Exploring Perceived Interactions Between Consequences of Traumatic Brain Injury

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Brenda van den Broek, MA; Peggy Spauwen, PhD; Rudolf Ponds, PhD; Caroline van Heugten, PhD; Boudewijn Bus, PhD

Objective: To explore the perceived interactions between consequences of traumatic brain injury (TBI). **Participants:** Fifteen clinicians experienced in working with patients with TBI. **Methods:** Participating clinicians completed an online questionnaire in which they estimated the degree to which consequences of TBI (taken from the Brief ICF Core Set for Traumatic Brain Injury) causally relate to each other. Based on these perceived interactions, a visual network was constructed and centrality measures for this network were computed. **Results:** The resulting network demonstrates various strong perceived causal relations between the consequences of TBI. Impairments in consciousness were perceived to most strongly *cause* other TBI consequences in the network. Difficulties with acquiring, keeping, and terminating a job were perceived to be most strongly *caused by* other TBI consequences. Difficulties in partaking in complex interpersonal interactions were also perceived to play a central role in the network. **Conclusion:** In the perception of clinicians, consequences of TBI interact with each other and are thus not solely a direct result of the injury. While more research is needed to map the interactions between consequences of TBI, our results could have important implications for the way we understand and treat the problems patients are faced with after TBI. **Key words:** *clinicians*, *perceived causal relations network*, *symptomatology*, *traumatic brain injury*

TRAUMATIC BRAIN INJURY (TBI) causes more death and disability than any other trauma-related injury and affects an estimate of 69 million people worldwide each year.[1] According to a meta-analysis by Frost et al,[2] about 12% of the general adult population has a history of TBI. The consequences of TBI are manifold and can, especially in moderate to severe cases, be detrimental to the quality of life of survivors and their loved ones.[3] The International Classification of Functioning, Disability and Health (ICF) Core Sets for Traumatic Brain Injury, initiated by the World Health Organization,[4] provide an overview of the aspects of functioning that may be impaired following TBI and include difficulties in critical aspects of functioning such as attention, memory, higher-level cognitive abilities, and the ability to partake in complex interpersonal interactions. Although causal interactions between these consequences of TBI seem probable (eg, impairments in higher-level cognitive functions causing difficulties in partaking in complex interpersonal interactions), as far as we know no study to date has investigated the interactions between the problems survivors are faced with after TBI. More insight into these relations, however, could help advance the understanding and treatment of the often complex symptomatology of TBI.

While the relations between consequences of TBI have remained understudied, the interactions between symptoms of mental disorders such as depression,[5,6] posttraumatic stress disorder,[7,8] and psychotic disorders[9,10] have been studied extensively in the last decade. These studies are representative of the emerging network approach to psychopathology in which mental disorders are viewed as complex dynamic networks of symptoms that cause and interact with each other, rather than as common causes of a number of

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distinct symptoms.[11–14] In this view, a mental disorder such as a depression is thus not seen as the underlying cause of symptoms such as sleep difficulties, fatigue, and diminished ability to think or concentrate. Instead, it is conceptualized as arising from the causal interplay between symptoms (eg, sleep difficulties causing fatigue, fatigue causing diminished ability to think or concentrate, etc). This approach has proven to be a valuable framework for understanding the dynamics of mental disorders[12,14] and was used in the current study to investigate possible interactions between consequences of TBI.

One could argue that, since the consequences of TBI do have a clear common cause (ie, the injury itself), a network approach is unsuitable for understanding its symptomatology. However, as Fried and Cramer[15] have argued, the same could be said for multiple other disorders (such as posttraumatic stress disorder, caused by trauma) for which the network approach has already proven its value. Fried and Cramer[15] state that the network approach can still be suitable in such contexts, as long as direct interactions between symptoms seem to make sense. They propose to conceptualize these disorders as so-called *hybrid networks*, which contain both a common cause and a network structure between symptoms. In addition, it is known that brain injury characteristics (such as location and severity) do not fully explain the consequences survivors are faced with after TBI[16,17] and that (the severity of) consequences can fluctuate over time within survivors,[18] indicating that there might be more at play than direct relations between injury and sequelae. It is therefore probable that the network approach provides a valid framework for investigating the interactions between consequences of TBI.

