ratings I used should be representative of a broad range mood rating scales used. The first scale, the Positive Affect Negative Affect Scales

---

[17] These percentages are based upon 10 episodes per 50 to 80 glucose tests in field studies.

(PANAS , Watson, Clark, & Tellegen, 1988) is a twenty-item adjective list with two factors, Positive Affect (PA - 10 items) and Negative Affect (NA - 10 items). The internal consistency for PANAS ratings based upon current moods was very good ranging from .89 to .94 for each factor (Watson & Clark, 1997; Watson et al., 1988). Using Formula 2, this is equivalent to a minimum average intercorrelation (or item reliability estimate) of .45.

The second 8-item mood adjective list (Parkinson, Briner, Reynolds, & Totterdell, 1995) considered was more similar to the adjectives list used in the current study with specific emotional states being evaluated (e.g., cheerful, alert, calm, tense, depressed tired). For these adjective ratings, alpha levels were .65 or greater for each 4-item factor (positive and negative). For this study, the estimated item intercorrelations or reliabilities were .36 using Formula 2.

Therefore, I assumed a somewhat lower average reliability (ρ_o) of .25 for the occasion-specific ratings. Using the .25 occasion-specific reliability, the overall desired average reliability per person of .75, and Formula 1, the minimum number of abnormal glucose assessments per adolescent range needs to be 9. To convert this to the total number of glucose assessments needed, with a base rate of 20% a minimum of 45 (= 9*5) assessment per adolescent were estimated.

Sample Size Estimate Procedure

Sample size determination was based upon the models that assess the basic research question in the proposed research questions. Power calculations for supplementary analyses or potentially more elaborate statistical models were not assessed. Sample size calculations were based upon the information available for mood ratings. Little information was available for the social interaction comparisons.

The information used for the sample size calculations for mood ratings were presented in Tables 5 and 6. For each sample size determination procedure, Type 1 error rate was set at .05 with the desired statistical power of .80 or a Type 2 error rate of .20. The estimated mean standardized difference was .55 based upon an $r = .30$. Using Formula 3, the standard error value needed to be .20 or less to achieve the desired statistical power. Formula (3) is

$$\text{StdErr} \leq \text{ES} / (Z_{1-\alpha} + Z_{1-\beta}) \text{ where}$$

StdErr is the estimated standard error for each combination of Level 1 and 2 sample sizes,

ES is the hypothesized mean standardized difference effect size, &

$Z_{1-\alpha}$ & $Z_{1-\beta}$ are the Z-values from a standard normal distribution table for α and β, respectively.

With $Z_{1-\alpha} = 1.96$, $Z_{1-\beta} = .84$, and ES = .55, the standard error of the regression coefficients needed to be .20 or less. Standard errors depend on both the overall sample size and the relative distribution of samples sizes at Level 1 and Level 2. Given that we needed a Level 1 sample size of at least 45 for reliability purposes, we attempted to identify the Level 2 sample size that provided standard errors of the regression coefficients less than .20 with a Level 1 sample size of 45.

Table A. *Means and covariance matrices of the predictors for mood ratings.*

I.	Level 1 Random effects		
	BG	BG est.	BG*BG est.
BG	8.61		
BG est.	1.64[2a]	1.213	
BG*BGest.	1.39[b]	.52[b]	2.5[+]
II.	Level 2 Fixed effects		
	BG_SD	BG_AI	Mood Belief
BG_SD	4.01		
BG_AI	-22.56[3c]	5763	
Mood Belief	-0.033[d]	1.15 [3e]	0.093
III. Means	5.81	383	0.623

Note. [1] Based upon field study data of 125 adolescents (Johnston, et al., 2000) with the variance estimates assumed to be similar at both Levels 1 and 2. [2] Based upon field study data of 23 adolescents (Freund et al., 1986). [3] Based upon field study data of 35 adolescents (Wiebe et al., 1994). [+] Based upon the average variance of the its two components. [a] Equivalent to $r = .51$. [b] Equivalent to an estimated, moderate size, $r = .30$. [c] Equivalent to an $r = -.47$. [d] Equivalent to an $r = -.05$.

[e] Equivalent to an $r = .16$ which is based on an average of high and low BG_AI-Belief r's.

