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Consciousness without cortex: a hydranencephaly family survey

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ABSTRACT

Aim: Hydranencephaly is commonly taken to exemplify the developmental vegetative state, based largely on the assumption that radical loss of cortical tissue is incompatible with consciousness. The aim of the study reported here was to survey primary caregivers of children born with hydranencephaly for behavioural evidence indirectly informative about the conscious status of these children.

Methods: The survey recruited 108 primary caregivers through a parent support group and was conducted online via a commercial survey hosting facility. As part of a more extensive questionnaire, participants answered 106 questions bearing on the environmental responsiveness, emotional reactivity, mood and agency of the child in their care.

Results: The survey elicited a many-facetted and detailed set of caregiver answers and written observations regarding the child's behaviour. A conservative measure of agreement among respondents' answers yielded a generic portrait of the responsiveness and expressive behaviour of a hydranencephaly child.

Conclusion: The generic behavioural characteristics of hydranencephaly thus assessed are incompatible on multiple counts with the unconsciousness characteristic of the vegetative state. This bears on what is included under the concept of quality of life for children with hydranencephaly, and hence on appropriate forms of treatment and care in their case.

INTRODUCTION

Massive loss of cerebral hemispheric tissue during gestation, leading to the birth of a child missing most of the cerebral cortex (hydranencephaly), is compatible with post-natal survival over many years and even decades (1–3). As can be seen from the survivorship curve in Fig. 1, the common belief that hydranencephaly exhibits drastically compromised life expectancy extending to only days or weeks is mistaken. The figure is based on 357 individuals with the diagnosis hydranencephaly and shows that hydranencephaly conforms to a so called Type II survivorship pattern, which means that a small and approximately constant fraction of individuals die in each age bracket. At the time of writing, the oldest individual in this sample was 35 years old. Her position in the population is by no means a statistical outlier, but simply the longest survival in a continuous distribution of life spans typical of hydranencephaly.

The robust evidence for long-term survival in hydranencephaly depicted in Fig. 1 means that children born with hydranencephaly should be expected to live as a matter of course. This raises in acute form the issue of the appropriate care and treatment of these individuals, whether in medical or family settings. Given their loss of the greater part or all of what conventionally is regarded as the 'organ of consciousness', namely the cerebral cortex, the treatment issue cannot be properly addressed without resolving the question of whether these children are capable of experience, that is, whether they are conscious or not (4,5). The answer to that question bears on whether they are capable of experiencing pain, discomfort and distress, but also other hedonic states extending to comfort, pleasure and joy. That is, the question of whether they are conscious or not bears directly on every aspect of how these individuals should be treated and on what is included under the concept of quality of life in their case.

To date there has been scant attention to this issue in the medical literature. The drastic loss of cortical tissue in hydranencephaly, coupled with an identification of the conscious state with cortical function, has encouraged the default assumption that these children are not conscious

Key notes

- The contentious issue of the conscious status of children with hydranencephaly was addressed through an online survey of primary caregivers of children born with hydranencephaly.
- A conservative assessment of agreement among caregivers across survey answers yielded a composite portrait of responsiveness and expressive behaviour in hydranencephaly.
- Generic characteristics of hydranencephaly emerging from this analysis are incompatible with the state of unconsciousness defining the vegetative state.

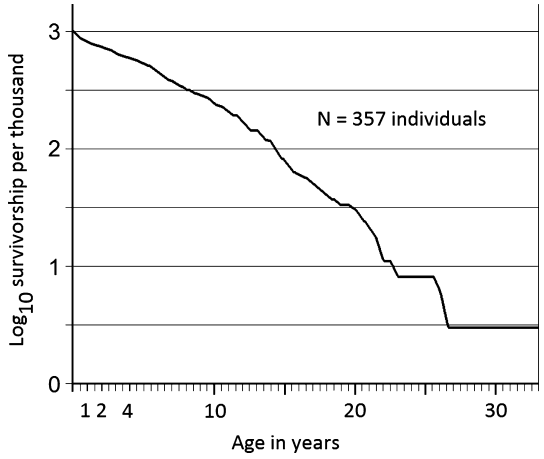

Figure 1 Survivorship curve for a total of 357 individuals diagnosed with hydranencephaly who were born between 1979 and 2011. Their caregivers were reached through the internet support group hydranencephaly.yahoo.com. Barb Aleman, who founded the group, collected dates of birth and death from the group's contact list and other administrative materials. Survivorship was calculated in half year intervals up through the first half of 2012, and displayed in the conventional form of the logarithm of survivorship at birth per thousand individuals. The oldest individual in the group was 33 years and 5 months when the calculation was made and is still living at the time of publication.

