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Paediatric traumatic brain injury and the dysregulation profile: The mediating role of decision-making

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ABSTRACT

Decision-making is often impacted by paediatric traumatic brain injury (TBI). However, there are few tools available to assess these skills in children, with even less research on the consequences of decision-making deficits on dysregulation following TBI. This prospective preliminary study investigated whether decision-making mediated the effect of TBI on dysregulation in children. The performance of school-aged children aged between 7 and 15 years with TBI ($n = 49$) and that of typically developing controls ($n = 22$) was compared on The Decision-making Task, and on parent ratings of the dysregulation profile as characterized by the Child Behaviour Checklist-Dysregulation Profile. Relative to the Control group, the TBI group performed more poorly on the decision-making task, and parents of the TBI group rated their children to be more poorly on the dysregulation profile. Mediation analyses indicated that decision-making mediated the relationship between TBI and the dysregulation profile. Our preliminary findings suggest the need for further research in the area of decision-making, and its impact on dysregulated behaviours in children following TBI.

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Traumatic brain injury; Mediation; Decision-making; Dysregulation profile; Paediatric

Traumatic Brain Injury (TBI) is a significant cause of death and acquired disability in children and adolescents worldwide, with one of the highest incidence rates reported in Australia (Dewan et al., 2016; Langlois et al., 2006). Early brain insult can impact executive function skills, such as decision-making, which develop throughout childhood and adolescence (Anderson, 2002). Deficits in decision-making can lead to secondary problems in emotional and behavioural dysregulation (Catroppa et al., 2017; Schachar et al., 2015). However, the nature of

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relationship between decision-making deficits and problems of dysregulation remains unexplored in children following TBI.

Decision-making is a process of making an "optimal" selection from a set of options based on one's subjective values and preferences (Kühberger et al., 2002; Vaidya & Fellows, 2017), which may be impacted by cognitive, affective, and physiological processes (Rochat et al., 2018). Therefore, effective decision-making may be characterized by the ability to consider relevant information in real-world scenarios, compare subjective utility of different available options, and then make competent choices that are context-appropriate and underpin adaptive goal-oriented behaviour (Bechara, 2005; Guerra et al., 2014; Miyapuram & Pammi, 2013; Modecki et al., 2017; Rangel & Hare, 2010; Sonuga-Barke et al., 2016). Ineffective decision-making may be construed as the repeated participation in decisions that are impulsive, inefficient, inconsistent, or socially inappropriate (Bechara et al., 1994; Bechara et al., 2000; Sonuga-Barke et al., 2016), and often evident following childhood TBI (Schmidt et al., 2012). Typically, impairments in decision-making are measured by tests such as the Iowa Gambling Task (IGT: Bechara et al., 1994) (Clark & Manes, 2004), or the Cambridge Gambling Task (CGT: Rogers et al., 1999b), however, both may be considered measures of risk-taking and have limited applicability to the everyday life of children (Sood et al., 2021). Findings from existing literature have indicated deficits in decision-making on the IGT (Hanten et al., 2006), with increased injury severity associated with poorer outcomes in children following TBI (Schmidt et al., 2012). An alternative approach to the typical measures of decision-making involves the use of information-boards paradigm. This paradigm involves explicit searching for information about available options in an information matrix of real-life scenarios followed by a final choice (Glöckner & Betsch, 2008; Payne, 1976). As the information-boards paradigm is based on the process models, it analyses decision-making by observing the pre-decisional information and the post-decisional outcome such as the decision-maker's behaviour on the way to making the decision (Glöckner & Betsch, 2008; Kühberger et al., 2002; Payne, 1976). Therefore, one may argue that ineffective decision-making may be associated with dysregulated behaviour.

Dysregulation or poor regulation is the inability to adapt one's responses across a variety of contexts (Althoff et al., 2010). Impairments in executive function skills are considered core mechanisms of dysregulation (Hofmann et al., 2012). Dysregulation of affect, behaviour, and/or cognition in childhood has been associated with an increased likelihood of disruptive behaviour and a broad range of psychopathology including substance abuse, personality disorders, mental health problems, and suicidal ideation in adulthood (Aitken et al., 2019; Althoff et al., 2010; Deutz et al., 2016; Masi et al., 2015). Typically, dysregulation is characterized by the Child Behaviour Checklist Dysregulation Profile (CBCL-DP or DP) (Ayer et al., 2009) which consists of elevated scores on the three AAA-scales: (a) Anxious/Depressed, (b) Aggressive Behaviour,

