WMRF – Final Report

The Effects of Blood Glucose Levels on Driving Behaviour and Executive Functioning in Young People with Type 1 Diabetes

Dr Joanna M. McClintock, Consultant Psychologist, Waikato Regional Diabetes Service, Waikato Hospital.

Dr Robert B. Isler, Associate Professor in Psychology, University of Waikato School of Psychology.

Dr Nicola J. Starkey, Associate Professor in Psychology, University of Waikato School of Psychology.

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Introduction

Hyperglycaemia (high blood glucose levels) has been demonstrated to impact negatively on executive functioning skills, however, the impact on everyday risky activities such as driving is unknown. Hazard perception is an executive functioning skill recognized as being a predictor of vehicle crashes and driving safety (Isler & Starkey, 2011).

Type 1 diabetes is an autoimmune condition resulting in the body's inability to produce insulin, a hormone that breaks down glucose in the blood. Without insulin, the body is not able to metabolise glucose for energy which results in high levels of glucose in the blood, which is known as hyperglycaemia (International Diabetes Federation, 2011). For people with diabetes who experience hyperglycaemia, there is likely not enough insulin in their system to transfer the blood glucose to the brain for energy; thus their ability to utilise executive functioning skills becomes impaired.

Executive functions are a set of cognitive skills involving the ability to control and planfully apply one's own mental skills (Anderson, 2008; Luria, 1973). They also include the ability to sustain or flexibly redirect attention, the inhibition of inappropriate behavioural or emotional responses, the planning of strategies for future behaviour, the initiation and execution of these strategies, and the ability to flexibly switch among problem-solving strategies (Martin, 2006; Weinberger et al., 2005). Driving is an everyday activity that relies heavily on higher-level cognitive skills, particularly those of executive function, including judgment, attention, planning, anticipating consequences, and hazard perception (Kurzthaler et al., 2005, Isler & Starkey, 2011).

The New Zealand Transport Authority (2013) and the American Diabetes Association (2014) acknowledge that metabolic control impacts on the cognitive functions associated with driving. The majority of research examining driving safety and diabetes has focussed on the impacts of hypoglycaemia (e.g., Cox, Gonder-Frederick, & Clarke, 1993; Cox, Gonder-Frederick, Kovatchev, Julian, & Clarke, 2000; Quillian, Cox, Gonder-Frederick, Driesen, & Clarke, 1994).

Hyperglycaemia is recognised by the American Diabetes Association (2014) to impact on driving abilities; however, there is not enough research to justify guidelines around driving and hyperglycaemia. The New Zealand Transport Association's advice that "you shouldn't drive if you are severely hyperglycaemic", however, do not provide any specifics as to a definition of hyperglycaemic.

Studies that have looked at hyperglycaemia and driving have primarily used adult populations and have often included participants with type 2 diabetes (Cox, Ford, Ritterband, Singh, & Gonder-Frederick, 2011; Sommerfield, Deary, & Frier, 2004). These studies found that hyperglycaemia detrimentally impacts on the cognitive skills involved in driving. Although we can learn from these studies the impact of diabetes is recognised to be cumulative. Therefore, the longer you have diabetes the higher the risk of complications, including cardiovascular, retinopathy, and neuropathy which will all impact on driving safety (DCCT Research Group, 1993). In comparison, young people are novice drivers, are at much less risk of micro and macro vascular diabetes-related complications and therefore may provide a clearer picture of the impacts of hyperglycaemia (without diabetes-related complications) on executive functioning and driving safety.

The aim of this project was to investigate the effect of hyperglycaemia (high blood glucose levels) on executive functioning, and higher-level driving skills in young people with Type 1 diabetes. We hypothesised that acute hyperglycaemia would have a negative effect on performance on tests of

executive functions and safe driving skills in young people with Type 1 diabetes compared to performance when blood glucose levels were within the target range.

