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Changes in Responsiveness when Brain Injury Survivors with Impaired Consciousness Hear Different Voices

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Abstract

Primary objective—The researchers sought to determine whether individuals with impaired consciousness secondary to acquired brain injury (ABI) changed in responsiveness when purposefully presented with familiar, unfamiliar, and synthetic voice messages.

Research design—Researchers used an ABA single case study design across stimuli. Participants were 3 minimally-responsive ABI survivors.

Methods and procedures—Participants heard auditory stimuli two times daily for thirty days. Data from video recordings included tallies of behavioural responses at 10-second intervals throughout baseline, intervention, and post-intervention phases of each session. Statistical calculations allowed determination of responsiveness changes across time intervals within sessions.

Main outcomes and results—Unique response profiles emerged across survivors. Two participants demonstrated responsiveness changes with presentation of auditory stimuli. None demonstrated a clinically-significant differential response based on voice type.

Conclusions—Findings suggest that auditory stimulation results in arousal changes in some ABI survivors regardless of the familiarity of voices presented.

Rehabilitation professionals typically provide sensory stimulation to survivors of acquired brain injury (ABI) who exhibit impaired consciousness. The theoretical intent of this treatment is to stimulate nervous system plasticity and reorganization, combat the negative effects associated with sensory deprivation, and simultaneously prevent sensory overload and habituation [1–4]. For individuals who quickly regain normal consciousness, the specific materials used and modalities targeted for this stimulation may be of little consequence [5]; however, for individuals who experience prolonged periods of impaired consciousness, selection of the most appropriate and helpful stimulation materials is important. In particular, certain materials may facilitate increased arousal and awareness more rapidly and effectively than others [6–7].

In recent years, investigators have determined that at least some people with impaired consciousness demonstrate brain activation patterns similar to those of neurologically-intact adults when exposed to certain types of sensory stimuli [8–14]. Regarding auditory stimuli, researchers have determined that variations in the types of sounds presented impact the

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likelihood with which a person will demonstrate brain activation. For example, Kotchoubey and colleagues [15] elicited more frequent mismatch negativity responses associated with event-related potentials among people with minimal consciousness or in vegetative states when presenting musically complex sounds rather than simple sine tones. In other studies, Boly and colleagues [8–9] used PET scan technology to document more widespread brain activation when people with minimal consciousness heard auditory stimuli with high emotional content (i.e. their own names or people's cries) than when hearing meaningless auditory sounds. Using fMRI or PET scan technology, two other groups of researchers [11,13] confirmed the salience of people's own names as auditory stimuli particularly likely to elicit brain activation among minimally conscious individuals and at least some people in vegetative states. In contrast, people in these populations demonstrated less brain activation when hearing auditory stimuli that were lower in salience (i.e. other people's names) or were meaningless regarding linguistic content (i.e. time-reversed narrative samples) [13–14]. Perhaps most striking has been fMRI documentation by Owen and colleagues [12] showing that a person in a vegetative state had brain activation patterns indistinguishable from those of neurologically-intact participants when given verbal instructions to perform two mental imagery tasks.

Evidence of brain activation does not, by itself, mean that a person will emerge from a state of impaired consciousness; only those individuals who regain a means of interacting and re-establishing meaningful relationships with others will be successful in recovering further [16]. Because of this, one of the specific intents of sensory stimulation intervention is to increase a survivor's interaction with the environment [17]. Hence, taking note of behavioural responses in addition to analyzing brain activation patterns is important when considering the impact of different types of sensory stimuli. In keeping with this notion, some researchers have studied the impact of different types of sensory stimulation materials on people with impaired consciousness by examining easily-observed behaviours and physiological responses that suggest increased arousal, awareness, and response to the environment. For example, Jones and her colleagues [7] presented four types of auditory stimuli to an individual with minimal responsiveness to determine which elicited the greatest change in behavioural (i.e. gross body and/or facial movement) and physiological (i.e. pulse rate and respiratory rate) responses. The four kinds of stimuli included recordings of (a) familiar voices of family and friends, (b) non-preferred music, (c) preferred music, and (d) nature sounds. Findings indicated that the participant demonstrated significant increases in behavioural and physiological responsiveness when listening to recordings of familiar friends' and family members' voices and a significant decrease in physiological responsiveness when hearing preferred music. Neutral stimuli (i.e. non-preferred music and nature sounds) were not consistently associated with significant increases or decreases in arousal.

Anecdotal accounts from professionals as well as friends and family members support the findings reported by Jones and her colleagues [7] in that they suggest survivors are more responsive to some types of stimuli than to others. Rehabilitation professionals often describe sensory stimulation programmes as having variable success increasing survivors' levels of arousal. However, family and friends of these same survivors may report that, outside of treatment sessions, the person 'lights up' or 'responds' when a particular loved one walks into the room and issues a greeting.