and (c) Attention Problems (Ayer et al., 2009). Previous research in typically developing children has identified DP as a useful proxy measure for identifying children at a risk of mental health problems later in life (Bellani et al., 2012). Following TBI, children are reported to exhibit dysregulation, with worse outcomes in attention, anxiety/depression, and aggression (Anderson et al., 2012; Ganesalingam et al., 2006, 2007; Ganesalingam et al., 2011), resulting in adverse behavioural functioning (Ganesalingam et al., 2006; Konrad et al., 2000). While existing research has focussed on characterizing this deficit in regulatory abilities as a predictor of behavioural and social outcomes (Chavez-Arana et al., 2019; Ganesalingam et al., 2006, 2007; Ryan et al., 2019), none to our knowledge have considered dysregulation as an outcome of early brain insult or have characterized dysregulation using the CBCL-DP (Ayer et al., 2009) in children following TBI.

Therefore, while previous research has investigated decision-making in children post TBI and aspects of dysregulation, the relationship between decision-making and the DP is poorly understood. To address this gap in the literature, the present study aimed to investigate decision-making post childhood TBI and its association with DP relative to a typically developing control group. We hypothesized that decision-making would mediate the effect of TBI on DP, in comparison to the typically developing control group (Figure 1). To our knowledge, this is the first preliminary study to investigate decision-making as a mediator between childhood TBI and DP.

Method

Participants

Participants consisted of (a) TBI group ($n = 49$), and (b) typically developing control group (Control) ($n = 22$).

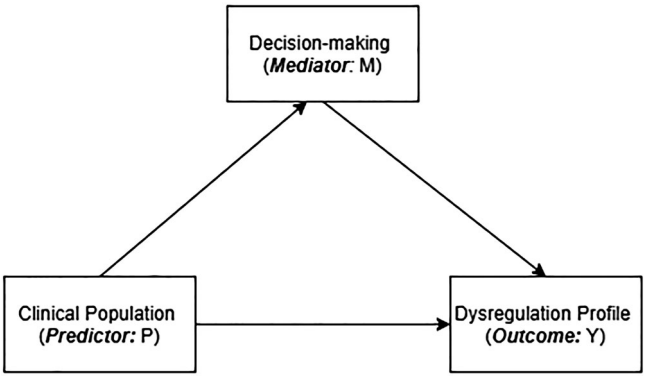

Figure 1. The proposed model for the relationship between clinical population and DP, as mediated by decision-making.

TBI participants were recruited between 2017 and 2019. Participants with TBI were part of the screening procedure for a randomized controlled trial (RCT; Sood et al., 2018) (HREC 35181). Therefore, the current study is based on secondary data analysis from this RCT trial. Recruitment was via audit lists of TBI presentations at The Royal Children's Hospital (RCH); The RCH Victorian Paediatric Rehabilitation Services state-wide registry; previous research projects where consent for re-contact was specified; and unsponsored social media commercials for the RCT. The inclusion criteria were: (i) school-aged children (7–15 years of age); (ii) documented evidence of TBI at least 6 months previously; (iii) no other premorbid neurological or learning difficulties, or severe sensory or physical impairment; (iv) overall intellectual ability ≥80; and (v) fluent in English. TBI was characterized by loss of consciousness, post traumatic amnesia, or at least two symptoms of concussion (Catroppa et al., 2017). TBI severity was categorized by the Glasgow Coma Scale (GCS: Teasdale & Jennett, 1974) into mild (GCS 13–15), moderate (GCS 9–12), and severe (GCS 3–8) at the time of the hospital presentation.

The Control group were recruited within the same time-span and consisted of typically developing children recruited via schools in a concurrent study examining social cognitive and decision-making outcomes in children (HREC 36249). The inclusion criteria were: (i), (iii), (iv), and (v).

Measures

Demographic information

Demographic information was obtained through a questionnaire completed by the participants' parents.

Socioeconomic status (SES)

The Australian Socioeconomic Index 2006 (AUSEI06: McMillan et al., 2009) was used to measure the participants' SES, with parent education used as an index for determining the SES. AUSIE06 converts scores on parental education/occupation status in line with the official educational/occupational classification of the Australian and New Zealand Standard Classification of Occupation (ANZSCO) into a score ranging from 0 to 100. Higher score on AUSIE06 indicates better SES.

Intelligence

General intellectual ability was derived from the Wechsler Abbreviated Scale of Intelligence – Second Edition (WASI-II: Wechsler, 2011) or the Wechsler Intelligence Scale for Children-Fifth Edition (WISC-V: Wechsler, 2014) ($M = 100$, $SD = 15$). This was administered at the time of recruitment to determine eligibility (iv). While WASI-II was administered to the TBI participants, WISC-V was administered to the Control group in line with the respective study protocols.