Method

Of 119 potential patients with type 1 diabetes of the Waikato Regional Diabetes Service 14 young people participated in the study. Each participant attended two assessment sessions (approximately 2 hours long). One assessment session was when the participant had a blood glucose level between 4 mmol/L – 9.4 mmol/L (euglycaemic) and the second when the participant had a blood glucose level above 15 mmol/L (hyperglycaemic).

As can be seen in Table 1, the majority of participants were male. Half of the participants had their full licence and the majority had not had a car crash nor had they received warnings or convictions for their driving. The mean HBa1c suggest that participants overall metabolic control was sub-optimal, with only 2 participants having and Hba1c of less than 58 mmol/mol.

Table 1

Summary of the Demographic, Medical and Driving History of the Participants

	Descriptive Statistic
Demographics	
Male gender n, %)	10 (71.4)
Mean age (yrs)	19.29, sd=2.01, range=17- 23
Right Handed (n, %)	12 (85.7)
Medical History	
Mean age at diagnosis (yrs)	11.29, sd=5.07, range=4-20
Mean time since diagnosis (yrs)	7.96, sd=5.0, range=0.17-19
Early onset diabetes< age 5 years (n, %)	2 (14.3)
Diabetes related hospital admission (n, %)	3 (21.4)
Diabetic ketoacidosis episodes (n, %)	8 (57.1)
Mean HbAlc (mmol/mol)	80.36, sd=26.68, range=47-130
Driving history	
Licence type (n, %)	
None	1 (7.1)
Learner	2 (14.3)
Restricted	3 (21.4)
Full	7 (50.0)
Mean weekly travel (kms)	141.50, sd =145.14, range=5-456
Crashes (n, %)	
None	11 (78.6)
One	3 (21.4)
Convictions	
None	10 (71.4)
One	2 (14.3)
Two	2 (14.3)
Warnings[a]	
None	12 (85.7)
One	1 (7.1)

[a] data was missing for one participant.

Following consent, demographic and biomedical markers were obtained (HbA1c and random blood glucose level). Blood glucose levels were measured every hour during both assessment sessions.

During both assessments, participants completed a selection of neuropsychological tasks from the CogState and Delis-Kaplan Executive Functions System (D-KEFS). Computer based driving tasks were also completed in both sessions including the Stoplight Task, Situation Awareness Test, and Hazard Perception Task. Table 2 details the measure and the domain being assessed and Appendix A provides further detail about the measures.

Table 2
Objective Measures and Domain Being Assessed

	Domain Being Assessed
Executive Functioning Measures	
CogState - Timed Chase Test	Visual-motor functioning
CogState - Groton Maze Learning Test	Spatial problem solving
CogState - Groton Maze Learning Recall	Visual Learning and memory
CogState - Set-Shifting Task	Executive functioning and spatial problem solving
CogState - One Back Task	Working memory and attention
CogState - Two Back Task	
D-KEFS - Colour Word Inference Test	Cognitive flexibility
D-KEFS - Trail Making Test	Visual scanning and attention, flexibility of thinking and working memory
Driving Tasks	
Stoplight Task	Decision making
Situation Awareness Test	Lapses and errors in driving
Hazard Perception Task	Accuracy of Identifying Hazards, response time and errors

Participants' performance on these objective measures were compared between euglycaemic and hyperglycaemic conditions to determine how blood glucose levels affect executive function and high level driving skills. All of the objective measures were designed for repeated administration with minimal learning effects.

General cognitive ability was assessed using the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II), alongside subjective ratings of executive functioning and driving behaviour (see Appendix A) when participants blood glucose level was within the euglycaemic range.

Results

The descriptive statistics for the self-report and clinical measures are presented in the Table B1 in the Appendices.

Repeated measures ANOVAs or ANCOVAs (full scale IQ was included as a covariate in the analyses of the executive function measures) were used to determine the effect of hyperglycaemia on the objective executive functioning measures and the driving-related measures (summarised in Table 3). Participants blood glucose levels were significantly different across the two sessions (Euglycaemic mean = 7.24, sd = 1.44; Hyperglycaemic mean = 19.17, sd = 3.81; $F(1,13) = 132.99$, $p < .001$, $\eta_p^2 = .91$). Table 3 presents the descriptive statistics and the results of the analyses. As can be seen, there were no significant differences in the outcome measures across the two conditions.