In the current study, we investigated possible causal interactions between consequences of TBI by constructing a *perceived causal relations network*. In a perceived causal relations network, causal relations between symptoms are based on the perceptions of these relations held by either patients themselves[19,20] or by well-informed clinicians.[21,22] The current study made use of perceptions of clinicians. The data were collected via questionnaires in which clinicians experienced in working with patients with TBI estimated the degree to which consequences of TBI cause each other. In doing so, the current study is the first to explore interactions between consequences of TBI. Based on the exploration of perceived interactions in the current study, substantiated hypotheses can be formulated, which can be tested in future studies. A better understanding of relations between consequences of TBI furthers our knowledge of the complex symptomatology of TBI and can as such inform and improve care.

METHODS

Participants

For this study, we recruited clinicians to complete a questionnaire. To partake in our study, clinicians had to be employed as a psychologist, psychiatrist, rehabilitation specialist, or nursing home physician in a healthcare facility, and had to be experienced in working with patients with TBI. These requirements were established to ensure that participants were familiar with the symptomatology of TBI and would be able to reason about possible interactions between consequences.

A snowball sampling method was used to avoid that all participants would come from the direct network of the researchers. Thirty-five potential participants from the network of the authors were invited to participate and additionally requested to invite potential participants (who also met the requirements for participation) from their network and so on. A total of 15 participants (mean age 44.3 years, 5 males) completed the questionnaire. Table 1 provides an overview of their characteristics. On average, they had 13.3 years of experience working with patients with TBI (ranging from 5 to 35 years). All participants worked in a healthcare facility (hospital, mental health institute, or rehabilitation center) in the Netherlands.

Materials

The researchers involved in this study developed an online questionnaire consisting of 4 components: an introduction, demographic questions, perceived causal relations questions, and reflection questions about the study. A psychologist from the network of the researchers beta tested the questionnaire to check for errors or ambiguities. The responses of this beta tester were not included in the data.

The introduction of the questionnaire informed participants of the purpose of the study and provided instructions on how to complete the questionnaire. The introduction described that participants would be asked

TABLE 1 *Overview of participant characteristics*

	n	Male/ female	Experience, mean (SD), y
Psychologists	8	2/6	15.6 (8.9)
Psychiatrists	4	2/2	11.3 (7.1)
Rehabilitation specialists	1	0/1	12.0
Nursing home physicians	2	1/1	8.5 (2.1)
Total	15	5/10	13.3 (7.6)

to estimate the degree to which difficulties in a certain aspect of functioning would cause difficulties in another aspect of functioning. They were advised to base their estimation on their well-informed opinion. Since it was our aim to create a perceived network of the consequences of TBI in general, without focusing on any specific type of TBI survivor, participants were told that the questions they would answer did not pertain to a particular patient but rather to the general symptomatology of TBI. A purposefully generic vignette was presented that participants could keep in mind while scoring the relations. This vignette described patient X, who was described as an adult with TBI after a traffic accident in need of care in any setting (inpatient or outpatient). The only other information provided on patient X was that he was no longer suffering from posttraumatic amnesia but had not necessarily reached a chronic stable phase, and that he had progressed to level VI or higher of the Rancho Los Amigos Revised Scale.[23]

The demographic questions served to collect information about the characteristics of the participants and their experience in working with patients with TBI. In this part of the questionnaire, participants also provided informed consent to use their answers for research purposes.

The perceived causal relations questions asked participants to rate the degree to which difficulties in a certain aspect of functioning would cause difficulties in another aspect of functioning on a scale from 0 (*not at all*) to 100 (*completely*). The areas of functioning included in these questions were taken from the Brief ICF Core Set for Traumatic Brain Injury.[4] To prevent the questionnaire from becoming too extensive, thereby potentially hampering the response rate, not all subsets of the Brief ICF Core Set were included. Only the items from the subsets Body Functions and Activities & Participation were selected to be used in the current study, leaving out the subsets Body Structures and Environmental Factors. The only item in the subset Body Structure is Structure of the Brain. This item was left out since it does not reflect a consequence of TBI but rather reflects the nature of the injury (or common cause of the hybrid network) itself. The subset Environmental Factors, which includes items such as Social Security Services and Products & Technology, was left out since the aim of our exploration was to investigate perceived interactions between TBI consequences within patients without complicating the picture further by involving environmental factors. Table 2 provides an overview of the included aspects and their definitions. Participants scored all possible relations between the aspects in Table 2 bidirectionally. Hence, participants, for instance, rated both the degree to which difficulties in self-care would cause difficulties in family relationships and the degree to which difficulties in family relationships would cause difficulties in self-care and these scores did not need to be equal. Mouseovers provided definitions of all the aspects of functioning. The order in which relations were presented to participants was randomized (by means of the randomization function in the survey software) as to avoid any possible order effects.