Decision-Making

Decision-making was measured using an experimental information-boards paradigm, The Decision-Making Task (DMT: Sood et al., 2021 [Manuscript submitted for publication]). The DMT was developed to assess decision-making in three relatable and ecologically valid decision-scenarios (for example, choosing a book – see Figure 2). For each decision-scenario, performance on the DMT involved the selection of two least important and two most important attributes (characteristics, for example, author) each of the decision-scenarios, followed by a final choice in an information matrix of 6 attributes and 3 alternatives (options, for example, book A), and providing qualitative feedback on the task. Four raw scores (the amount of information searched, recall of least important attributes, recall of most important attributes, and choice) were combined to generate a raw composite score (range 1–4), with lower scores (1–2) indicating ineffective decision-making and higher scores (range 3–4) indicating effective decision-making ($\alpha = 0.627$) (convergent validity as shown by significant correlations between the DMT and measures of working memory, executive function, adaptive behaviour, and behavioural outcomes) (refer Sood et al., 2021).

Dysregulation

Dysregulation was assessed by the CBCL-DP (Achenbach & Rescorla, 2001). The CBCL is a standardized parent questionnaire consisting of 113 questions that are used to assess behavioural and emotional problems in study participants. The DP consists of the following three CBCL subscales: attention problems, anxious/depressed, and aggressive behaviour. T-scores for each of the three subscales were calculated (M = 50, SD = 10), and then summed to create a

	Author	Type	Library	Book club	Reviews	Movie
Book A	Not so favourite author	Least favourite type	Available in school library	Sometimes discussed	Not good reviews	No movie made on the book
Book B	Favourite author	Not so favourite type	Not available in school library	Always discussed	Good reviews	Movie made on the book
Book C	Least favourite author	Favourite type	Sometimes available in school library	Never discussed	Best reviews	No movie made on the book

Which alternative would you like to select?		
○ Book A	○ Book B	○ Book C
	Submit	

Figure 2. Practice decision-scenario of the Decision-Making Task.

composite score (Kim et al., 2012). This standardized composite score was used in analyses, with higher scores indicating more dysregulated behaviour ($\alpha = .97$).

Statistical analysis

Descriptive statistics for demographic, injury, and cognitive variables were evaluated using SPSS Version 27 (IBM, 2020) and reported in Table 1.

Preliminary analysis explored correlations between decision-making and DP. Mediation analyses were conducted in Mplus V 8.5 (Muthén & Muthén, 1998) to quantify and test the indirect pathways of influence from antecedent variable (X) to an outcome variable (Y) through a proposed intermediary variable (M, a mediator) (Montoya & Hayes, 2017). Model fit was evaluated on multiple parameters of relative chi-square, root mean square error of approximation (RMSEA), comparative fit index (CFI), and the standardized root mean square residual (SRMR). Four conditions were tested in order to determine the presence of a simple mediating relationship (Baron & Kenny, 1986; Holmebeck, 1997; Shrout & Bolger, 2002). Path-c: The predictor (clinical population) would be significantly related to the outcome (Y: DP). Path-a: The predictor (X: clinical population) would be significantly related to the mediator (M: decision-making). Path-b: The mediator (decision-making) would be significantly related to the outcome (DP). Path-c': The effect of the predictor (clinical population) on the outcome (DP) would be less significant after controlling for the mediator (decision-making). Complete mediation occurs when path-c' is not significant. Partial mediation occurs when path-c' is significant but smaller than path-c (Fairchild & McDaniel, 2017).

In order to investigate the mediation relationship (Figure 1), three regression analyses were conducted. In analysis 1, decision-making (M) was regressed on the clinical population (X), with a significant relationship confirming the first condition. In analysis 2, DP (Y) was regressed on the clinical population (X), with a significant relationship fulfilling the second condition. In analysis 3, DP

Table 1. Demographic data for control group and TBI group.