(4). Thus, hydranencephaly is casually mentioned as an example of the vegetative state in the 1994 report of the Multi-Society Task Force on the Persistent Vegetative State (6), without supporting evidence or arguments. However, in the single published report of neurological examination of the conscious status of such children in their home environment, four out of the four children assessed were deemed to be not only physiologically awake but conscious (5).

More recently, a review of the grounds offered by clinical neurology, comparative neurology and theoretical neuroscience for assuming that the cerebral cortex is necessary for a conscious state to exist concluded that good grounds for that assumption are lacking (4). While the cerebral cortex undoubtedly contributes prominently to the elaborate conscious *contents* of adult humans, the complex neurological organisation of the upper brainstem may be capable of sustaining a conscious *state* on its own, even in the absence of a cerebral cortex. This may be so in particular in situations in which the maturing brainstem never becomes subject to cortical afference, as in hydranencephaly. What consequences might a noncortically-dependent conscious state in hydranencephaly have for the quality of life of these children?

Since the conscious state by definition is a private one (7), all approaches to answering the questions just posed must of necessity be indirect ones. Children with hydranencephaly typically have severe motor disabilities of cerebral palsy type, but not to such an extent that they lack various forms of behavioural reactivity and expressive behaviour. Assessed over time in familiar surroundings, these spontaneous or reactive behaviours are bound to contain clues and hints regarding whatever cognitive states and capacities these behaviours imply and presuppose. In the absence of systematic, longitudinal, observational studies of children with hydranencephaly – studies that simply have not been performed but deserve to be undertaken – the primary caregivers of these children offer an important source of information regarding their behaviour. Here, we report on a first attempt to tap this informational resource by surveying primary caregivers of children diagnosed with hydranencephaly regarding their impressions and observations of the children in their care.

SURVEY METHOD AND PARTICIPANTS

The survey was conducted by one of the authors (BA) via the internet, using the software and hosting facilities of the commercial survey website HostedSurvey.com which also archives the raw survey data. Primary caregivers of children with hydranencephaly were reached through the parent support group Hydranencephaly@YahooGroups.com (a mailing list forum) and the hydranencephaly website Hydranecephaly.com. At the time of the survey, these forums engaged some 200 families, mostly in the United States, but also in Canada, Great Britain and a small number from five additional countries. Participants were encouraged to volunteer for the survey by repeated invitations and reminders posted on these forums. Since active participation in the forums fluctuates considerably over time, the survey remained open from March 2006 until the end of May 2007, resulting in a total of 108 participating caregivers.

The primary purpose of the survey was to gather practical information from the families as a means to assist their daily and long-term needs in caring for a child with hydranencephaly. A majority of the survey's total of 408 questions therefore dealt with details of the children's family background, health, physical condition, medications and various aids and equipment used in their care. The questionnaire was not designed to provide a formal inventory of the children's behaviour. However, given the connection between the issue of proper care of these children and that of their conscious status, 106 of the questions pertained to matters which in one way or another might bear on or reflect their conscious status. The answers to these 106 questions form the subject matter of this report.

Of those 106 questions, 53 had yes/no answers, and fell into the following four thematic clusters:

1. Responsiveness or reactivity to environmental stimuli and events, including the presence of familiar and unfamiliar individuals (22 questions, see Table 1),
2. Signs of emotional reactions and mood in the child (14 questions, see Table 2),
3. Signs of initiative or agency on the part of the child (14 questions, see Table 3),
4. Other indications that might bear on conscious status (three questions).

Table 1 Survey answers to questions pertaining to a child's responsiveness and reactivity to environmental stimuli or events