Finally, the reflection questions about the study asked the participants to rate how relevant they found the study (on a 0-100 scale), how difficult they found it to score the relations (on a 0-100 scale), and to provide any comments they had on the questionnaire.

Procedure

Participants were invited to complete the questionnaire via an e-mail with a link to the questionnaire. They could thus complete the questionnaire on their own device at whatever moment was convenient for them. If necessary, participants could save their answers and continue completing the questionnaire at a later time. It was not possible for participants to complete the questionnaire more than once. It was estimated that completing the questionnaire would take participants approximately 35 minutes. The majority of the participants did indeed complete the questionnaire within 35 minutes or less. The other participants most likely engaged in other activities while the questionnaire was active on their device since their completion times exceeded 60 minutes. Data collection lasted 2 months (April 19, 2019, to June 19, 2019). The study was approved by the institutional review board of the first author's main affiliation.

Analysis

The perceived causal relations between the aspects of functioning were visualized using the qgraph package in R,[24] which allowed us to create a visual network of the aspects of functioning (nodes) and their perceived mutual relation (edges). The scores attributed to the relations by the 15 participants were averaged and used as the strength (weight) of the edges. Standard deviations of the weights were also calculated to assess the extent to which participants agreed on the strength of the relations.

In addition, to investigate which nodes play a central role in the network, centrality measures[25] were calculated for all the nodes in the network. The centrality measures investigated were the outdegree, indegree, and betweenness. The outdegree refers to the total weight of the edges originating from a node. In our network, this therefore indicates the degree to which a certain consequence of TBI is perceived to cause the other consequences in the network. The indegree could be seen as the opposite of the outdegree and refers to the total weight of the edges directed toward a node. In our network, this measure thus indicates to what degree a

TABLE 2 *Aspects of functioning and their definitions of the subsets Body Functions and Activities & Participation from the Brief ICF Core Set for Traumatic Brain Injury*[a]

Subset	Aspects of functioning	Definition
Body Functions	Higher-level cognitive functions	Specific mental functions especially dependent on the frontal lobes of the brain, including complex goal-directed behaviors such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviors are appropriate under what circumstances; often called executive functions.
	Emotional functions	Specific mental functions related to the feeling and affective components of the processes of the mind.
	Energy and drive functions	General mental functions of physiological and psychological mechanisms that cause the individual to move toward satisfying specific needs and general goals in a persistent manner.
	Control of voluntary movement functions	Functions associated with control over and coordination of voluntary movements.
	Memory functions	Specific mental functions of registering and storing information and retrieving it as needed.
	Sensation of pain	Sensation of unpleasant feeling indicating potential or actual damage to some body structure.
	Attention functions	Specific mental functions of focusing on an external stimulus or internal experience for the required period of time.
	Consciousness functions	General mental functions of the state of awareness and alertness, including the clarity and continuity of the wakeful state.
Activities & Participation	Carrying out daily routine	Carrying out simple or complex and coordinated actions to plan, manage, and complete the requirements of day-to-day procedures or duties, such as budgeting time and making plans for separate activities throughout the day.
	Conversation	Starting, sustaining, and ending an interchange of thoughts and ideas, carried out by means of spoken, written, sign or other forms of language, with one or more people one knows or who are strangers, in formal or casual settings.
	Walking	Moving along a surface on foot, step by step, so that one foot is always on the ground, such as when strolling, sauntering, walking forward, backward, or sideways.
	Complex interpersonal interactions	Maintaining and managing interactions with other people, in a contextually and socially appropriate manner, such as by regulating emotions and impulses, controlling verbal and physical aggression, acting independently in social interactions and acting in accordance with social rules and conventions.
	Acquiring, keeping, and terminating a job	Seeking, finding and choosing employment, being hired and accepting employment, maintaining and advancing through a job, trade, occupation, or profession, and leaving a job in an appropriate manner.
	Self-care	Caring for oneself, washing and drying oneself, caring for one's body and body parts, dressing, eating and drinking, and looking after one's health.
	Recreation and leisure	Engaging in any form of play, recreational, or leisure activity, such as informal or organized play and sports, programs of physical fitness, relaxation, amusement or diversion, going to art galleries, museums, cinemas, or theaters; engaging in crafts or hobbies, reading for enjoyment, playing musical instruments; sightseeing, tourism, and traveling for pleasure.
	Family relationships	Creating and maintaining kinship relationships, such as with members of the nuclear family, extended family, foster and adopted family and step-relationships, more distant relationships such as second cousins or legal guardians.