Standard Error Calculations

To calculate the standard errors of the regression coefficients in two level designs, I used a specialized, DOS based program (Bosker, Snidjers, and Guldemond, 1999) based on the statistical paper by Snijders & Bosker (1993). The program, Power IN Two-level designs (PINT)[18] required specifying: the inter-correlations among the various predictors (the variance / covariance matrices), the percent of variance explained in the outcome variable, how this outcome variance was distributed between Level 1 (occasion) and Level 2 (person), the minimum number of Level 1 units to be sampled, and the cost of sampling Level 2 units relative to the cost of sampling Level 1 units. Thus, the first step is to specify your statistical model including all the predictors to be used and what they will be used to predict.

[18] This program is freely available online at http:// stat.gamma.rug.ml/snijders/ .

The mood model. The main regression model for moods is below. The Level 1 model contains three random-effect predictors: glucose levels, the occasion-specific BG-estimation accuracy, and the interaction between these two terms. This means that glucose levels, BG estimates, and their interaction term are assumed to vary somewhat from person-to-person. The Level 1 intercept represents the average mood rating per person. It also is random, and so is assumed and statistically modeled as varying from person-to-person. Four Level 2 predictors will be used to model or explain the variability in the average mood ratings (intercepts) and in the relation between glucose levels and moods. Individual differences in glucose variability will be used to model variability in the intercepts that is the person-to-person variability in moods. Standard deviations in glucose levels (BG_SD), BG-estimation accuracy (as measured by the Accuracy Index, AI), and Mood Belief Accuracy will be used to model the glucose-mood relations. These predictors of the glucose-mood relation represent cross-level interactions. I am not attempting to explain or model the variability in occasion-specific BG estimates or the interaction term, as it is not the focus of this research project.

Mood Model Equations

Level 1

Mood Ratings = Intercept + glucose level + glucose estimate. + glucose* glucose estimate.

Level 2

Intercept = Intercept + BG_SD

glucose level = Intercept + BG_SD + BG_AI + Mood Belief Accuracy

glucose estimate = Intercept

glucose level * *glucose estimate* = Intercept + BG_SD + BG_AI + Mood Belief Accuracy

Note. All Level one predictors were specified as random effects, while all Level 2 predictors were by necessity specified as fixed effects.

Terms:

BG_SD refers to each participant's standard deviations in BG levels based on all BG tests.

BG_AI refers to each participant's Accuracy Index score.

Mood Belief Accuracy refers to each participant's accuracy in knowing how BG levels influence their moods.

The regression coefficient standard errors were based upon means of all fixed effects (see Table A III), the covariance matrix of fixed effect predictors at Level 2 (and 1, if present; see Table A II), the covariance matrix for random (and fixed, if present) effect predictors at Level 1 (see Table A I), the unexplained (residual) variance in ratings (the outcome) at Level 1, the covariance matrix of ratings (the outcome) at Level 2 including random effect variance relations (see Table B), the relative cost of sampling Level 2 units relative to Level 1 units, the total number of Level 1 units to be assessed (BG-related

assessments), and the minimum and maximum sample sizes as well as the increment or step size in sample size changes.

The total explained variance in mood ratings at Level 1 was estimated to be 65%, mostly (50%) due to individual differences in mood ratings (Level 2). In the statistical model, this was represented with a random intercept. This estimate was taken from a study of positive mood and negative mood ratings performed every two hours (waking time) for a 2 week period by 30 adults (Parkinson et al., 1995). In this study, 45 to 55 % of the total variance in mood ratings was attributable to individual differences.

The other 15% of the explained variance associated was assumed to be accounted for by Level 1 random predictors glucose levels, BG estimates, or their interaction. Previous field studies assessing the relation between glucose levels and symptoms have used correlations of .3 to .4 as their criteria (see Table 2). This translates into glucose levels accounting for 9 to 16 percent of the variance in symptoms ratings within person. With the additional predictors of BG estimates and the interaction term, I used the higher end of explained variance in mood ratings as an estimate.

Table B represents the residual or unexplained variance in mood ratings. With only two person-level predictors, glucose means and variability, for the intercept term, I expected that little of the intercept variability would be statistically modeled. I have assumed that the glucose-related variables would only account for 1% of the variability in average mood ratings per person (i.e., the intercept). Note, if other potential predictors (e.g., age, gender, Diabetes Quality of Life, Fear of Hypoglycemia, etc.) were added to the intercept model, the variance accounted for in average mood ratings could be much higher. However, with this simple glucose-related model of intercept variance, the unexplained variance in mean mood ratings variance will be estimated as .49, for assumed intercept level variances of .50.