Q#	Question	No. of resp.s	Yes%	No%	Other%	Perc. point spread*
A1	Is your child aware of his/her surroundings?	97	81	19		**
A2	**Can your child see?**	91	31	30	39	
A3	Does your child react to turning the room lights off or on?	88	77	23		**
A4	Does your child turn his/her head to or away from visual objects?	85	66	34		*
A5	Does your child turn his/her eyes to or away from visual objects?	77	51	49		
A6	Does your child have other reactions to conspicuous visual objects or events?	78	24	76		**
A7	Does your child ever peer around an obstacle to look at something?	86	13	87		**
A8	**Can your child hear?**	95	93	0	7	***
A9	Does your child turn his/her head to sound?	96	86	14		**
A10	Does your child turn his/her eyes towards sound?	91	74	26		*
A11	Does your child have other reactions to sounds?	89	74	26		*
A12	In general, are there some types of sounds that make your child respond more reliably than others?	83	69	31		*
A13	Does your child understand what is said to him/her?	84	38	62		
A14	Does your child understand any specific words?	86	34	66		*
A15	Does your child respond selectively to his/her own name?	90	66	34		*
A16	Does your child show that he/she recognises certain voices?	91	88	12		***
A17	Does your child indicate if he/she recognises something or someone?	94	77	23		**
A18	Does your child know you and your immediate family members?	94	91	9		***
A19	Does your child know the difference between a family member and a stranger?	94	83	17		**
A20	Can your child be comforted more by one person than another?	96	89	11		***
A21	Does your child show an awareness of his/her own body?	90	24	76		**
A22	Does your child show an awareness of objects?	90	57	43		

*A difference of 25, 50 and 75 percentage points between yes and no responses to a given question is indicated by *, **, and ***, respectively.

Table 2 Survey answers to questions pertaining to the child's emotional reactions and mood

Q#	Question	No. of resp.s	Yes%	No%	Perc. point spread*
B1	Does your child feel pain?	92	96	4	***
B2	Does your child cry?	99	91	9	***
B3	Does your child smile?	95	89	11	***
B4	Does your child show any indication of fear or dislike?	93	67	33	*
B5	Does your child show a strong aversion to someone or something (something they don't like to look at, particular activities/stories, smells, people, etc.)?	92	45	55	
B6	Does your child get mad or have temper tantrums?	92	41	59	
B7	Does your child give hugs or kisses?	96	26	74	*
B8	Does your child have a favourite toy?	92	43	57	
B9	Does your child have a favourite activity?	94	61	39	
B10	Does your child have a favourite position or piece of equipment?	92	51	49	
B11	Does your child have a security item?	75	40	60	
B12	Is your child ticklish?	93	56	44	
B13	If your child is ticklish, and you take the child's hand and move it against the child's body in the same way you do when you do the tickling, will he/she react?	55	38	62	
B14	Is the reaction the same as when you yourself do the tickling directly?	45	22	78	**

*A difference of 25, 50 and 75 percentage points between yes and no responses to a given question is indicated by *, **, and ***, respectively.

Most of these questions had follow-up questions (e.g. 'If yes, how does he/she show this?'), most of which latter were answered by entering written answers into the survey form. The full set of 106 survey questions is reproduced in an Appendix S1, available as Supporting Information online.

SURVEY RESULTS

The principal results expressed in terms of percentages of respondent answers to the 50 survey questions with yes/no answers are presented in Tables 1–3. Table 1 contains questions related to reactivity, Table 2 questions related to mood/emotion and Table 3 questions related to initiative.

Table 3 Survey answers to questions pertaining to initiative or agency on the part of the child

Q#	Question	No. of resp.s	Yes%	No%	Perc. Point spread*
C1	Does your child make any sounds?	90	93	7	***
C2	Can your child call attention to him/herself?	91	67	33	*
C3	Does your child reach for objects?	90	26	74	*
C4	Does your child do so spontaneously, when the object was not presented by others?	67	22	78	**
C5	Can your child make choices?	89	27	73	*
C6	Does your child have a yes/no response?	85	15	85	**
C7	Can your child activate switches purposefully?	88	31	69	*
C8	Will your child echo or imitate you?	90	29	71	*
C9	Does your child say and use meaningfully any words?	92	14	86	**
C10	Will your child take turns with you in play activities?	88	16	84	**
C11	Are you able to build up play sequences in which your child gets more and more excited as you keep at it?	87	31	69	*
C12	Does your child show signs of 'wanting more' during play or other joint activities?	91	34	66	*
C13	Have you ever seen your child turn to or touch or rub a part of his or her body that hurt?	90	9	91	***
C14	Does your child anticipate or expect events (i.e. a particular television programme, going to visit someone familiar, other events of daily routine, etc.)?	90	37	63	*

*A difference of 25, 50 and 75 percentage points between yes and no responses to a given question is indicated by *, **, and ***, respectively.

They are labelled A, B and C, respectively, to assist locating these questions in the Appendix S1, where they are interspersed with additional questions requiring written answers. Not every respondent answered every question. Typically, there were around 90 responses (modal score) to a given question. The number of respondents answering each question is listed along with percentages of 'Yes' and 'No' answers in the tables.