[a]From Laxe et al.[4]

certain consequence of TBI is perceived to be caused by the other consequences in the network. Finally, betweenness refers to the number of times a node lies on the shortest path between pairs of nodes in the network (ie, how often a node is passed when one draws the most efficient route from one node in the network to another). This measure captures the extent to which a certain consequence of TBI plays a bridging role between the other consequences in the network.

RESULTS

Supplemental Appendix A (available at: http://links.lww.com/JHTR/A360) provides an overview of the weights attributed to all the 240 relations between the 16 aspects of functioning, and the corresponding standard deviations. The weights attributed to the edges (perceived causal relations) between aspects of functioning varied between 1.87 and 92.80 and had an average value of 31.34 (SD 32.81). The standard deviations for the weights ranged from 3.74 to 43.01, and had an average value of 20.59.

For interpretation purposes, the network was visualized by constructing a network containing the edges with a weight of at least 1 SD above the average (ie, relations with a weight of $\geq$64.14). Higher weights, and thus stronger perceived causal relations, were visualized as thicker edges. The network is presented in Figure 1. The causal relations perceived to be strongest were impairments in consciousness causing impairments in attention (92.80), impairments in consciousness causing difficulties in acquiring, keeping, and terminating a job (92.60), and impairments in consciousness causing difficulties in maintaining and managing complex interpersonal interactions (89.60).

An overview of the centrality measures (outdegree, indegree, and betweenness) of all the nodes in the network is presented in Table 3. These measures are based on the visualized network presented in Figure 1 and, as such, are calculated taking into account only edges with a weight of at least 1 SD above the average. The node representing impairments in consciousness had the highest outdegree, meaning that this was the node with the highest total weight of edges originating from it. The node with the highest indegree, meaning that this is the node with the highest total weight of edges directed toward it, was the node representing difficulties in acquiring, keeping, and terminating a job. The node representing difficulties in complex interpersonal interactions had the highest betweenness value, meaning that this node most often lies on a shortest path between pairs of nodes in the network. On average, nodes from the subset Body Functions had a higher outdegree (202.65) than the nodes from the subset Activities & Participation (53.04). Nodes from latter, however, had a higher average indegree (197.02 vs 58.67).

Since the network presented in Figure 1 did not take into account the standard deviations associated with the weights (ie, the extent to which participants agreed on the strength of the relations), a second network was