To further evaluate the impact of various types of sensory stimulation, Wilson, Brock, Powell, Thwaites and Elliot [18] explored differences resulting from presenting personalized versus generic stimuli to three ABI survivors with minimal responsiveness. The researchers used each participant's eye, body, or vocalization responses to stimuli presented during one session to determine the target stimuli for subsequent sessions. For example, if a participant responded to an auditory stimulus during one session, that person was presented with a different auditory stimulus during the next session. This second auditory stimulus was systematically varied to be either personalized to the participant or generic. Results indicated that one participant had increased eye-opening behaviour with personalized stimuli; another participant demonstrated maximal arousal just prior to stimulation and at the completion of stimulation regardless of the level of stimulus personalization; the third participant showed no arousal changes when presented with any type of sensory stimulation.

The fact that people with impaired consciousness respond differentially to various types of auditory stimuli makes the selection of materials used in sensory stimulation programs important. Limited existing research and variable results obtained to date have led to continued uncertainty among rehabilitation professionals about best practises for developing and administering components of auditory stimulation interventions. As such, the purpose of the current study was to determine whether verbal stimuli differing in voice familiarity to survivors with impaired consciousness resulted in differential changes in arousal. The specific objective was to evaluate responses of three ABI survivors when each heard familiar, unfamiliar, and synthetic voices making encouraging statements about recovery.

Methods

Research Design

The researchers used an ABA single-case study design across stimuli as the foundation for this study. Single-case experimental design is appropriate for evaluating the efficacy of experimental treatment conditions [19]; as such, this was an appropriate design for the current research. The A phase consisted of a two-minute pre-intervention baseline period during which no auditory stimulation occurred and data were collected regarding behavioural responses indicative of a participant's level of arousal. During the four-minute B phase, the researchers played either familiar, unfamiliar, or synthetic voices of encouraging statements directed toward the participant while continuing to collect behavioural data. The second A phase was a post-intervention period of 2 minutes during which the auditory stimulation was withdrawn, but data collection continued. The purpose of this phase was to help ascertain whether any observed changes in arousal between the A and B phases were attributable to presentation of the auditory stimulation. The type of auditory stimulation (i.e. familiar, unfamiliar, or synthetic voices) was systematically alternated across data collection sessions.

Participants

Participants were three male survivors of ABI—RI, BA, and CA— who were in states of impaired consciousness at the start of the study. They were all at least 18 years old, were functioning at RLA level II or III, were more than 6 months post-injury, and demonstrated impaired functioning secondary to non-degenerative ABI. The researchers obtained informed consent for each individual to participate in the study from the person legally responsible for making medical decisions. The study was approved by the Institutional Review Board of the University of Nebraska – Lincoln.

RI sustained a severe ABI from hypoxia, and BA and CA sustained severe ABIs from blunt trauma. They were native speakers of American English and had no reported sensory or neurological challenges prior to injury. RI was 31 years old at the time of injury. At the initiation of the study, he was nine years post-injury and was functioning at Rancho Los Amigos (RLA) [20] level II/III. BA was 36 years old at the time of the injury. He was two years post-injury and functioning at RLA III. CA was 40 years old at the time of his injury, was four months post-injury at the start of the study, and was functioning at RLA level II/III.

Procedures

Stimulus preparation—Prior to the intervention sessions, the researchers made audio recordings of three types of stimuli: familiar, unfamiliar, and synthetic voices. Both familiar and unfamiliar voices were included as stimulus types, because ABI survivors are routinely exposed to both during the recovery process; synthetic voices were included because of the potential to use computer-generated speech to provide stimulation to survivors about pre-selected topics regardless of the immediate availability of a person to remain at bedside. For example, staff could set up a computer system equipped with text-to-speech software to read e-mail correspondence or recent reports about important activities (e.g. game performance by a hometown sports team or news about an election), thus providing appropriate and personally-relevant auditory stimulation to a survivor during times that acquaintances or rehabilitation staff were not available.

The familiar stimuli were recordings of friends' and family members' voices talking to the survivor. By combining the recordings of multiple friends and family members, the researchers obtained approximately five minutes of stimuli for each participant. Only recordings with normal prosody and appropriate content, as judged by the researchers, were included on the final stimulus tapes. Language content was generic yet directed towards the survivor and consisted primarily of encouraging comments (e.g. 'Keep working! We want you to come home soon'!)

The unfamiliar stimuli were recordings of unfamiliar voices speaking the same messages recorded by the friends and family members. Similarly, the synthetic stimuli were the same messages recorded using a synthetic speech generator [21]. Gender of voices used to make the unfamiliar and synthetic stimuli were consistent with the gender of friends and family members who made the familiar voice recordings.

Intervention sessions—Throughout the course of the study, each survivor participated in two stimulation sessions daily, four or five days per week. Survivors received the experimental intervention for a total of 30 days (i.e. 60 intervention sessions). To control for possible fatigue, one stimulation session always occurred during morning hours and the other during afternoon hours. All research sessions took place at least 30 minutes after any other treatment (e.g. physical therapy), and each session lasted no more than 30 minutes. Over the course of the study, survivors heard each stimulus type during 20 of the 60 intervention sessions, hearing only one stimulus type per session. The order of stimulus type was systematically alternated across sessions.