Demographic data	Control ($n = 22$)	TBI ($n = 49$)	t	P-value	d
Number of boys, *n (%)*	8 (36.4)	35 (71.4)	2.92	**0.005***	0.73
Age at testing (years), *M (SD)*	10.13 (2.03)	10.34 (2.74)	−0.32	0.748	0.08
Grade, *M (SD)*	4.09 (1.70)	5.15 (2.80)	−1.19	0.236	0.45
FSIQ/Estimated IQ, *M (SD)*	103.25 (14.70)	102.34 (11.37)	0.27	0.781	0.06
SES, *M (SD)*	59.33 (14.54)	62.14 (13.96)	−0.75	0.454	0.19
Decision-making, *M (SD)*	0.94 (0.23)	0.67 (0.47)	2.31	**0.024***	0.72
DP, *M (SD)*	158.85 (10.85)	167.78 (17.44)	−2.11	**0.039***	0.61

Note: *t*: t-statistic value; *d*: Effect sizes were calculated ($d = 0.2$, medium when $d = 0.5$, and large when $d = 0.8$; Cohen, 1988); *M*: mean; *SD*: standard deviation; *FSIQ/Estimated IQ:* full scale general intellectual ability as measured by the Wechsler scales; *SES:* socioeconomic status as measured by the AUSEI06; *DP*: Child Behavior Checklist – Dysregulation Profile; TBI: Traumatic brain injury.

*Significant ***p*-value < 0.05** are in bold.

(Y) was regressed on both the clinical population (X) and the decision-making (M) variables. To satisfy the third condition, decision-making (M) was required to be significantly associated with DP (Y), after the effect of the clinical population (X) on the relationship was controlled for. The fourth condition was determined by investigating whether the effect of clinical population on DP (analysis 1) was significantly reduced upon introduction of decision-making (M) (analysis 3). Mediation analysis was conducted with robust bootstrapping methods and maximum likelihood estimations (1000 iterations), with age as a covariate for decision-making as the decision-making scores were raw scores.

Results

Demographic information

The TBI group consisted of 43 children with a mild TBI, and 6 with a moderate-severe TBI. The participants in the TBI and the Control groups were matched for age at assessment, level of education, general intellectual ability, and SES (Table 1). However, results indicated a higher percentage of boys (71.4%) in the TBI versus control group (36.4%).

Significant group differences in decision-making and DP were observed. Participants in the Control group demonstrated more effective decision-making as compared to the TBI group, t (65) = 2.31, p = .024, d = 0.72. In addition, participants in the Control group exhibited lesser problems on DP as compared to the TBI group, t (63) = −2.11, p = .039, d = 0.61.

Preliminary analysis

Significant, modest associations were found between decision-making, DP, and clinical group (Table 2).

Mediation analyses

The three linear regression analyses revealed significant relationships between clinical population and DP, clinical population and decision-making, decision-making and DP (Table 3). Following this, a mediation model was conducted. The current mediation model was found acceptable as the ratio of chi-square to degrees of freedom was non-significant; the RMSEA was <0.05; the CFI was

Table 2. Descriptive statistics and Spearman's correlation coefficient table.

	N	M (SD)	1	2	3
1. Clinical Population	71	0.69 (0.46)			
2. Decision-making	67	0.74 (0.43)	**−0.27***		
3. DP	65	165.03 (16.17)	**0.29***	**−0.32***	

Note: *DP*: Child behavior checklist – dysregulation profile.
*Significant correlation < 0.05 are in bold.

Table 3. Summary of mediation analyses.

Path	Predictor	Outcome	E	S.E.	*p*-value
Path-c	Clinical population	DP	0.26	0.17	**0.026***
Path-a	Clinical population	Decision-Making	−0.45	0.16	**0.006***
Path-b	Decision-making	DP	−0.33	0.11	**0.003***
Path-c′	Clinical population	DP	0.12	0.14	0.382

Note: *Clinical Population:* Control (0) and TBI (1); *DP:* Child Behaviour Checklist- Dysregulation Profile; *E:* Standardized estimate; *SE:* standard error of the estimate.
*Significant correlation < 0.05 are in bold.

1.0; and the SRMR was <0.05. Age was used as a covariate for decision-making in the final mediation model ($E = 0.59$, $S.E = 0.09$, p-value < .001). The mediation analysis revealed that the effect of clinical population on DP was significantly reduced upon introduction of decision-making ($E = -0.36$, $S.E = 0.15$, p-value = .019). Since path-c′ was non-significant, decision-making completely mediated the relationship between clinical population and DP (Figure 3).