Table 1 lists results for questions pertaining to a child's responsiveness to environmental stimuli and events, starting with the general question of whether the child is aware of his or her surroundings (question A1, 'Is your child aware of his/her surroundings?'). Of 97 respondents answering this question, 81% answered 'Yes', and 19% 'No'. The follow-up question 'If yes, how does he/she show awareness?' received 70 written answers. Besides the bodily signs by which respondents identified reactions to environmental events (e.g. 'Bright eyes, smiles, moves head from side to side'), more than half of the answers included the eliciting environmental circumstances. Of these, 25 mentioned situation-specific reactions, such as 'He seems to be more relaxed whenever he comes home after being out. He looks around the room and smiles (as if to say he's happy to be home)', or 'She mostly knows if we are near her. She gets upset if we aren't. I know this because she becomes extremely stiff'. An additional eight answers indicated directionally specific reactions, such as 'Looks to people talking to her, looks to TV or sounds, coos, vocalises', and a further five named both situational and directional features of these reactions, such as 'Smiles when approached, gets startled, wants to be picked up, fusses if left alone and turn towards sounds'.

A child's awareness of its environment is mediated primarily by the two distance senses vision and hearing. We note the contrasting pattern of answers supplied to the questions 'Can your child see?' (A2) and 'Can your child hear?' (A8). For vision, 30% of respondents answered 'No', a further 39% used the option 'Sometimes' and only 31% answered with an unqualified 'Yes'. For hearing, no respondent answered 'No', 7% answered 'Don't know', and a full 93% gave an unqualified 'Yes' answer. This contrast in parental judgement regarding their child's seeing and hearing will receive detailed attention in the Discussion section. Note that these two questions about seeing and hearing are the only ones in the Tables with an option besides 'Yes' or 'No'.

A set of additional questions regarding both seeing (A3 to A7) and hearing (A9 to A16) aimed at further characterising the child's capacities in these regards. A great majority of respondents affirmed, for example, that their child reacts to having the room lights turned on and off, and there was strong agreement among them that they had not witnessed their child peering around obstacles to look at something. For hearing, we note that the strong agreement that the children can recognise certain voices (88% 'Yes' answers to question A16) does not extend to their understanding of spoken language and words: 62% said 'No' to questions A13 and 66% said 'No' to question A14. However, the question of whether the child responded selectively to his or her own name (question A15) received 66% 'Yes' answers.

Table 1 ends with a cluster of questions (A16 to A21) addressing the child's recognition and familiarity (e.g. whether the child indicates recognition, knows family members from strangers, recognises certain voices over others, etc.). Most respondents answered 'Yes', except on the question of whether the child shows awareness of his or her own body, which most respondents denied. Each of these questions had a written follow-up question on the pattern of 'If Yes, how was this shown?' which elicited a total of 298 written answers concerning the means by which respondents judged the differential responses of the children. The most common descriptors referred to

'smiling', which occurred a total of 89 times (e.g. 'He doesn't react to strangers' voices by smiling, just familiar ones'). Head turning or 'turning towards' featured in 48 answers (e.g. 'He would turn his head in the direction of our voices'), and another 23 answers noted the behaviour of the eyes, such as arrest of nystagmus, 'looks around', 'rolls eyes', etc. (e.g. 'turns his eyes towards the person, sometimes with mouth open'). Together these descriptors account for over half of the written answers to these six questions and occur in the written answers to many other similar follow-up questions as well.

Remaining written answers to questions A16 to A19 varied widely, but were typically specific and informative, as in the following examples: 'When strangers speak or touch her, she either screams or turns in on herself, as if asleep' (A19 follow-up); 'Quiet when picked up by family, cries when even touched by strangers. Would only take bottle from Mom at first, but now takes bottles from familiar people' (A18 follow-up); 'Arms waving, smile, pushes body like she want to jump into their hands' (A17 follow-up); and 'Seemed very fascinated with my husband's voice, would turn to look at him, seemed drawn to him' or 'He smiles with me (his grandma), laughs out loud for his mom, searches with his eyes for his teacher' (both to A16 follow-up, concerning the child's recognition of certain voices).

Table 2 lists percentages of yes/no responses to questions about the child's emotional reactions and expressiveness. There was strong agreement among 92 respondents that their child feels pain (96% 'Yes' and 4% 'No'). Of 85 written answers to the follow-up question 'If yes, how is this shown?' 70 featured 'crying' and its variants (from 'screaming' to 'whimpering'). An additional four answers featured 'body stiffening', another four 'grimacing', including 'shocked' or 'startled' look, and a further three 'flinching' and 'wincing'. Four respondents mentioned the triggering of seizures among their child's reactions to pain.