All intervention sessions were recorded using two digital video cameras. One camera recorded a whole-body view of the survivor and captured any gross motor movements. The second camera recorded a close-up view of the survivor's face to record any facial movements.

At the start of each session, the researcher greeted the survivor and ensured he was awake and seated in an upright, comfortable position. Then, the researcher collected a pre-intervention, two-minute baseline recording of the survivor's body and facial movements. No purposeful stimulation was provided during this pre-intervention period. After two minutes, the researcher played the auditory stimulus tape selected for that session for a four-minute period. The auditory stimulus was always presented at a comfortable listening level. After four minutes, the researcher silenced the auditory stimulus and collected another two minutes of post-intervention video recordings of the survivor's movements.

Data measurement—At the end of each intervention session, the researchers edited the digital video recordings by time-synchronizing the images from each camera and displaying both on a single screen. Next, the researchers removed all auditory information from the recordings to prevent the judges performing data measurement from knowing the type of auditory stimulus presented during any given session. The researchers also inserted a beep every ten seconds on the edited recordings for scoring purposes.

Two research assistants not involved in data collection served as judges for data measurement purposes. To perform data measurement, a judge viewed an edited recording and noted the presence or absence of 16 specific behavioural responses during each ten-second interval. Targeted behavioural responses included movements of the body, head, arms, hands, fingers, legs, feet, eyes (i.e. eye opening/closing, eyeball movement visible under closed eyelids, and visual scanning), lips, mouth, face (i.e. grimacing, smiling, and scowling), and tongue.

Inter-rater reliability—Inter-rater reliability for scoring the video recordings was determined by randomly selecting 25% of the edited videos and having both judges independently score them. The researchers computed inter-rater reliability by dividing the number of agreements by the sum of the agreements and disagreements and multiplying by 100. Inter-rater reliability was 93%, 94%, and 91% for RI's, BA's, and CA's videos, respectively.

Data analysis—For analysis purposes, data from each participant were segmented into one-minute time periods. The initial baseline period included two one-minute segments (B1, B2); the treatment period included four one-minute segments (T1, T2, T3, T4); and the post-treatment period included two one-minute segments (P1, P2). Figure 1 provides a graphic display of the time segments within each intervention session. The number of movements recorded by a judge viewing a participant's edited video recording was averaged across each of the six ten-second intervals comprising each one-minute time segment. All sessions using one type of auditory stimulus were collapsed together, and the number of motoric responses a participant made during selected time intervals was averaged.

Statistical analyses used four of the eight time segments: B2, T1, T4, and P2. Time segment B2 best represented the survivor's behaviour in the absence of auditory stimulation and after resolution of any stimulation he may have received as a result of initiating a treatment session. Inclusion of time segment T1 allowed assessment of any immediate effects of hearing auditory stimuli. Inclusion of time segment T4 allowed assessment of any delayed or accumulative response to the hearing of auditory stimuli. Inclusion of time segment P2 allowed for assessment of any change in behaviour associated with the cessation of auditory stimulation.

The researchers evaluated each participant's behaviour individually by performing one-way repeated-measures ANOVAs with the factor being time (B1, T1, T4, P2) and the dependent variable being the number of behavioural responses observed [22]. Follow-up tests allowed determination of pairwise differences among the means using the Bonferroni adjustment ($p = 0.008$) to minimize the chance of Type 1 errors [23]. Then, to determine whether participants differed in production of body movements based on the type of auditory stimulation heard, 3×4 repeated-measure ANOVAs were computed with the factor being time (i.e. B1, T1, T4, P2) and the dependent variable being the number of behavioural responses observed with each type of stimuli [22]. Again, follow-up tests using the Bonferroni ($p = 0.0167$) adjustment to minimize the chance of Type 1 errors allowed determination of pairwise difference among the stimulus types [23].

Results

Each of the survivor participants demonstrated a different response profile to the presentation of the experimental stimuli. Detailed results for each participant are presented separately below. The raw data report the average number of movements during each minute of data collection that a participant made in response to the three auditory stimulus types. The researchers then report the results of ANOVA computations and appropriate follow-up analyses to indicate whether changes in body movement production were statistically significant across time periods within sessions and across stimulus types over all sessions.

RI

RIs baseline level of movements ranged from an average of 1.87 movements per minute for familiar voices to 3.34 movements per minute for unfamiliar voices. With all stimulus types, RI produced the fewest average number of movements during time segment P2 (i.e. familiar voices: 1.43; unfamiliar voices: 2.34; synthetic voices: 1.66) and the greatest average number of movements during segment B1 (i.e. familiar voices: 1.93; unfamiliar voices: 3.34; synthetic voices: 2.68) with all stimulus types. This pattern is displayed graphically in Figure 2.