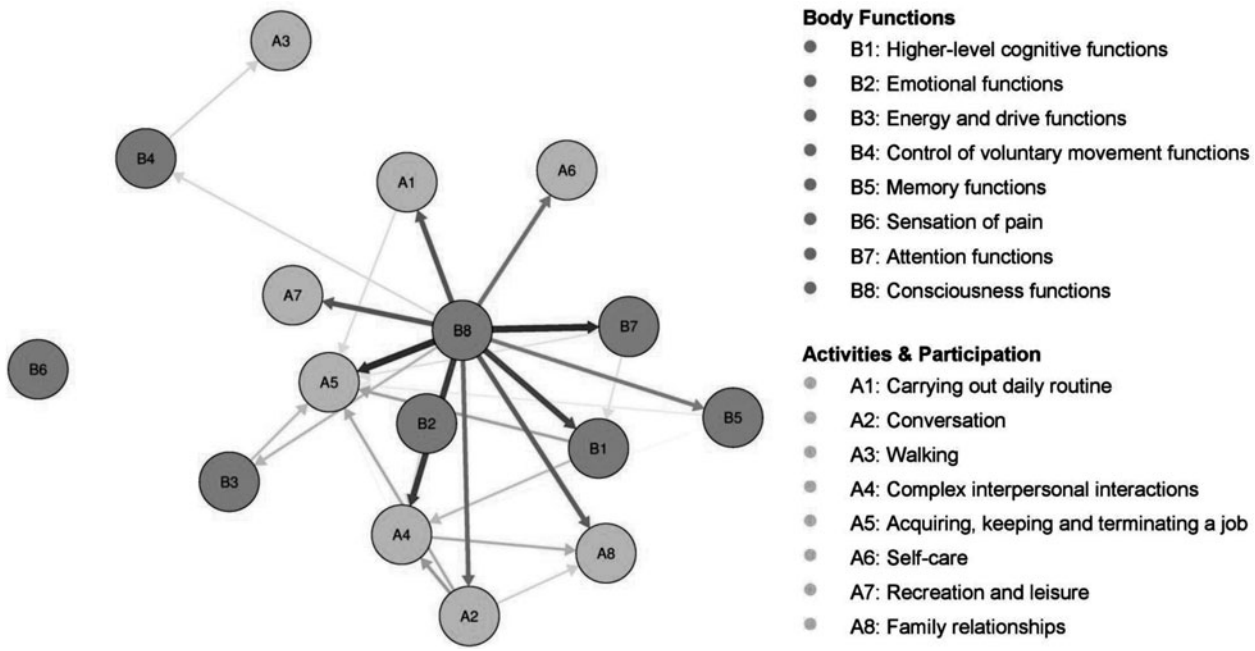

Figure 1. Network of perceived causal relations between consequences of traumatic brain injury. Relations with a weight of at least 1 SD above average (>64.14) are included, and thicker edges represent stronger relations.

TABLE 3 *Centrality measures of nodes in the perceived causal relations network*

Subset	Aspects of functioning	Outdegree	Indegree	Betweenness
Body Functions	Higher-level cognitive functions	146.00	156.40	2
	Emotional functions	68.07	0.00	0
	Energy and drive functions	71.67	72.13	0
	Control of voluntary movement functions	68.80	68.53	1
	Memory functions	131.13	79.53	0
	Sensation of pain	0.00	0.00	0
	Attention functions	135.46	92.80	0
	Consciousness functions	1000.07	0.00	0
	Average for subset	*202.65*	*58.67*	*0.38*
Activities & Participation	Carrying out daily routine	68.07	84.73	0
	Conversation	218.33	82.13	0
	Walking	0.00	68.80	0
	Complex interpersonal interactions	137.93	369.47	5
	Acquiring, keeping, and terminating a job	0.00	579.07	0
	Self-care	0.00	80.87	0
	Recreation and leisure	0.00	84.93	0
	Family relationships	0.00	226.13	0
	Average for subset	*53.04*	*197.02*	*0.63*

constructed. This network, presented in Figure 2, contains only those relations that the participants consistently perceived to be strong. To this end, only edges with a weight at least 1 SD above average (>64.41) and a below-average standard deviation (<20.59) were included. This network solely includes perceived relations caused by impairments in consciousness or causing difficulties in acquiring, keeping, and terminating a job. The 3 strongest perceived causal relations from the original network were still included in this second network, demonstrating that their standard deviations were below average.

Finally, participants indicated that they found the study relevant (average score 65.33, SD 26.17), but also felt that it was rather difficult to score their perception of the causal relations between consequences (average score