A similar procedure was used to estimate the unexplained variance in the relation between glucose-related predictors at Level 1. Of the 15% of the variance in mood ratings due to glucose-related variables, I will assumed that 8% was due to glucose levels, 2% due to glucose estimation accuracy, and 5% due to the interaction term. I did not attempt to model the variance in glucose estimates (Level 2 predictor variables), so the unexplained variance for these terms was unchanged at 2%. However, with the predictors used to model the 8% variance in mood ratings associated with glucose levels, I estimated that a majority of this variance (62.5%) would be accounted for by the Level 2 predictors. That is to say, that or 5 of the 8% variance was modeled, and so, the residual variance term is estimated to be 3% (see Table B). For the interaction term, glucose*glucose estimates, I have assumed that 2 of the 5% or 40% of the variance between the interaction term and moods would be accounted for by the Level 2 predictors. I have assumed that the a small correlation of .1 exists among the unexplained random effects (Table B off-diagonal estimates).

Table B. *Covariance matrix of the random effect predictors for mood ratings.*

	Matrix of unexplained variance in mood ratings			
Intercept	0.49			
BG	.012*	0.03		
BG estimate	.009*	.002*	0.02	
BG*BG estimate	.016*	.004*	.003*	0.03

Note. *These estimates are based upon an assumed $r = .1$.

The minimum within-adolescent sample size was previously estimated to be 45, and a sample size increment of 3 per day was used (Johnson et al., 2000). The maximum within-person sample size was set at 63. Therefore, the number of days of data collection under consideration ranges from 15 to 21 per adolescent assuming 3 glucose-related assessments per day.

The regression coefficients of primary interest were the random coefficients for glucose level, the Level 1 interaction term, and the cross-level interaction terms with glucose level and the Level 1 interaction term. The regression coefficient with the largest standard error sets the lower limit in terms of sample sizes. Table C shows the standard error associated with each relevant regression coefficient. A sample size of 20 adolescents each providing 45 glucose-related assessments produces an estimated standard error less than .20. A sample size of 20 represented 20% of the eligible participants with 100 12- to 17-year-olds adolescents with Type I diabetes living in or nearby the City of Winnipeg. Achieving a 20% recruitment rate seems plausible given the many steps that have been taken to enhance recruitment and retention (see below).

Table C. *The standard error estimates of key regression coefficients.*

Sample sizes	Level 1 Coefficients		Cross-Level coefficients					
			BG level by			BG*BG estimate		
Level 2 *N*	BG	BG*Est	*SD*	AI	Belief	*SD*	AI	Belief
18	0.2	0	0.14	0	0.02	0.02	0.207	0.14
20	0.19	0	0.13	0	0.02	0.01	0.196	0.14
22	0.18	0	0.13	0	0.02	0.01	0.187	0.13

Note. Abbreviations coef = coefficients, Est = estimate, BG = Blood glucose, *SD* = BG standard deviation, AI = Error Grid Analysis Accuracy Index, Belief = Mood Belief Accuracy. These estimates are based upon 45 measurements per adolescent (Level 1 sample size).

Retention

An additional, sample size related consideration was retention rates. The previous field study of adolescents with Type I diabetes mellitus, reported a retention rate of 58% (Wiebe et al., 1994)[19]. They used a similar field study data collection procedure. These adolescents, completed, on average, 40 glucose-related forms. They were given two entertainment passes upon the completion of 30 paper-pencil data-collection forms. If similar retention rates can be assumed for this study, then I may need to recruit up to 28-29 adolescents for the study to obtain complete data from 20 adolescents. However, recruitment will be conducted in blocks of 8 adolescents because of the limited number of handheld computers available.

[19] Note that the other studies of adolescents with Type I DM took place either in a camp setting (Freund et al., 1986) or in the hospital setting as in-patients (Nurick & Johnson, 1991). Such data would not provide relevant retention rate data.

Appendix F Socioeconomic Status Questionnaire

Please answer the following questions.

The answers you give are used to get a general description of the families that are taking part in this study. This information can then be compared with other studies to see how similar families in this study are to families in other studies.