To determine whether RI changed his production of body movements with the presentation of auditory stimulation, a one-way within-subject ANOVA was computed with the factor being time (B1, T1, T4, P2) and the dependent variable being the number of behavioural responses observed. Results of the ANOVA indicated a significant time effect ($F(3, 171) = 5.947$, $p \le 0.001$) that corresponded with a small effect size (partial $n^2 = 0.094$). Follow-up tests allowed determination of pairwise differences among the means using the Bonferroni adjustment ($p \le 0.008$) to minimize the chance of Type 1 errors. Bonferroni results revealed significant differences between B2 and P2 ($t = 3.37$, $p \le 0.001$), and between T1 and P2 ($t = 3.02$, $p \le 0.004$). No other pairwise comparisons reached significance (Table 1).

To determine whether RI differed in his production of body movements based on the type of auditory stimulation heard, a 3 × 4 within-subject ANOVA was computed with the factor being time (i.e. B1, T1, T4, P2) and the dependent variable being the number of behavioural responses observed with each type of stimulus. ANOVA results revealed a significant difference between stimulus types ($F(2, 55) = 3.482$, $p \le 0.037$) that corresponded with a small effect size (partial $n^2 = 0.112$). However, RI demonstrated differences in the frequency of his movements during the baseline periods preceding presentation of the different types of auditory stimuli. Because of this unstable baseline across voice types, the researchers decided attribution of the noted differences in movement production to the type of auditory stimulus was inappropriate. They believed the statistically significant difference found between voice types for RI most likely did not correspond with a clinically significant difference; rather the significance emerged because of substantial variability in RI's movement production across intervention sessions irrespective of the type of stimulation presented. Because of this, the researchers rejected the notion that voices contrasting in familiarity had a differential impact on RI, and they did not perform follow-up statistical analyses.

BA

BA displayed a pattern of increased movements with the presentation of auditory stimulation and decreased movements with the cessation of stimulation. This pattern occurred regardless of the type of auditory stimulus presented. BA's baseline level of movement was consistent across all sessions, ranging from an average of 2.74 movements per minute for unfamiliar voices to 3.35 movements per minute for familiar voices. With all stimulus types, BA produced the fewest average number of movements either during time segment B1 or B2 (i.e. familiar voices-B2: 3.35; unfamiliar voices-B1: 2.74; synthetic voices-B2: 3.02) and the greatest average number of movements during segments T4 (i.e. familiar voices: 3.57, unfamiliar voices: 3.97; synthetic voices: 4.14). This pattern is displayed graphically in Figure 3.

To determine whether BA changed his production of body movements with the presentation of auditory stimulation, a one-way within-subject ANOVA was computed using the same procedure used for RI. Results revealed a significant time effect ($F(3, 174) = 9.68$, $p \leq 0.001$) that corresponded with a small effect size (partial $n^2 = 0.143$). Follow-up tests allowed determination of pairwise differences across the different time intervals. Using the Bonferroni ($p \leq 0.008$) adjustment to minimize the chance of Type 1 errors, significant differences occurred between B2 and T1 ($t = -0.136$, $p \leq 0.003$), B2 and T4 ($t = -4.222$, $p \leq 0.001$), and between T4 and P2 ($t = 3.682$, $p \leq 0.001$). No other pairwise comparisons reached significance (Table 2).

To determine whether BA responded differentially regarding his production of body movements based on the type of auditory stimulation he heard, a 3 × 4 within-subject ANOVA was computed. Results revealed no significant difference ($F(2, 56) = 0.031$, $p \leq 0.9693$). Because of the lack of a significant finding, no follow-up pairwise comparisons were performed.

CA

In general, CA demonstrated little systematic change in his production of movements either with the introduction or cessation of auditory stimulation. The number of movements CA produced during one-minute segments ranged from a low of 0 to a high of 10.67; thus CA's movements were quite variable. Collapsed over all types of auditory stimulation, the fewest average number of movements (i.e. 7.20) occurred during the T2 segment, and the greatest average number of movements (i.e. 7.57) occurred during the T1 segment. CA's movement data is displayed graphically in Figure 4.

Performance of a one-way within-subject ANOVA to assess changes over time indicated no significant time effect ($F(3, 59) = 0.791$, $p \leq 0.5002$). Because of the lack of a significant finding, no pairwise comparisons were computed. Performance of the 3 × 4 within-subject ANOVA to assess responsiveness to different types of auditory stimuli also revealed no significant difference ($F(2, 57) = 0.311$, $p \leq 0.734$). Again, no follow-up pairwise comparisons were computed.

Discussion

The researchers examined whether three individuals with impaired consciousness: (a) demonstrated changes in behaviour when presented with auditory stimulation; and (b) responded differentially to auditory stimulation presented with familiar, unfamiliar, and synthetic voices.