Table 3

The Effects of Hyperglycaemia on Driving Related Outcome Measures and Tests of Executive Function. Data are Presented as Mean (95% CI).

	Euglycaemic (mean, 95%CI)		Hyperglycaemic (mean, 95% CI)		ANOVAs
Driving Outcome Measures					
Hazard Perception					
Accuracy (proportion correct)	.59	(.48-.70)	0.58	(.46 –.69)	F (1,13) = 0.06, p = .81, η_p^2 = <.01
Reaction time (msec)	4.24	(3.52-4.96)	4.23	(3.60 – 4.87)	F (1,13) = 0.01, p = .97, η_p^2 <.01
Situation Awareness					
Total	4.01	(3.78-4.25)	4.09	(3.84 – 4.32)	F (1,13) = 0.27, p=.62, η_p^2 = .02
True Positives	1.79	(1.58-2.00)	1.80	(1.56 – 2.04)	F (1,13) = .04, p=.85, η_p^2 =<.01
Stoplight (number of crashes)	1.09	(0.73-1.45)	0.64	(.18 – 1.09)	F (1,10) =2.60, p=.14, η_p^2 = .21
Executive Function[a]					
One back (accuracy)	1.16	(.94-1.34)	1.14	(.94 – 1.34)	F (1,11) = 0.01, p=.94, η_p^2 = <.01
Two back (accuracy)	1.18	(1.03-1.34)	1.11	(.89 – 1.32)	F (1,11) = 4.41, p=.06, η_p^2 = .29
Timed Chase Task (mps)	1.72	(1.61-1.83)	1.73	(1.61 – 1.84)	F (1,11) = .83, p=.38, η_p^2 = .07
Groton Maze Learning (errors)	39.46	(30.28-48.64)	39.54	(21.14 – 47.94)	F (1,11) = 1.01, p=.34, η_p^2 = .08
Groton Maze Recall (errors)	3.62	(1.92-5.31)	5.84	(3.30 – 8.40)	F (1,11) = .84, p=.38, η_p^2 = .07
Set Shifting (errors)	20.46	(14.91-26.02)	18.23	(11.89 – 24.57)	F (1,11) = .13, p=.73, η_p^2 = <.01
Trails Number Letter (SS)	11.00	(9.99-12.01)	10.33	(8.76-11.91)	F (1,10) = .01, p=.96, η_p^2 = <.01
Colour Word Inhibition (SS)	11.29	(9.65-12.92)	11.43	(10.04-12.81)	F (1, 12) = 1.70, p=.22, η_p^2 = .12
Colour Word Inhibition Switch (SS)	11.21	(10.01-12.42)	10.86	(9.63-12.08)	F (1,12) = .08, p=.78, η_p^2 = <.01

[a] WASI-II full scale IQ was included as a covariate. The adjusted means are presented. An η_p^2 of .01, .06., and .14 represent small, medium, and large effect sizes, respectively.

SS – scaled score

To determine if participants overall control of their diabetes (as measured by HbA1c), related to the driving and executive function outcomes (in the euglycaemic condition), a series of Pearson's correlations were conducted. The only significant correlations were between HbA1C and the behavioural regulation index on the BRIEF ($r(14) = .583$, $p=.014$) and the depression scale of the HADS $r(14) =.578$, $p = .03$). Higher levels of HbA1c were associated with poorer behavioural regulation and higher scores on the HADS depression scale.

