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A screening protocol incorporating brain-computer interface feature matching considerations for augmentative and alternative communication

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Abstract

Purpose: The use of standardized screening protocols may inform brain-computer interface (BCI) research procedures to help maximize BCI performance outcomes and provide foundational information for clinical translation. Therefore, in this study we developed and evaluated a new BCI screening protocol incorporating cognitive, sensory, motor and motor imagery tasks.

Methods: Following development, BCI screener outcomes were compared to the Amyotrophic Lateral Sclerosis Cognitive Behavioral Screen (ALS-CBS), and ALS Functional Rating Scale (ALS-FRS) for twelve individuals with a neuromotor disorder.

Results: Scores on the cognitive portion of the BCI screener demonstrated limited variability, indicating all participants possessed core BCI-related skills. When compared to the ALS-CBS, the BCI screener was able to modestly discriminate

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possible cognitive difficulties that are likely to influence BCI performance. In addition, correlations between the motor imagery section of the screener and ALS-CBS and ALS-FRS were non-significant, suggesting the BCI screener may provide information not captured on other assessment tools. Additional differences were found between motor imagery tasks, with greater self-ratings on first-person explicit imagery of familiar tasks compared to unfamiliar/ generic BCI tasks.

Conclusion: The BCI screener captures factors likely relevant for BCI, which has value for guiding person-centered BCI assessment across different devices to help inform BCI trials.

Keywords: Amyotrophic lateral sclerosis, assessment, augmentative and alternative communication, Brain-computer interface, motor imagery

Individuals with neuromotor disorders such as amyotrophic lateral sclerosis (ALS) may have severe speech and motor impairments that necessitate intervention with augmentative and alternative communication (AAC) methods. Traditional AAC access methods rely on at least some form of physical movement for device control to create messages (e.g., eye gaze tracking, button selection; Beukelman & Mirenda, 2013), which can limit the utility of AAC for individuals without any movement, leaving them without any reliable form of communication. Brain-computer interfaces (BCIs) have the potential to restore communication for individuals with neuromotor impairment by providing a link between an individual's brain activity and the communication device without requiring any voluntary motor control for accessing AAC. Most often BCIs use electroencephalography (EEG) to control communication devices (Wolpaw et al., 2002) that is obtained through two major paradigms: 1) sensory attention modulation, including steady state evoked potentials (e.g., Sutter, 1992) and auditory steady state response (e.g., Lopez, Pomares, Pelayo, Urquiza, & Perez, 2009), and methods utilizing the P300 event related potential elicited by either visual (e.g., Donchin, Spencer, & Wijesinghe, 2000) or auditory stimulation (e.g., Halder et al., 2010) and 2) motor-based systems, specifically those utilizing motor imagery to elicit the sensorimotor rhythm (e.g., Blankertz et al., 2006; see Brumberg, Pitt, Mantie-Kozlowski, and Burnison (2018); for a complete review of BCI applications for AAC). Therefore, individuals with neuromotor disorders have been identified as ideal candidates for BCI intervention (Fager, Beukelman, Fried-Oken, Jakobs, & Baker, 2012), though the process of selecting the BCI that will best meet their current and future communication needs is not yet resolved.

Currently, BCIs are most often used in research settings with long-term and in home BCI trials still in the early stages (e.g., Holz, Botrel, Kaufmann, & Kübler, 2015; Sellers, Vaughan, & Wolpaw, 2010). However, for BCI devices to be successfully transitioned into clinical practice for AAC, it is crucial that person-centered factors for successful BCI intervention are identified and used to create feature matching assessment procedures for selecting the most appropriate BCI for AAC (e.g., Hill, Kovacs, & Shin, 2015). Further, these procedures should be developed based on the perspectives of a multidisciplinary team (e.g., engineers, AAC related disciplines), along with individuals who use BCI and their caregivers (Pitt & Brumberg, 2018). Feature matching is the process of pairing an individual to the most appropriate AAC device based upon their current and future profile, level of support, communication needs, and trial-based preferences, and is crucial for facilitating successful AAC device outcomes (Gosnell, Costello, & Shane, 2011). The AAC feature matching framework is also important for both clinical and research procedures in BCI, since performance with specific BCI techniques may be influenced by a range of person-centered factors. For instance, one's ability to perform first-person motor imagery (covertly performing an action while imagining the associated physical sensations) is important for using motor imagery BCIs (Vuckovic & Osuagwu, 2013), while intact vision and visual attention are needed for visually based sensory attention modulated style devices (P300 and steady state visually evoked potential). Differences over these factors may result in variable BCI performance across and within subjects (Ahn & Jun, 2015). See Pitt and Brumberg (2018) for a review of feature matching considerations across a full range of BCI devices for AAC.