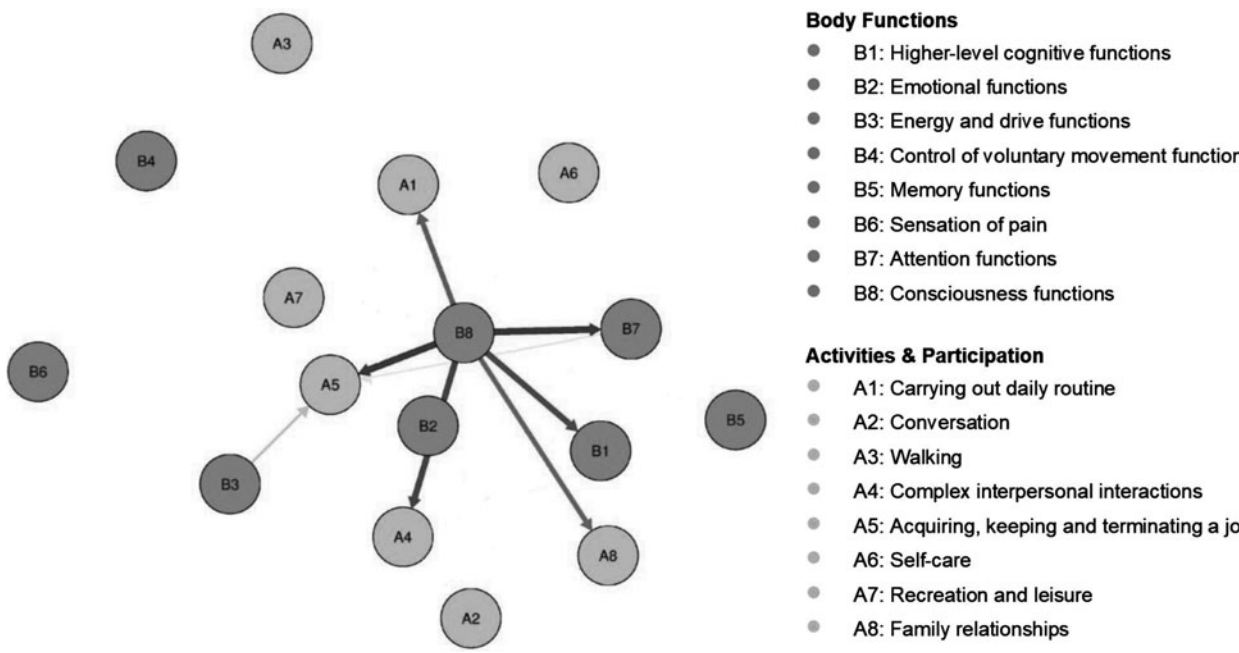

Figure 2. Network of perceived causal relations between consequences of traumatic brain injury. Relations with a weight of at least 1 SD above average (>64.14) and a below-average standard deviation (<20.59) are included, and thicker edges represent stronger relations.

59.93, SD 19.93). Additional comments provided by some of the participants related to the extensive length of the questionnaire, difficulties scoring some of the relations, and some minor difficulties with the survey software.

DISCUSSION

The current study is the first to explore the perceived interactions between consequences of TBI. To this end, a perceived causal relations network[19,21] was constructed based on the perceptions of these relations held by 15 clinicians experienced in working with patients with TBI.

The resulting network demonstrates various strong perceived causal relations between the consequences of TBI. This indicates that, at least in the perception of clinicians, the consequences of TBI do interact with each other, just like the symptoms of mental disorders such as depression[5,6] and posttraumatic stress disorder.[7,8] In our network, impairments in consciousness (defined as impairments in general mental functions of the state of awareness and alertness, including the clarity and continuity of the wakeful state[4]) were most strongly perceived to cause other problems. Amongst others, impairments in this aspect of functioning were perceived to cause problems in attention functions, memory functions, and the ability to acquire, keep, and terminate a job. While most cases of impaired consciousness after TBI are temporary and resolve quickly, some cases persist for extended periods or even permanently.[26] Especially in those cases, it is certainly imaginable that this consequence of TBI causes a myriad of other problems. The TBI consequence that was most strongly perceived to be *caused by* other consequences in our network was difficulties in acquiring, keeping, and terminating a job. Among others, it was perceived to be caused by impairments in higher-level cognitive functions, energy and drive functions, and attention functions. High unemployment has consistently been reported for TBI survivors,[27,28] and has previously been linked to fatigue[29] and impaired communication skills.[30]

On average, impairments from the subset Body Functions were perceived to be stronger *causes of* other consequences than difficulties from the subset Activities & Participation, while difficulties from the subset Activities & Participation were perceived to be more strongly *caused by* other consequences than impairments from the subset Body Functions. Intuitively, this finding makes sense. It is generally more likely that problems with body functions cause problems in activities and participation (eg, memory problems causing employment problems) than the other way around (eg, employment problems causing memory problems). This trend is also observed in earlier network studies, such as in the work of Frewen et al,[19] who found that social and occupational problems were more likely to be an effect of psychological symptoms than a cause.