In keeping with the frequency of the answer 'crying' to the pain question, most respondents by far answered the question 'Does you child cry?' in the affirmative, as was the case for the question about smiling. There was fair agreement that the children exhibited fear or dislike (question B4), as shown by crying (21 instances of the total of 59 written answers), closely followed by grimacing and other facial expressions (19 instances), startle or body stiffening (eight instances) and turning away (four instances). Some respondents judiciously separated signs of fear from those of dislike in their written answers, as in 'She startles and gets spasms when she gets scared. If she dislikes, she shuts down', or 'Fear: startle reflex; dislike for food is shown in facial/mouth expressions'. There was also fair agreement among respondents that the child did not give hugs or kisses, a question that is also relevant to the issue of initiative featured in Table 3. Regarding the low number of answers to questions B13 and B14, which involved performing a test on the child, it should be noted that 29 of the children were not alive at the time the survey was taken.

In addition to the questions concerning emotional expression listed in Table 2, the survey contained a multiple choice question directly addressing the child's mood, namely 'What is your child's general mood?' Of 98 respondents 58 checked 'Happy', 25 'Quiet', 13 'Irritable' and two checked 'Can't tell'. Many written answers to follow-up questions of the type 'How can you tell?' or 'How does the child show or indicate this?' also employed emotion-related terms. The total of 21 such questions (see the Appendix S1, where they are marked by an asterisk) generated a total of 1122 written answers. Of these nearly half (a total of 548) included emotion-related terms, as follows: smile (199 instances), cry (195), laugh (86), coo (29), fuss (19), giggle (16), whimper (3) and squeal (1).

Most questions designed to elicit judgements regarding signs of initiative on the part of the child (Table 3) tended to receive 'No' answers, though not without exceptions. Of the 91 respondents who answered the question 'Can your child call attention to him/herself?' 67% answered 'Yes' and 33% 'No'. The follow-up question 'If yes, how?' elicited 62 answers, with descriptors for loud vocalisation, such as hollering, yelling and screaming being the most common (21 instances). An additional nine answers explicitly included 'loud' or 'louder and louder' in the description. Fourteen further respondents answered crying, and another 13 other forms of vocalisation. That is, the overwhelming majority of answers referred to vocalisation, but five answers referred to other means such as 'shaking her crib by kicking her legs'. There were 55 written answers to the further follow-up question 'If yes, in what situations would he/she be most likely to do this?' (i.e. call attention to self). Of these, 31 referred to social situations (such as 'If he is in the living room and we are in the kitchen, he will squeal till we come and talk to him', 'When you are playing with him and then stop', or 'When he hears someone in the room and they aren't talking to him'), 11 referred to bodily needs (such as 'When hungry, wet, tired' or 'When in her wheelchair too long'), a further six combined both of these (such as 'When hungry, soiled diaper, wanting to be held, or wants someone to "talk" to him') and finally, seven miscellaneous answers (such as 'When she was upset' or 'Following seizures').

The question of whether the child makes sounds (question C1) elicited strong affirmative agreement among respondents (93% 'yes' and 7% 'no'). This is hardly surprising, given that even passive respiratory noise qualifies as sound. That the responses reflect more than this is apparent from answers to the follow-up question 'If yes, what are they?'. The 83 written responses rank-ordered in frequency of occurrence include the following terms: cooing (29 instances), laughing (17), crying (13), babbling (13), groaning/growling/gurgling (8), yelling/hollering/shouting (8), grunting (6), squealing (4), moaning (4), screaming (3), whimpering (3) and giggling (3). Some respondents filled in an assortment of syllables or syllable combinations such as 'ah', 'ooh', 'agah', 'ma-a' and 'abhoo'. Finally, respondents showed strong agreement in denying that they had ever seen their child turn to or touch or rub a

part of his or her body that hurt (9% 'yes' and 91% 'no' of 90 answers).

The survey included three additional questions that do not fall under the topical headings of Tables 1 through 3, but bear nevertheless on the children's responsiveness and expressive behaviour. They are listed, along with their follow-up questions, at the end of the Appendix S1 and pertain to absence seizures, nystagmus and startle reactions. To the question 'Does your child drift into absences (blank stare, unresponsive, etc.)?' 60% of 101 respondents answered 'Yes' while 40%t answered 'No'. The behaviour was said to occur 'frequently' by 38% of 63 respondents, 'occasionally' by 46% and 'rarely' by 16%, and to last from seconds to minutes. Respondents claimed that it is easy to tell when the child 'is back' (87%) relying on indicators such as blinking, looking around, resuming play and becoming responsive again (e.g. 'Eyes blink and then she looks around', 'Blinks, responds to me finally, eyes move', 'Eyes stop twitching, lips return to normal colour, no pooling of drool, etc.', 'Blankness in her face goes away', or 'He will snap out of it and start laughing').