Regarding the first issue, each of the survivor participants demonstrated a unique response profile given the presentation of auditory stimuli. Specifically, the auditory stimulation produced a calming effect on RI, a stimulating effect on BA, and no consistent effect on CA. These findings are consistent with those of Wilson, Brock, and colleagues [18] who reported three distinct patterns of responsiveness among their three research participants given exposure to personalized and generic stimuli. The findings also confirm those of researchers [7,18] who have reported that the presentation of auditory stimulation prompts changes in arousal for at least some ABI survivors in states of impaired consciousness. However, because different response profiles emerged across study participants, professionals must be sensitive to individual differences when providing sensory stimulation intervention and making judgments about its effectiveness as a treatment technique. The finding of different response patterns across participants highlights the heterogeneity that exists within the ABI population as well as raising questions about the overall efficacy of sensory stimulation treatment, the ways in which professionals select systems and stimuli for presentation, and the ways in which they measure changes in responsiveness.

Regarding the issue of differential responses to voices contrasting in familiarity, RI was the only participant to demonstrate significantly different behaviours related to this factor. However, this significant result was attributable to RI's inconsistent baseline performance across intervention sessions rather than to changes associated with different stimulus voices. This finding, paired with the lack of significant results obtained from data analysis involving the other two participants, prompted the researchers to reject the notion that voices contrasting in familiarity have differential impacts on ABI survivors with impaired consciousness.

Clinical implications

Individual variability—Individualized patterns of responsiveness are the norm among survivors of ABI because of the diffuse and variable nature of sustained damage. As noted by Mapou [24], areas of retained sensory, motor, and cognitive function vary across survivors according to the location and extent of neurological damage. For example, some survivors may have impaired perception within one or more sensory systems following ABI, whereas others may have no apparent sensory deficits but, instead, lose motor strength, coordination, or control to one or more body parts. The most common scenario is one in which ABI partially impairs multiple aspects of sensory, motor, and cognitive functioning, with different aspects affected across individuals.

Variations among ABI survivors regarding neurological impairments correspond with variations in how they respond to multisensory stimulation programmes. Despite the fact that all three participants in the current study behaved in manners consistent with RLA level III [20,25], their responses to environmental stimuli and their general arousal and activity levels varied considerably. For example, this variability was apparent through a comparison of the behaviours displayed by RI and CA. RI demonstrated substantially impaired motor functioning and produced a limited number of reflexive and volitional body movements throughout the course of intervention (i.e. between 1.5 and 3.5 movements per minute); in contrast, CA demonstrated less pervasive motor impairment and was more variable regarding the location and frequency of body movements produced. Still, cognitively, both participants displayed behaviours consistent with RLA level III.

The contrast evident between these two participants highlights the need that exists for clinicians to exercise care when making judgments about survivors' responses to sensory stimulation interventions. Motor responses are not clear, accurate, or reliable indicators of perceptual or cognitive functioning. RI's limited movements reflected his severely compromised motor system; they may or may not have related to his perceptual or cognitive processing. Alternately, the frequency of CA's movements may have reflected increased agitation overall rather than specific responses to his perception of the auditory stimuli presented as part of this research. Individualized and idiosyncratic interactions among motor, sensory, and cognitive deficits confound professionals' interpretations of responsiveness to sensory stimulation.

Overall efficacy of sensory stimulation programmes—The efficacy of intervention programmes for individuals with impaired consciousness remains questionable. Some researchers have documented inconclusive results regarding the benefits of sensory stimulation [26–27], whereas other researchers have provided support for the application of this type of treatment [28]. Recent findings confirming that at least some ABI survivors with impaired consciousness not only perceive auditory stimuli but also demonstrate cortical response patterns to language content similar to individuals without brain damage have strengthened the argument for providing this type of sensory stimulation [8,11–14].

The data regarding the three participants in the current research lend credence to the contention that sensory stimulation variably affects ABI survivors with impaired consciousness. In BA's case, the presentation of auditory stimulation appeared efficacious in increasing his arousal level. Specifically, his activity increased with initiation of auditory stimulation and continued to increase throughout the stimulation period; then, his arousal level decreased gradually with cessation of the stimulation. In RI's case, presentation of auditory stimulation appeared to have a calming effect rather than one of arousal. For CA, no consistent pattern of responsiveness to the auditory stimuli emerged. Thus, the demonstrated response profiles prohibit formation of a single judgment concerning efficacy but, instead, support the notion of individual instances of benefit regarding alterations in arousal.

Stimulation modality and form—With multimodal sensory interventions, professionals intentionally stimulate a variety of sensory modalities in an attempt to elicit changes in arousal and awareness, and, even with unimodal sensory interventions targeting audition, professionals typically incorporate a greater range of stimulus types than voices alone. However, the investigation of arousal changes with the presentation of voices still warrants attention because speaking to a survivor is customary during routine care as well as during purposeful sensory stimulation interactions. Exposure to voices—both known (e.g. provided by family and friends) and unknown (e.g. provided by staff members, hospital personnel, or synthetic speech generators)—as well as other types of auditory stimuli falling along familiarity and preference continuums is common in hospital and rehabilitation settings. The value of this exposure remains uncertain, and a survivor's exposure to auditory stimulation outside structured treatment sessions makes its evaluation as a component of formalized treatment difficult.