Discussion

To the best of our knowledge, the current study is the first study to investigate the interplay among paediatric TBI, decision-making, and DP. Of note, relative to the typically developing control group, the TBI group exhibited more ineffective

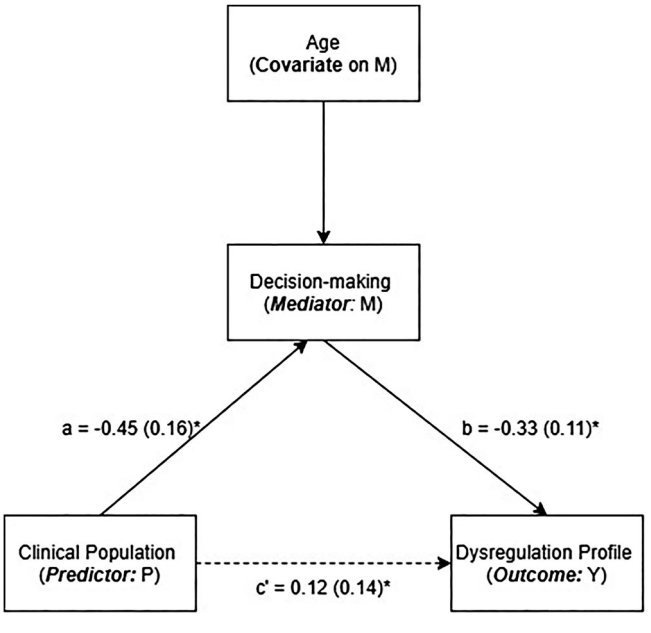

Figure 3. Complete mediation of decision-making between clinical population and DP, with age as a significant covariate for decision-making. a = direct effect of TBI on mediator Decision-making; b = direct effect of mediator Decision-making on Dysregulation Profile; c′ = indirect effect of TBI on the dysregulation profile. Standardized path coefficients shown for each path. *Statistical Significant Effect.

decision-making and more dysregulation. We hypothesized that decision-making would mediate the relationship between TBI and DP following TBI. The hypothesis was supported by the findings of this study, that is, decision-making mediated the relationship between paediatric TBI and DP, when controlling for age.

The group comparisons showed ineffective decision-making in the TBI group compared to the control group, that is, the TBI group were found to search less relevant information, make a final choice that did not closely reflect their preferred attributes, and were less likely to recall initial choices of least and most preferred attributes. Our findings suggest that the TBI group were unable to effectively use available knowledge and encode important information in decision-scenarios relative to the Control group. In addition, the TBI group also exhibited more dysregulation relative to the control group. This finding is consistent with the previous literature in this area of paediatric TBI which found presentations of disruptive behaviour, and mental health problems such as anxiety and depression in children following TBI (Ganesalingam et al., 2006; Li & Liu, 2013).

The mediation analysis demonstrated that decision-making was a significant mediator of the relationship between childhood TBI and DP. These findings suggest that decision-making may be one of the underlying deficits in children who display difficulties in DP following TBI. Problems of dysregulation may be seen as an indication for likelihood of mental health problems in children following TBI that may worsen over time (Chavez-Arana et al., 2019). Our findings converge with the previous studies suggesting the important role of core executive function skills such as decision-making in the development of regulatory abilities (Hofmann et al., 2012; Schachar et al., 2015).

Decision-making is a continuous process required for adaptive everyday functioning. Ineffective decision-making may contribute to poor regulation of emotion, behaviour, and cognition, thereby increasing the risk of problems in behaviour and social skills, and impacting overall goal attainment in children following TBI.

Strengths

This is the first study in the field of paediatric TBI to identify decision-making as a mediator of dysregulation post childhood TBI, thereby filling a gap in this area. Another strength of this study pertains to the use of a novel child-appropriate measure of decision-making, the DMT, and the use of a robust measure of dysregulation.

Limitations

The findings of this study should be interpreted in the context of its limitations. The small sample size may limit the robustness of the results. In addition, injury

related factors such as injury severity may impact on decision-making and DP. While the TBI and the Control group were matched on age range, they were not matched on size or sex. Furthermore, we did not control for sex in the mediation analysis due to small sample size.

Clinical implications

The current study highlights the relationship between decision-making and dysregulation in children following TBI and provides the understanding that decision-making may impact dysregulated behaviour. Thus, clinical evaluation of children following TBI may include assessment for decision-making deficits, with context- and age-appropriate measures to understand specific aspects of decision-making and identify targeted interventions. Preliminary results from this study suggest that decision-making may be a target for intervention as it underpins dysregulated behaviour in children following TBI.

Conclusion

This is the first study to investigate the relationship between paediatric TBI, decision-making, and the DP. Findings from this study provide preliminary evidence for the role of decision-making as a mediator between childhood TBI and DP. Future studies using a larger size and different TBI severity groups along with a longitudinal study design may further validate the current findings. In addition to the current study of decision-making, future studies may also investigate risk-taking aspects of decision-making.

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Authors' contributions

All authors contributed to the study concept, the trial, and this manuscript. All authors read and approved the final manuscript.

Disclosure statement

No potential conflict of interest was reported by the authors.

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