Nystagmus is relevant to the children's responsiveness in that sensory events, or focused attention may arrest the repetitive eye movements. Of 89 respondents, 53% answered 'Yes' to the question 'Does your child have nystagmus (repetitive, jerky eye movements)?' Of these 51 respondents, 40 answered 'Yes' to the question 'Does the nystagmus ever stop or get noticeably less?' Of the 30 written answers to the follow-up 'If yes, when?' seven took the question to refer to long-term or permanent changes rather than (as intended) momentary ones, as indicated by answers such as 'When he got his glasses'. Of the remaining 23 answers, eight indicated that nystagmus abated when the child was relaxed, resting or well rested; five stated that it stopped when the child noticed, recognised, or focused on someone or something; one that it occurred when the child was focusing on something; three that it related to seizures; and six found no pattern.

Turning to startle reactions, 74% of 78 respondents answered 'Yes' to the question 'Is your child easily startled?' Various versions of the answer 'startles' also made its appearance among answers to other questions. It was by far the most common term among written answers to question A11 ('Does your child have other reactions to sounds?'), where it occurred in 34 out of 65 answers, often with an indication that it was triggered by sudden or loud sounds. It occurred a further eight times among 61 written answers specifying the child's reaction to the room lights being turned on, and five times among 59 written answers to the question how the child exhibits fear or dislike, typically specified as a sign of being frightened.

DISCUSSION

The survey contains internal evidence that respondents, in giving their answers, were not unduly swayed by 'parental bias'. Some survey questions were worded in such a way that respondents prone to exaggerate the capacities of their child could do so without compromising their conscience. Question C13 asked: 'Have you ever seen your child turn to or touch or rub a part of his or her body that hurt?' The behaviour is a natural one and presumably would be welcomed as such by parents. The wording 'have you *ever*' combined with the broad 'turn to', 'touch' or 'rub' would make it difficult to be certain of never ever having witnessed such an event, yet 91% of respondents answered 'No'. This was not because respondents thought their child did not feel pain (96% asserted the child did so, the most unequivocal answer in the entire survey).

Similarly, for question A7, 'Does your child ever peer around an obstacle to look at something?' 87% answered 'No', despite the ease with which certain spatial relations between child and objects in the home might be interpreted in that way, and therefore easily could have justified an affirmative answer. On question B7 ('Does you child give hugs and kisses?'), 74% of respondents answered 'No', though a parent would welcome such behaviour. We note also the contrasting pattern of answers regarding whether the child sees and hears. For hearing (question A8, 'Can your child hear?'), 93% answered 'Yes', while for seeing only 31% did so (question A2, 'Can your child see?'), with a further 37% answering that the child could see 'sometimes'. As we shall see at a later point in this discussion, the two senses are differentially impaired in hydranencephaly for neurological reasons unlikely to be known to respondents; yet, they correctly identified vision as the impaired sense compared to hearing.

The pattern of these answers provide little support for the supposition that parental bias has been a substantial factor in shaping survey responses. We therefore take them to approximate what can reasonably be concluded about the behaviour and competences of these children on the basis of long-term and daily informal observation. This does not, of course, mean that the survey results provide a direct quantitative index to the abilities of children with hydranencephaly. The informal nature of the observations in themselves are a limitation, compounded by additional uncontrolled factors such as the contexts in which they were made, the health status of the child and the details of the distribution of brain damage beyond the bare clinical diagnosis of hydranencephaly. We have accordingly adopted a conservative approach to interpreting our results, based on the size of the percentage point difference between 'Yes' and 'No' answers (in either direction) to a given question.