At anytime if you do not want to answer a question you may skip it and go onto the next one.

Thank you in advance

Name: _____ Date: _____

Name of Son or Daughter: _____

1. Marital Status (Check one)

Married ☐ Common-Law ☐

Living with a partner ☐ Single (never married) ☐

Widowed ☐ Separated ☐

Divorced ☐

2. How would you best describe your race or colour? Check off all that apply.

White ☐

Chinese ☐

South Asian (E.G. East Indian, Pakistani, Punjabi, Sri Lankan) ☐

Black ☐

Native/Aboriginal Peoples Of North America (North American Indian, Métis, Inuit/Eskimo) ☐

Arab/West Asian (E.G. Armenian, Egyptian, Iranian, Lebanese, Moroccan) ☐

Filipino ☐

South East Asian (E.G. Cambodian, Indonesian, Laotian, Vietnamese) ☐

Latin American ☐

Japanese ☐

Korean ☐

Other (Specify) ☐ _____

3. Excluding kindergarten, how many years of elementary and high school have you successfully completed? (Check one only.)

___ 1-5 Years ___ 6 ___ 7 ___ 8 ___ 9 ___ 10 ___ 11 ___ 12 ___ 13

___ 0 No schooling

If you have ever **attended** any other kind of school such as a *university*, *community college*, *business school*, *trade or vocational school*, *CEGEP* or *other* post-secondary institution, please answer the following questions.

If you have **not**, please skip to question number 4.

3.b. What is the highest level of education that you have attained? (Mark one only.)

___ 1 Some Trade, Technical or Vocational School, or Business College

___ 2 Some Community College, CEGEP, or Nursing School

___ 3 Some University

___ 4 Diploma or certificate from trade, technical or vocational school, or business college

___ 5 Diploma or certificate from Community College, CEGEP or Nursing

___ 6 Bachelor or undergraduate degree, or teacher's college

___ 7 Master's

___ 8 Degree in medicine, dentistry, veterinary medicine or optometry

___ 9 Earned doctorate

___ 0 Other specify_____

3.c. Are you currently attending a school, college or university?

___ 1 Yes ____ 2 No → Skip to question 4

3.d. Are you enrolled as a full-time or part-time student?

___ 1 Full-time ____ 2 Part-time

4.a. Are you currently working outside the home?

___ 1 Yes ____ 2 No → Skip to question 5

4.b. Are you working full-time or part-time?

____ 1 Full-time ____ 2 Part-time

5. Can you estimate in which of the following groups your household income falls?

_____ No income
_____ Less than $5,000
_____ Less than $10,000
_____ Less than $15,000
_____ Less than $20,000
_____ Less than $30,000
_____ Less than $40,000
_____ Less than $50,000
_____ $50,000 to less than $60,000
_____ $60,000 to less than $80,000
_____ $80,000 or more

Appendix G Adolescent Information Request Form

Adolescent Information Form ID _____

Please answer the following questions.

The answers you give on this sheet are used to get general description of the adolescents taking part in this study. This information can then be compared with other studies to see how similar the adolescents in this study are with adolescents in other studies.

If you do not want to answer a question, you may skip it and go onto the next one.
Thank you in advance.

Birthdate: day/month/year:_____

Gender (please circle): Male Female

Current Grade at school: _____

Diabetes-related information

When did you get diabetes? _____ year _____month

Insulin:

Please circle how you take insulin: Pen & Syringe, or Pen, or Syringe, or Pump

How many insulin needles or injections do you take per day 2 3 4 5+

How many of the needles are cloudy doses (long-term) ? 1 2 3

How many of the needles / injections are clear insulin doses?
2 3 4 5+ pump (all of the time)

At what level do you consider your sugar level high? _____ mmol/L

How often do you test you sugar levels per day usually? _____

Appendix H Diabetes Quality of Life for Youths Survey

Please circle the number on the right that is most like your thinking.