Regarding this issue, the current findings contradict the idea that survivors respond more readily to familiar than nonfamiliar or generic stimuli. Hence, anecdotal reports endorsing the presentation of familiar stimuli because of a greater likelihood of survivors having personal and emotional connections to them than to unfamiliar or generic stimuli appear unfounded. Instead, other factors, such as the content of the message, the prosody with which the message is conveyed, or even the novelty of the voice—as in the case of synthetic speech—may be more important issues than premorbid familiarity.

Outcome measures—Because differences exist in the integrity of ABI survivors' motor systems, using changes in motor movement production corresponding with sensory stimulation presentation may be an inadequate means of evaluating an intervention's impact. For example, RI produced limited reflexive and volitional body movements throughout all intervention sessions; differences between his maximum and minimum average number of movements never exceeded 2 across auditory stimulus types and never exceeded 1 within a single type of auditory stimulation. This minimal variation is troublesome in that it may have been difficult to document had the researchers not recorded intervention sessions and performed retrospective, time-intensive analyses of body movement production. In contrast, CA presented a substantially different scenario regarding the production of body movements. Specifically, CA demonstrated such frequent movements during baseline periods that his data may have reflected a ceiling effect. If presentation of the experimental stimuli had calmed CA, a visible reduction would have been evident regarding his production of body movements; however, because this was not the case, determining whether the stimuli had an excitatory or no effect on him was difficult.

Practitioners need multiple methods with which to assess arousal changes in ABI survivors, so they can select the ones most appropriate for given situations. In addition to accommodating variations among survivors regarding the production of body movements, these methods must take into consideration the time and equipment constraints associated with most clinical settings. Supplementing behavioural observations with physiological measurements—such as pulse rate or respiration rate—is one possibility. Alternately, using precise means of measuring behavioural changes—such as tallying the absolute number of movements or the duration or extent of movements rather than using a time sampling procedure to measure the presence or absence of movements—may prove necessary in some instances; however, such procedures are extremely time intensive and not practical for many clinical applications.

Study limitations

An important limitation of the current study was that the researchers only examined behaviour changes associated with presenting ABI survivors with auditory stimulation in the form of voices addressing them. This is only one of several types of stimuli typically used for sensory stimulation [29]. Without examining the effects of other types of auditory stimuli—as well as stimuli targeting other sensory systems—conclusions about the overall efficacy of sensory stimulation interventions are not possible. Using only behavioural responses to measure changes in arousal was another study limitation. As discussed previously, the behaviours displayed by two of the current study participants—RI and CA—provide insight into this limitation. Finally, the type of research design and small sample size limit the extent to which the research findings can be generalized.

Future directions

The use of auditory stimulation to improve a survivor's level of responsiveness is an area of research warranting further investigation. In this study, the researchers found differential effects across survivors regarding the presentation of auditory stimulation but no differences within or across survivors associated with voice familiarity. Additional research with a greater number of participants is still a necessity. In general, practitioners need information about the most appropriate means of selecting stimuli and measuring the effects of stimuli on individual survivors. With specific regard to auditory stimulation, one of the most pressing areas of further research concerns how different types of content included in spoken messages impact people with impaired consciousness. Assuredly, technological advances will continue to provide greater and greater opportunities for personalizing the content of sensory stimulation and improving the ability of rehabilitation professionals to present stimulation in timely and cost-effective manners; however, to make the best use of these advances, professionals need more information about the differential effectiveness and impact of various materials incorporated into sensory stimulation programmes.