When the size of that *difference* lies between 75 and 100 percentage points (which means that at least 87.5% of respondents have answered one way, and at most 12.5% of respondents the opposite way), we interpret this high degree of agreement among respondents to the effect that the attribute in question is obvious, easily accessible to observers, and present (or absent, as the case may be) in most of the children in the survey. Given the size of our sample, and the lack of any reason to believe it to be unrepresentative of hydranencephaly, we repose high confidence in such answers as reflecting generic characteristics

of hydranencephaly and have marked them with three asterisks in Tables 1 through 3. Percentage point differences between 50 and 75 points (i.e. at least 75% one way and at most 25% the opposite way) are marked with two asterisks in the tables and are accorded a fair level of confidence in this regard. Percentage point differences between 25 and 50 (at least 62.5% one way and at most 37.5% the opposite) are marked with a single asterisk in the tables, and we response some, but low, confidence in these items as reflections of an actual, generic characteristic of hydranencephaly. When the percentage of 'Yes' and 'No' answers is sufficiently close for the difference between them not to reach 25 percentage points, we repose no confidence in them as reflecting generic attributes of hydranencephaly and have left them unmarked in the tables.

With this background, if we combine the characteristics marked by two and three asterisks in Tables 1 through 3, we would obtain a composite caregiver portrait of the capacities of a child with hydranencephaly regarding which we could be reasonably confident that they reflect generic attributes of hydranencephaly. Such a child is aware of his or her surroundings (question A1 and follow-up) and reacts differentially to immediate family members versus strangers (questions A18-20). This discrimination is likely to rely heavily on recognition of familiar voices (question A16), because the child hears (question A8), but is visually impaired (A2), though not to such an extent as to lack reactions to conspicuous visual objects or light and dark (question A6, A3). The child responds selectively to his or her own name (question A15), but does not understand spoken language (questions A13, A14). On this latter point, the majority of 'No' answers is not large enough to meet our confidence criterion, plausibly accounted for by the fact that some of the meaning of speech is conveyed by its prosody and emotional contour, an interpretation indirectly supported by substantial agreement on question C9 to the effect that the child does not use words meaningfully.

Regarding emotional reactivity, the child reacts to pain (question B1), but without turning to or acting on its source (question C13). He or she also smiles, cries (questions B2, B3) and makes other non-verbal sounds indicative of emotional state or mood such as cooing, laughing and moaning/groaning (question C1 and its follow-up, plus numerous written answers to other questions enumerated under Results). By contrast, answers to most questions regarding signs of initiative generated more 'No' than 'Yes' answers, but without sufficient percentage point spread to meet our confidence criterion (questions C4, C6, C10). The severe motor limitations of the children may play a role here, in keeping with their often severe symptoms of cerebral palsy type.

We note also that with respect to both 'reaching for objects' and 'awareness of own body' (question A21, to which 76% of respondents answered 'No'), the visual modality, compromised in many of these children, is likely to play a prominent role. We typically do not reach for auditory objects without also seeing them, and our body acquires definition as an object on a par with other solid objects only when vision is added to somatosensation. Finally, evidence for initiative on the part of the child is equivocal, though the child gives some evidence of being able to call attention to self (question C2), uses overwhelmingly vocal means of doing so, and does so in socially or bodily appropriate situations (such as being left alone or needing a diaper change).

Needless to say, this composite portrait of some of the behaviours and competences of children with hydranencephaly cannot be reconciled with the diagnosis 'developmental vegetative state' that is commonly applied to them (6; see also 4, 5). These children are not only 'physiologically awake' in the sense of going through a sleep-wake cycle, but they are alert and responsive to environmental events during wakefulness. They turn to salient stimuli, show situationally contingent emotional reactions and distinguish familiar voices from those of strangers (see Results section), all of which is incompatible with the unconsciousness of the vegetative state.

This conclusion is reinforced, moreover, by the fact that many of these children exhibit episodic 'absences' in the waking state. These episodes, typically said to last from seconds to minutes, conform behaviourally to absence seizures, and 53 of the 61 respondents found it easy to tell when the child is 'back again' by signs such as 'Gasps and eyes "come down"', 'Blinks, responds to me finally, eyes move' or 'He will snap out of it and start laughing'. Since the child obviously is not asleep during the episode, what the child 'returns to' at the end of the seizure can only be consciousness. Behaviourally, these children thus appear to be conscious while awake, occasionally lose consciousness during an absence seizure, only to return to consciousness as the seizure abates, just as do other children with absence epilepsy. The affliction has not as yet been studied physiologically in hydranencephaly. Absence epilepsy is known to involve subcortical structures (4,8). Since EEG seizures can be recorded in hydranencephaly even in complete absence of cortical tissue (9), systematic study of absence seizures in children with hydranencephaly should shed further light on their conscious status.