1=Never; 2=Very seldom; 3=Sometimes 4=Often 5=All the time

Impact of Diabetes		Scale
	How often ...	
1	do you feel pain associated with the treatment for your diabetes?	1 2 3 4 5
2	are you embarrassed by having to deal with your diabetes in public?	1 2 3 4 5
3	do you feel physically ill?	1 2 3 4 5
4	does your diabetes interfere with your family life?	1 2 3 4 5
5	do you have a bad night's sleep?	1 2 3 4 5
6	do you find your diabetes limiting your social relationships and friendships?	1 2 3 4 5
7	do you feel good about yourself?	1 2 3 4 5
8	do you feel restricted by your diet?	1 2 3 4 5
9	does your diabetes keep you from driving a car or using a machine?	1 2 3 4 5
10	does your diabetes interfere with your exercising?	1 2 3 4 5
11	do you miss work, school, or household duties because of your diabetes?	1 2 3 4 5
12	do you find yourself explaining what it means to have diabetes?	1 2 3 4 5
13	do you find your diabetes interrupts your leisure-time activities?	1 2 3 4 5
14	are you teased because you have diabetes?	1 2 3 4 5
15	do you feel that because of your diabetes you go to the bathroom more than others?	1 2 3 4 5
16	do you find you eat something you shouldn't rather that tell someone that you have diabetes?	1 2 3 4 5
17	do you hide from others that fact that you are having an insulin reaction?	1 2 3 4 5
18	do you find that your diabetes prevents you from participating in school activities (e.g., being active in a school play, being on a sports team, being in the school band) etc)?	1 2 3 4 5
19	do you find that your diabetes prevents you from going out to eat with your friends?	1 2 3 4 5
20	do you feel that your diabetes will limit what job you will have in the future?	1 2 3 4 5
21	do find that your parents are too protective of you?	1 2 3 4 5
22	do you find that your parents worry too much about your diabetes?	1 2 3 4 5
23	do you find that your parents act like diabetes is their disease, not yours?	1 2 3 4 5

1=Never; 2=Very seldom; 3=Sometimes 4=Often 5=All the time

Worries about Diabetes		Scale
	How often do you worry ...	
1	about whether you will get married?	1 2 3 4 5
2	about whether you will have children?	1 2 3 4 5
3	about whether you will not get a job you want?	1 2 3 4 5
4	about whether you will pass out?	1 2 3 4 5
5	about whether you will be able to complete your education?	1 2 3 4 5
6	that your body looks different because you have diabetes?	1 2 3 4 5
7	that you will get complications from your diabetes?	1 2 3 4 5
8	about whether someone will not go out with you because you have diabetes?	1 2 3 4 5
9	that your teachers treat you differently because of your diabetes?	1 2 3 4 5
10	that your diabetes will disrupt something you are currently doing in school (e.g., act in a play, continue on a sports team, be in the school band etc)?	1 2 3 4 5
11	that because of your diabetes you are behind in terms of dating, going to parties, and keeping up with your friends?	1 2 3 4 5

1=Very Unsatisfied; 2=Somewhat unsatisfied;
3=Neither; 4=Somewhat satisfied; 5=Very satisfied;

Satisfaction with Life		Scale
	How satisfied are you with ...	
1	the amount of time it takes to manage your diabetes?	1 2 3 4 5
2	the amount of time you spend getting checkups?	1 2 3 4 5
3	the time it takes to determine your sugar level?	1 2 3 4 5
4	your current treatment?	1 2 3 4 5
5	the flexibility you have in your diet?	1 2 3 4 5
6	the burden your diabetes is placing on your family?	1 2 3 4 5
7	your knowledge about your diabetes?	1 2 3 4 5

Speaking generally ...		Scale
	How satisfied are you with ...	
8	your sleep?	1 2 3 4 5
9	your social relationships and friendships?	1 2 3 4 5
10	your work, school, and household activities?	1 2 3 4 5
11	the appearance of your body?	1 2 3 4 5
12	the time you spend exercising?	1 2 3 4 5
13	your leisure time?	1 2 3 4 5
14	life in general?	1 2 3 4 5
15	your performance in school?	1 2 3 4 5
16	how your classmates treat you?	1 2 3 4 5
17	your attendance in school?	1 2 3 4 5

Compared with others your age, would you say your health is:

1. Excellent	2. Good	3. Fair	4. Poor

Appendix I Fear of Hypoglycemia Survey

ID _____

Name _____

Date _____

- Behaviour: Below is a list of things people with diabetes do in order to avoid low blood sugar. Read each item carefully. Circle one of the numbers to the right that best describes what you do during your daily routine to AVOID low blood sugar.