In terms, of the relationship between the driving and executive function measures, hazard perception accuracy was associated with better performance on the DKEFS number letter sequencing ($r(14) = .57$, $p = .03$) and better overall executive function as measured by the global executive composite from the BRIEF ($r(14) = -.73$, $p < .01$; note that higher scores indicate poorer executive function). In addition, a higher number of crashes on the Stoplight task were associated with poorer performance on the DKEFS Inhibition Switching task ($r(14) = -.66$, $p = .03$).

Conclusions

No statistical differences in measures of executive functioning or higher-level driving skills between hyperglycaemic or euglycaemic states in young people with type 1 diabetes mellitus. Additionally, there were no universal trends across driving skills and executive functioning.

Consistent with previous research in young people with diabetes, poorer glycaemic control as measured by HbA1c was related to poorer behavioural regulation such as problem solving and emotion dysregulation (McDonell et al., 2007; Miller et al., 2012). The relationship between higher HbA1c and clinical measures of depression (HADS) also aligns with previous research (e.g., Andreoulakis et al., 2012). The correlations between better executive function and accuracy of hazard identification are also consistent with previous research where poorer executive functioning predicted vehicle crashes and driving safety (Isler & Starkey, 2011).

The current study size impacts significantly on the findings. Practical issues that will need to be considered for future studies include recruiting young people which provides challenges. Additionally, the length of testing sessions could also be a barrier to recruitment.

This is the first time that such a study has been conducted and provides a starting point for an important body of research.

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Appendix A
Assessment Measures

Objective Measures of Executive Functioning

The **CogState Research Test Battery** (CogState; http://cogstate.com/academic/#.Uxgt4zfUfng) is a reliable and valid computerised touch screen assessment of cognitive function including psychomotor performance, attention, memory, and executive functioning. The CogState consists of a number of individual tasks, which can be put together to form a test battery; five subtests were used in the current study.

Timed Chase Test. This assesses a person's visual motor function; using a touch screen. Participants "chased" a target on a grid as quickly and accurately as they can.

Groton Maze Learning Test. This subtest uses a maze learning paradigm to assess executive function and spatial problem solving. Using a grid, participants attempted to make their way through a hidden maze, to get from the identified start to finish receiving trial and error feedback. They then repeated the maze trying to recall the pathway they have previously completed.

Set-Shifting Task assesses executive functioning and spatial problem solving. Using the computer screen, a card was presented (colour or number) and they had to guess whether the card is the "target" card; they received feedback as to whether they have guessed correctly. A series of cards were then presented and the target stimulus changed dimension, forcing the participant to relearn the new target. Multiple shifts were made through the assessment.

One Back Task assesses working memory and attention. Participants were shown a card and had to indicate if the card shown is the same as the previous card.

Two Back Task also assesses working memory and attention. Participants were shown a card on a screen and had to decide if the card is the same as the card that was shown two cards ago.

The **Delis-Kaplan Executive Function System** (D-KEFS; Delis et al., 2001) is a well validated measure consisting of nine subtests presented in an interactive game-style way assessing components of executive functioning. Two subtests were used in the current study.

Colour Word Interference Test. This assessed cognitive flexibility. Participants were asked to inhibit reading coloured words while naming the colour; the participant was then asked to switch between naming the colour and reading the conflicting word.

Trail Making Test. There subtests assessed visual scanning and attention, flexibility of thinking and working memory. In the first condition, participants drew a line from one number to another in numerical order. In the second condition, participants connected letters and numbers in numerical and alphabetical order.

Computer Based Driving Tasks

The **Stoplight task** (Steinberg et al., 2008) is computerised task which assessed decision making under uncertainty and derives an overall measure of risky driving. The participant was required to 'drive' a car to a destination within a specific time period. The drive incorporated 8 intersections, and on approaching the intersection the light turns to orange. The participant has to decide whether to stop or to attempt to cross the intersection.

The **Situation Awareness Test** assessed observational ability and the skills required to obtain an overview. Traffic situations were shown briefly on a computer screen and participants had to choose from five possible options what was in the picture.