We note the agreement between our conclusion regarding the conscious status of these children and what was reported by neurologist Alan Shewmon and colleagues on the basis of examining four children with hydranencephaly in the setting of their familiar home environment. They concluded that all four of these children were conscious, despite their massive loss of hemispheric tissue (5). The home environment may be essential for observing the full range of behaviour of these children. According to our results, some of these children react to unfamiliar environments or the mere presence of strangers by a kind of withdrawal. Thus, of the 75 written answers detailing the signs by which the child shows differentiation between familiars and strangers, a full 60% contained language indicating inhibition, avoidance or distress, such as 'no eye contact with strangers', 'doesn't smile readily for strangers', 'if a stranger talks to him he gets very still and casts his eyes down', 'clams up for strangers' or 'when strangers speak or

touch her she either screams or turns in on herself and acts as if she is asleep'.

Primary caregivers of these children accordingly enjoy a privileged position as observers of their behaviour. They also provide the constant loving care and stimulation that may be a prerequisite for the child to even develop or exhibit the kinds of behaviour detailed in our survey and reported by Shewmon and colleagues. The contrast between these behaviours and the unresponsiveness and passivity exhibited by some institutionalised individuals with hydranencephaly is striking. For example, the clinical picture of the institutionalised woman with hydranencephaly reported by Bae and colleagues conforms well to that of the vegetative state (1). See also ref. 10 for a striking informal account of what may hide behind such an appearance.

Given the conscious state of these children coupled with the fact that they have lost most of their cerebral cortex before birth, what neural mechanisms might support consciousness in this condition? As one of us has argued at length elsewhere, the mystery may be far less than it seems, provided that the role of subcortical mechanisms in the constitution of the conscious state even in the intact brain is taken into account (4). The superior colliculus in the roof of the midbrain contains a sophisticated neural machinery for the integration of the visual, auditory and somatosensory modalities within a shared efferent framework for directional orienting movements (11).

Even in the absence of a cerebral cortex, collicular connections with the hypothalamus, the substantia nigra, the zona incerta – the latter connected with the red nucleus (12,13) – and the periaqueductal grey matter make the superior colliculus a midbrain interface between neural systems related to target selection, action selection and emotion/motivation. Spatially organised mutual interaction between these three functional domains has been proposed to provide the key to the conscious state in neural terms (4,14). The collicular interface between them may accordingly not only explain the children's orientation to environmental events, but the conscious condition in which it takes place.

Many of these children do of course have remnants of cerebral cortex that might contribute to their abilities, though this residual cortex is highly variable and typically of unknown functional integrity (4). The typical pattern of tissue damage and sparing in hydranencephaly (15–18) often leave variable remnants of occipital, midline and ventral temporal tissue spared, yet hardly ever dorsal temporal auditory cortex. If spared cortex accounts for the sensory capacities of these children, one would predict spared vision and compromised hearing, yet the observed pattern of sensory loss is the exact opposite of this: spared hearing with compromised vision.

As we saw in survey responses to questions A2 and A8 ('Can your child see?' and 'Can your child hear') respondents answered overwhelmingly 'Yes' (93%) to the hearing question, while for vision only 31% gave an unqualified 'Yes', with a further 39% checking 'Sometimes' and the rest 'No'. This result agrees well with other evidence that in hydranencephaly, hearing is generally preserved, whereas vision tends to be compromised (4,5,10,19–22). Note that in hydranencephaly, the brainstem auditory system, culminating in the sophisticated pitch extraction arrangement of the midbrain inferior colliculus (23–26) is intact, while the visual pathway tends to be affected already at the level of the optic nerve (27). The latter derives blood supply from the anterior cerebral artery, typically compromised in hydranencephaly. Thus, the contrasting visual and auditory responsiveness of children with hydranencephaly is more readily accounted for by what we know about the status of their *subcortical* sensory connections centred on the midbrain than by the pattern of spared *cortical* tissue.

To conclude our discussion, we note that the apparent capacity of children with hydranencephaly to experience a spectrum of hedonic states spanning from distress to contentment, pleasure and even joy, as expressed through screaming, crying, fussing, smiling, giggling and laughter, bears directly on the issue of the care appropriate for these children that we raised in our introduction. The indications that they are not only physiologically awake but conscious during waking makes it appropriate to apply the concept of quality of life to these children. The exertions of caregivers for their comfort and well-being would seem well placed, in other words. Those exertions, moreover, appear to have a fair prospect of success: 59% of our respondents declared the general mood of their child to be 'happy', 26% 'quiet', 13% 'irritable' and 2% were unable to tell. The implication of our survey results in this regard, then, is that children with hydranencephaly hardly differ from other children in the dependence of their contentment and flourishing on the level of committed care they receive.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1 The 106 survey questions on which the present report is based.