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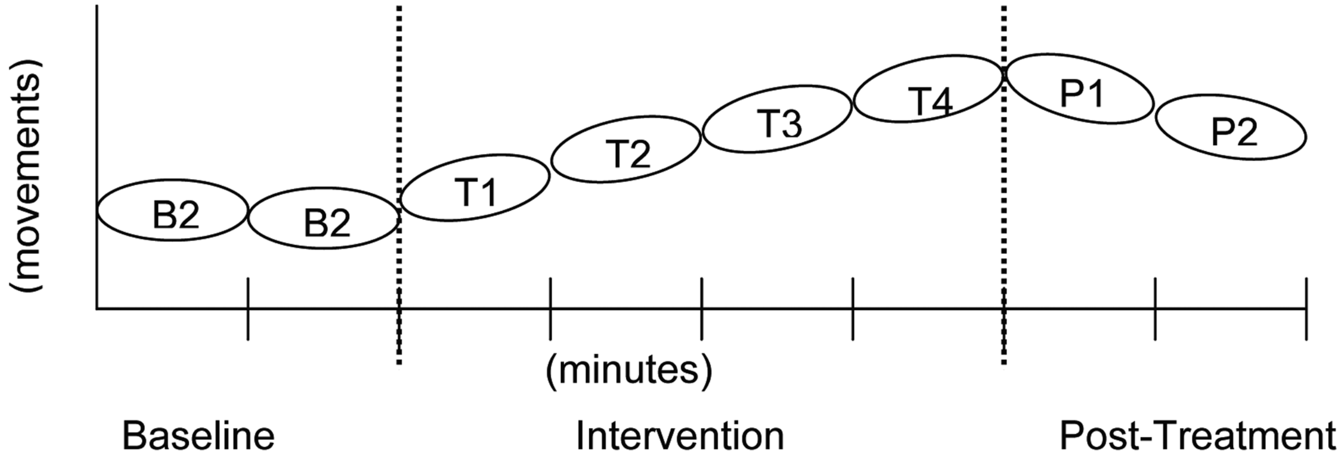
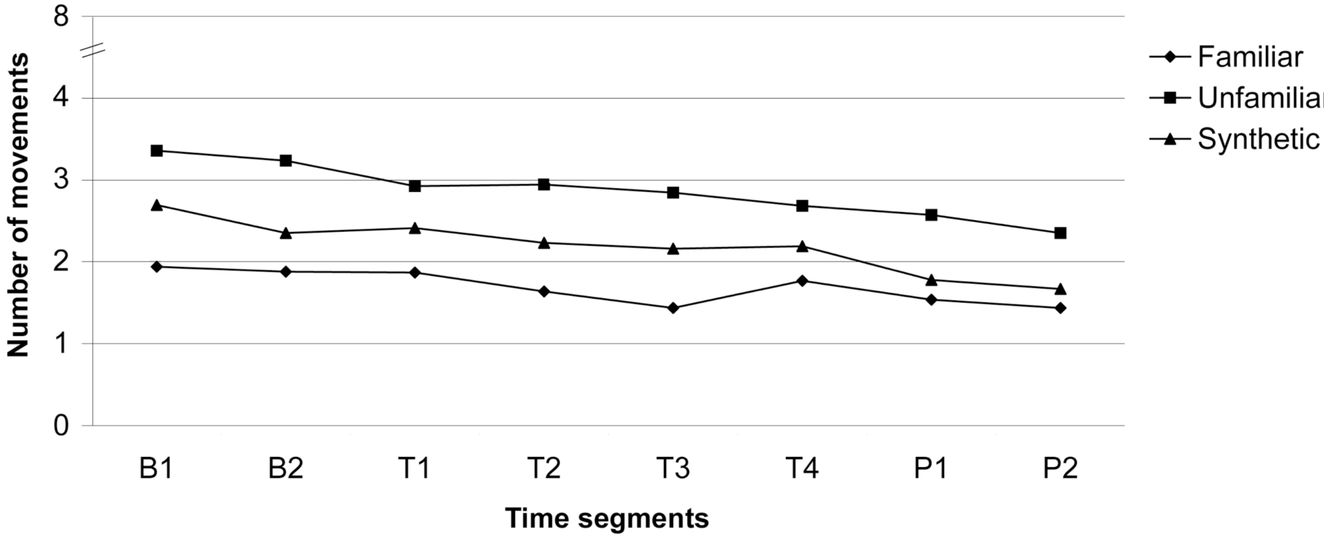

(movements)
B2
B2
T1
T2
T3
T4
P1
P2
(minutes)
Baseline
Intervention
Post-Treatment

Figure 1.



8
4
3
2
1
0
Number of movements
B1
B2
T1
T2
T3
T4
P1
P2
Time segments
Familiar
Unfamiliar
Synthetic

Figure 2.