The **Hazard Perception Test** (Isler, Starkey & Williamson, 2009) consisted of 4 trials of online video-based traffic simulations seen from a driver perspective and the participants need to click on immediate hazards. The test recorded the percentage of hazards detected and also the time it takes the participants to respond to the hazards.

General Cognitive Ability

The **Wechsler Abbreviated Scale of Intelligence – Second Edition** (WASI-II; Wechsler, 2011) is a validated 4 subtest measure of general cognitive ability. The WASI has been widely used in clinical and research settings and is suitable for people aged 6 – 90 years of age.

Subjective Measures

The **BRIEF-SR** (Behaviour Rating Inventory Executive Functioning-Self-Report; Guy et al., 2004), is a self-administered measure of executive functioning and assesses a young person's ability to complete tasks

The **BRIEF – Parent Report** (Behaviour Rating Inventory Executive Functioning-Parent Report; Gioia, Isquith, Guy, & Kenworthy, 2000) assesses the parents' perception of a young person's abilities on several domains of executive functioning.

The **Driver Behaviour Questionnaire** (DBQ; Parker et al., 1995; Reason et al., 1990) is a 28 item measure that assesses errors and violations during driving. Errors and lapses as measured by the DBQ have been found to be significant predictors of crashes (see Winter & Dodou, 2010 for a recent meta-analysis).

The **Driver Attitude Questionnaire** (DAQ; Parker, Stradling & Manstead, 1996) is a 20 item scale that assesses participant's attitudes towards speeding, drink driving, close following and overtaking.

Driving Self-Evaluation (Horswill, Waylen, & Tofield, 2004) consists of four questions requiring participants to self-evaluate their driving behaviour. These focused on accident concern, thrill from driving, accident likelihood and driving skill evaluation.

The **Hospital Anxiety and Depression Scale** (HADS; Zigmond & Snaith, 1983) is a brief screening instrument for anxiety and depression. Screening for anxiety and depression is important as they can affect participant's performance on the cognitive and neuropsychological tests.

The **Barrett Impulsiveness Scale - Short form** (BIS-SF; Spinella, 2007), assessed impulsivity. Three subscale (non-planning, motor impulsivity, and attention impulsivity) and the total score are used to indicate levels of impulsivity.

The **Attitudes Towards Risk** questionnaire (ATR; Franken, Gibson, & Rowland, 1992) was used to assess the participants attitudes to psychological and physical risks.

Brief Sensation Seeking Scale (Brief-SSS; Hoyle et al, 2001) is a self-report measure of sensation seeking consisting of eight items.

Appendix B
Descriptive Statistics

Table B1
Descriptive Statistics for the Clinical and Self-Report Measures

Measure	Mean (sd), min-max	Number (%) meeting cut-offs	
Clinical			
BRIEF			
General Executive Composite (GEC)	50.00 (10.31) 35-77	Elevated (>65)	1 (7.1)
Behaviour Regulation Index (BRI)	49.00 (9.99) 35-74	Elevated (>65)	1 (7.1)
FSIQ	114.29 (10.22) 101-134		
		Below average	0
		Average (90-109)	4 (28.6)
		High Av (110-119)	8 (57.1)
		Superior (120-129)	0
		V superior (130-139)	2 (14.3)
HADS			
Anxiety	6.14 (3.25) 1-13	Clin caseness (8+)	5 (35.7)
Depression	2.07 (2.09) 0-7		
Self-report questionnaires			
DAQ			
Speed	15.35 (2.46) 9-19		
Drink Drive	12.63 (2.82) 10-19		
Close Following	12.21 (3.17) 6-19		
Overtake	14.07 3.50) 8-19		
DBQ			
Errors	3.29 (2.37) 0-7		
Lapses	5.50 (3.41) 0-13		
Violations	5.21 (3.12) 0-10		
Aggressive Violations	3.57, (3.37) 0-10		
Sensation seeking	2.99 (0.63) 2.13-4.13		
Impulsivity	37.07 (3.71) 29-43		
Attitudes to Risk	23.00 (7.79), 13-38		