	To avoid low blood sugar, I ...	Never	Rarely	Sometimes	Often	Always
1	eat large snacks at bedtime.	0	1	2	3	4
2	avoid being alone when my sugar is likely to be low.	0	1	2	3	4
3	let my blood glucose run a little high to be on the safe side	0	1	2	3	4
4	keep my sugar high when I will be alone for awhile	0	1	2	3	4
5	eat something as soon as I feel the first sign of low blood sugar	0	1	2	3	4
6	reduce my insulin when I think my sugar is low	0	1	2	3	4
7	keep my sugar high when I plan to be in a long meeting or at a party	0	1	2	3	4
8	carry fast-acting sugar with me	0	1	2	3	4
9	avoid exercise when I think my sugar is low	0	1	2	3	4
10	check my sugar often when I plan to be in a long meeting or out at a party	0	1	2	3	4

- Worry: Below is a list of concerns people with diabetes sometimes have. Please read each item carefully. Do not skip any. Circle one of the numbers to the right that best describes how often you WORRY about each item because of low blood sugar.

	I worry about ...	Never	Rarely	Sometimes	Often	Always
11	Not recognising/realising I am having low blood sugar	0	1	2	3	4
12	Not having food, fruit, or juice with me	0	1	2	3	4
13	Passing out in public	0	1	2	3	4
14	Embarrassing myself or my friends in a social situation	0	1	2	3	4
15	Having a reaction while alone	0	1	2	3	4
16	Appearing stupid or drunk	0	1	2	3	4
17	Losing control	0	1	2	3	4
18	No one being around to help me during a reaction	0	1	2	3	4
19	Having a reaction while driving	0	1	2	3	4
20	Making a mistake or having an accident	0	1	2	3	4
21	Getting a bad evaluation or being criticised	0	1	2	3	4
22	Difficulty thinking clearly when responsible for others	0	1	2	3	4
23	Feeling lightheaded or dizzy	0	1	2	3	4

Appendix J Mood and Symptom Belief Checklist

Rate each symptom from 0 (not at all) to 6 (very much). Please do this once for when you have Low sugar levels, and once for when you have High sugar levels.

How much do you feel or act: *the symptom*.

1. Hungry
2. Sweaty
3. Shaky
4. Weak
5. Tired or Sleepy
6. Dizzy or Light-headed
7. Clumsy
8. Blurry Vision
9. Difficulty thinking
10. Daydreaming
11. Headache
12. Dry Mouth or Eyes or Nose
13. Tingling around mouth
14. Queasy stomach or nausea
15. Cold hands
16. Hot face
17. Itchy
18. Coughed a lot
19. Acted odd
20. Irritable
21. Aggressive
22. Argumentative
23. Frustrated
24. Restless
25. Tearful
26. Worried or Anxious
27. Sad
28. Depressed
29. Alert
30. Elated
31. Energetic
32. Confident
33. Relaxed or Mellow
34. Cheerful or Happy
35. Giddy or Silly
36. Caring or affectionate

Appendix K Mood and Symptom Rating Checklist

Please rate each symptom from 0 (not at all) to 6 (very much). For the last ½ hour, how much have you felt or had: *the symptom* .

1. Hungry
2. Sweaty
3. Shaky
4. Sleepy or tired
5. Tingling around mouth
6. Hard to think clearly
7. Queasy stomach or sick
8. Headache
9. Dry Mouth or Eyes or Nose
10. Thirsty and used bathroom a lot
11. Itchy
12. Acted Odd
13. Aggressive / Irritable
14. Sad
15. Frustrated
16. Worried or Anxious
17. Argumentative
18. Full of Energy
19. Contented / Calm
20. Relaxed or Mellow
21. Cheerful
22. Giddy or Silly

Appendix L Social Interaction Ratings Checklist

Please rate each question using a scale of 0 to 6, where 0 = not at all and 6 = very much.

In the last ½ hour, how much you have *laughed and joked* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *acted silly* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *had a stressful interaction* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *had a caring and affectionate interaction* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *had upsetting or saddening interaction* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *had an annoying interaction* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

In the last ½ hour, how much you have *argued* with some one else or other people?

not at all 0 1 2 3 4 5 6 very much

Appendix M Sample Participant Feedback

Family name and address go here

Dear adolescent name goes here,

I would like to start by thanking you for participating in the Adolescent Diabetes Study. In this study, I was examining how glucose levels relates to physical symptoms, moods, and social interactions. This is a summary of the data you provided from the Start Date to the End Date using with the Handspring Visors.