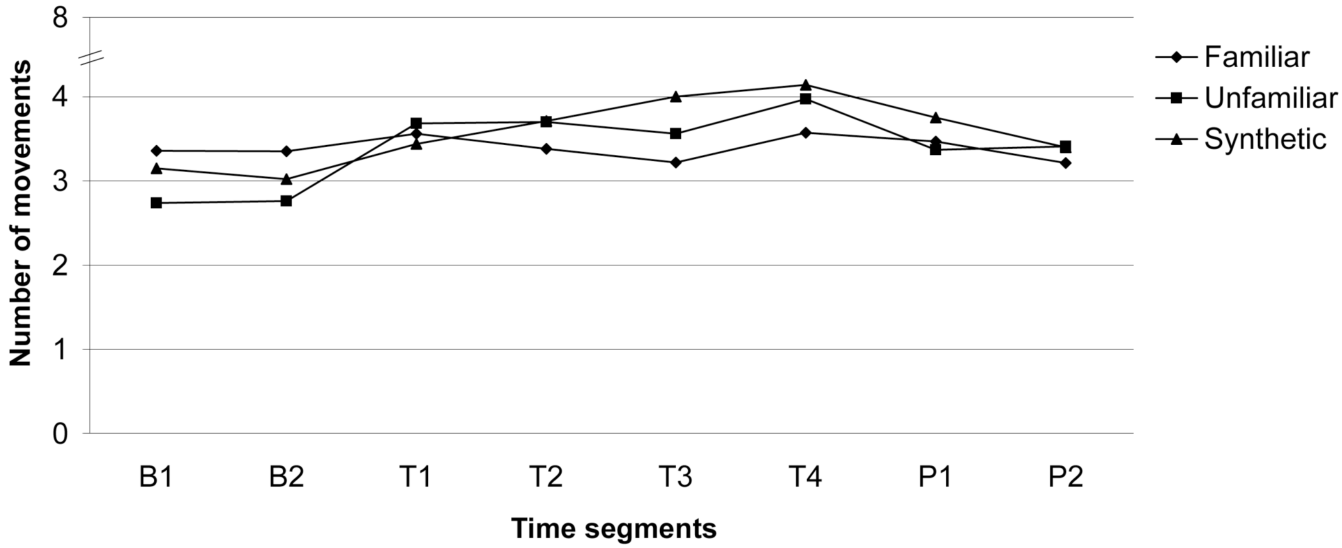

8
4
3
2
1
0
Number of movements
B1
B2
T1
T2
T3
T4
P1
P2
Time segments
Familiar
Unfamiliar
Synthetic

Figure 3.

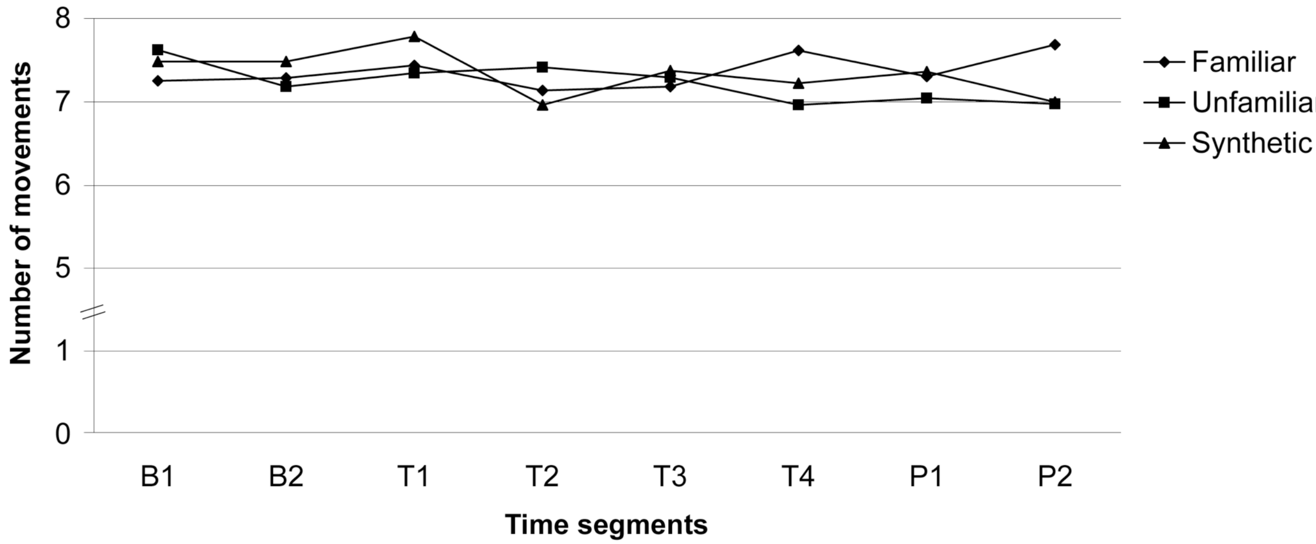

8
7
6
5
1
0
Number of movements
B1
B2
T1
T2
T3
T4
P1
P2
Time segments
Familiar
Unfamiliar
Synthetic

Figure 4.

Table 1

R.I.'s Pairwise Comparisons following for Auditory Stimulation

Comparison	**Mean Diff.**	***df***	***t*-value**	***p*-value**
B2, T1	.127	59	.950	.346
B2, T4	.265	59	1.709	.0927
B2, P2	.659	57	3.37	.001*
T1, T4	.130	59	.800	.427
T1, P2	.580	57	3.015	.004*
T4, P2	.397	57	2.259	.028

*denotes significant difference $p = .008$

Table 2

B.A.'s Pairwise Comparisons following for Auditory Stimulation

Comparison	**Mean Diff.**	***df***	***t*-value**	***p*-value**
B2, T1	−.505	59	−3.163	.0025*
B2, T4	−.840	58	−4.222	.0001*
B2, P2	−.289	58	−1.908	.0613
T1, T4	−.332	58	−2.215	.0307
T1, P2	.219	58	1.475	.1457
T4, P2	.551	58	3.682	.0005*

*denotes significant difference $p = .008$