What is noteworthy as well is the perceived central role of difficulties in partaking in complex interpersonal interactions. Out of all the TBI consequences included in the network, this consequence most often laid on the shortest path between other consequences, indicating that it has a relatively large influence on the network by playing a bridging role between the other consequences. This finding is in line with the findings from recent studies suggesting that communication problems can have a strong negative effect on important aspects of life after brain injury.[30–33] Pain, on the other hand, does not seem to have a strong causal relation with any of the other consequences in the network. While one could expect pain to cause difficulties in certain aspects of functioning such as recreation and walking, these relations do not appear to be very strong. Presumably, other problems such as impairments in energy and drive functions and higher-level cognitive functions may play a more central role in the symptomatology of TBI.

Since the standard deviations associated with the relations in our network indicated a rather large diversity in the extent to which the participating clinicians agreed on the strength of the relations, a second network was constructed. In this second network, only relations that the participants consistently perceived to be strong were included. The fact that this network solely included perceived relations caused by impairments in consciousness or causing difficulties in acquiring, keeping, and terminating a job further substantiates that these consequences are perceived to play a central role in the symptomatology of TBI.

It is important to emphasize that the network presented here is a *perceived* causal relations network. This means that the network is based on how clinicians *believe* certain consequences of TBI cause each other. Although the clinicians participating in the current study all had extensive experience in working with patients with TBI, the relations presented in this article thus do not necessarily fully correspond to reality. Previous work has indicated that clinicians turn to various sources when they look for information (textbooks,[34,35] colleagues,[34–36] and research papers[34,37]), which might all, accurately or erroneously, influence their perception of a condition and its symptomatology. Our study should therefore be seen as an exploration based on which substantiated hypotheses can be formulated, which can be tested in future studies.

An interesting next step could be the construction of perceived causal relations networks based on perceptions held by caregivers or patients and compare these to the network constructed in the current study. While the clinicians in our study were experienced in

working with patients with TBI, and their perceptions can therefore be considered relevant, perceptions held by caregivers and patients might tell a different, equally interesting, side of the story, especially since previous work has shown that doctors' and patients' perceptions of disability can differ.[38] Another interesting advancement would be to build a causal relations network based on actual patient data, rather than on perceptions. Such a network would likely represent reality more closely. However, establishing causal relations based on patient data is not trivial,[14,15,39,40] and, as such, perceived causal relations networks can form a useful starting point.

When interpreting the results of the current study, it is important to consider the limitations that might affect their generalizability. Besides the fact that our results are based on perceptions of a relative small number of clinicians, some other aspects of the study require attention in this regard. First, the vignette presented to the participants will likely have affected the results. Since we aimed to create a perceived network of the consequences of TBI in general, without focusing on a certain type of TBI survivor, the vignette was purposefully generic. However, since the sequelae survivors are faced with vary considerably,[41] causal relations networks will most likely differ for different (types of) patients.[14] What is also important to note is that the consequences included in the current study do not constitute an exhaustive list of all problems that might result from TBI. The resulting network is therefore not a complete network of all problems that can occur after TBI and their relations. Future studies might wish to include more/different TBI consequences to further advance our understanding of the interplay between consequences of TBI. In addition, the questions in our questionnaire were phrased such that difficulties in a certain aspect of functioning were assumed to only be able to cause other difficulties. However, in certain rare cases, at least theoretically, difficulties in one aspect of functioning might have a positive effect on other aspects of functioning. Future network studies could consider allowing for these types of relations as well. Finally, the snowball method used to recruit participants in the current study might have introduced some bias.[42]

In spite of its limitations, the current study constitutes a valuable step in uncovering the interactions between consequences of TBI. While relations between certain pairs of TBI consequences have been studied before,[29–33] the current study is the first to take a network approach to visualize perceived interrelations between a set of 16 consequences central to the symptomatology of TBI. Our results form a fruitful basis for future research that could provide further insights in the ways the network approach might help us comprehend the complex symptomatology of TBI. In time, these insights could improve care by helping us determine treatment of which TBI consequences will likely have the most extensive positive effect on the rest of the "TBI network" and, as such, on the lives of survivors.

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