Blood Glucose Levels

You completed **60** trials during the field study. Your average glucose level was **8.3** mmol/L and it ranged from **2.7** to **20.1** mmol/L. You reported that your sugar levels were less than 4.0 mmol/L (low) 7 times and greater than 10.0 mmol/L (high) **16** times.

Guessing your sugar levels

High and Low Guesses

How accurate were you at guessing your glucose levels? Of the 7 lows you experienced, you missed **2** of them. So, you correctly guessed **71** % of your lows. Of the **16** highs you experienced, you missed **9** of them. So, you correctly guessed **44** % of your highs.

Number Guesses

For the next set of results, I have assumed that if your sugar levels were higher than 10 mmol/L or lower than 4.0 mm/L you would want to do something to either lower or raise your sugar levels. Then, I divided up your guesses into 5 groups: A) accurate, B) benign errors, C) correction errors, D) detection errors, or E) erroneous errors.

A) There are 2 types of *Accurate* guesses: 1) a guess that is within 20% of your actual level, or 2) guessing that you are low when you really are low.

Out of **60**, you made **20** Accurate guesses.

B) A *Benign error* means that your guess was off by more than 20%, but still would not cause you to make a bad treatment decision.

You made **24** Benign error guesses.

C) A *Correction error* means you thought you needed to correct your sugar level, but you did not need to correct it.

You made **10** Correction error guesses.

D) A *Detection error* means you thought your sugar level was fine, but you did not to correct it because you were either high or low.

You made **5** Detection error guesses.

E) An *Erroneous error* is the worse type of error. It can mean that you thought you were high, but you were actually low. Or, you thought you were low, but you were actually high. This Erroneous error can lead you to make dangerous treatment mistake.

You made **1** Erroneous error guesses.

Guess Percentages

Of your **16** errors that could have led to treatment problems, **62.5** % of them were Correction errors, **31.25** % of them were Detection Errors, and **6.25** % of them were Erroneous errors. Out of your **60** guesses, you got **33** % of them Accurate, and **73** % of your guesses were either Accurate or Benign errors.

Physical Symptoms, Moods, or Social Interactions

Each time you tested your sugar levels, you rated a list of 11 physical symptoms, 11 moods, and the quality of your recent social interactions. I used a couple of different statistical methods to identify which of your symptoms, moods, and social interactions were related to your sugar levels (see Methods 1 and 2 below).

Method 1: Rating Score differences

a. Rating Scores when low vs Rating Scores when normal.

b. Rating Scores when high vs Rating Scores when normal.

Method 2: Rating Score Correlations

a. Did your Rating Scores change as your sugar levels gradually got lower?

b. Did your Rating Scores change as your sugar levels gradually got higher?

Defining your sugar level as high if it was greater than 8 mmol/L or greater than 10 mmol/L was not very useful for comparing normal sugar level ratings against high sugar level ratings because your mean sugar level was 10.7 mmol/L. Instead, I defined high sugar levels as 15 mmol/L or higher for you.

Statistically, your sugar levels were related to the items listed below. The list is separated into those items related to your low sugar levels and those items related to your high sugar levels.

Low glucose levels	High-glucose levels
Physical Symptoms	Physical Symptoms
more hungry	more thirsty or need to 'pee
more sweaty	more dry mouth, nose, or eyes
more headache	less sleepy or tired
more shaky	
	Moods or Actions
Moods or Actions	less acting oddly
less energetic	less frustrated
	Social Interactions with Others
	less likely to have been very chatty

Note. Other symptoms or moods also may be related to your sugar levels. These other symptoms or moods, however, may have not occurred over the data collection period. If you had experienced more lows or more highs, other symptoms may have shown up in your data.

You might be able to make use of this information in the future. If you feel one of these symptoms, moods, or are having one of these social interactions (and you see no other reason why you might be feeling or acting this way), it may be a good idea to test your sugar levels.

I hope you have found this feedback interesting and informative. If you have any questions, please feel free to contact me. *Name here*, your participation in this study was very important, and should help us better understand how sugar levels effect adolescents' day-to-day lives. Thank you and your family very much for participating in my study. It was a pleasure meeting you and your family.

Sincerely,

Darren Campbell

Department of Psychology