Screening protocols can help overcome and understand performance variations across BCI types (Ahn & Jun, 2015), and their use is an important goal for standardizing clinical and research practices in BCI (Fried-Oken, Mooney, Peters, & Oken, 2013). Currently, the development of screening procedures for BCI are still in their early stages. In fact, only one BCI screening protocol has been published, which focuses on evaluating the presence of skills needed for successful use of an attention modulated P300 rapid serial visual presentation

(RSVP) speller BCI (Fried-Oken et al., 2013). Though the first of its kind, the screening protocol by Fried-Oken et al. (2013) focuses only on visual P300 BCIs, and therefore does not include domains valuable for other types of BCI (e.g., motor imagery, auditory attention modulated; Brumberg et al., 2018). For instance, motor imagery BCI control is influenced by motor imagery skill (Vuckovic & Osuagwu, 2013) and strategy (i.e., first person versus third person imagery; Neuper, Scherer, Reiner, & Pfurtscheller, 2005), therefore, a multi-BCI screener must assess both visual and motor imagery domains (Pitt & Brumberg, 2018). Similarly, auditory assessments are important for identifying skills needed to operate auditory-based BCIs (e.g., Pitt & Brumberg, 2018). Last, a general screening tool should make all assessment domains accessible to individuals with both auditory and visual deficits (e.g., simultaneous assessment using visual and auditory stimuli/instructions) and use a common minimal mode of communication (e.g., binary, yes/no response).

Non-BCI, commercial/clinical screening tools have been used to bridge the gaps in BCI assessment with mixed results. For instance, Geronimo, Simmons, and Schiff (2016) utilized the ALS Functional Rating Scale (ALS-FRS; Cedarbaum & Stambler, 1997) and the ALS Cognitive Behavioral Screen (ALS-CBS; Woolley et al., 2010) for predicting P300 and motor imagery BCI performance. The ALS-FRS is designed to measure an individual's physical motor abilities, and the study by Geronimo and colleagues found that it did not correlate to P300 or motor imagery based BCI performance (Geronimo et al., 2016). However, cognitive ability was found to influence BCI performance with portions of the ALS-CBS, a tool which screens for the potential presence of *any* cognitive impairment, able to predict initial outcomes for both motor imagery (attention and word initiation portions) and P300 (attention and tracking portions) BCIs (Geronimo et al., 2016). It is important to note however, that the ALS-CBS is a general-purpose medical assessment and was not designed for screening dimensions of cognition important for BCI operation. Therefore, it does not include tasks specifically designed to assess motor imagery or other BCI related skills, which may limit its general use as a broad screening tool applicable across many BCI modalities. Further, the ALS-CBS requires verbal and/or written responses, which may not be possible for individuals with advanced paralysis who most need BCI techniques to communicate, and adaptation of the ALS-CBS (or portions) for use with individuals with minimal communication (e.g., binary, hierarchical tree responses) may result in responses that require additional interpretation for comparison to current guidelines. Therefore, other screening protocols are needed to assess specific cognitive, sensory, motor and motor imagery skills for BCI success.

The purpose of this study is to identify and address some of the limitations of existing screening tools for BCI purposes, by developing and evaluating a new feature matching-based screening protocol generalizable to multiple BCI modalities. We additionally compared our screener to the ALS-CBS and ALS-FRS to determine the degree of consistency in our results and overlap between our screener and existing protocols. Our new protocol marks an initial step in the generation of BCI screening tools incorporating AAC-style feature matching considerations across multiple BCI devices. Clinically, screeners are only one tool for selecting the most appropriate AAC device and should be combined with trial experiences of different feature matched AAC devices in order to gather stakeholder input and establish trial-based preferences (Beukelman & Mirenda, 2013). Therefore, our BCI screener was designed to identify the presence of BCI related skills (cf. ALS-CBS evaluation of levels of concern for cognitive impairment) in the cognitive, sensory and motor domains to guide and support the selection and trialing of feature matched BCI devices for AAC while excluding others which are likely inappropriate for supporting an individual's strengths. With this in mind, scores for the cognitive portion of the BCI screener were expected to be high unless ALS-CBS scores indicated a significant concern for cognitive impairment, which would exclude the most cognitively demanding BCIs while leaving other BCIs available for possible trialing subject to motor, psychological, and sensory screening results. Other domain score correlations to the ALS-CBS and ALS-FRS were expected to be minimal since we designed our BCI screener to focus on BCI-specific tasks, which are not currently captured by commercial screening tools. A secondary goal was to specifically improve screening for motor imagery BCIs by identifying motor imagery tasks that were best suited for assessing motor imagery using a first-person approach (a known predictor of motor imagery BCI performance; Neuper et al., 2005) versus third-person.

Methods

The methods used to develop and evaluate this protocol were based on those employed for other screening tools. For example, the ALS-CBS was designed based on prior research investigating cognitive tasks related to changes in cognition and behavior (Woolley et al., 2010). Likewise, we identified task items with the most relevance to BCI, then compared our screening protocol to other standard tests to evaluate our main hypothesis that a BCI screener provides specific information not captured by existing screening tools. The screening protocol form and instructions are included in supplemental data A and B.

Development of the screening protocol

Identification of the domains selected for screening assessment
Domains included in the screening protocol were based on a literature review of BCI and motor imagery assessment and selected by a core research team consisting of a BCI engineer, neuroscientist, and two speech-language pathologists (SLPs) certified in clinical competency (one with expertise in BCI and one in motor speech disorders). The domains identified for inclusion were: 1) sensory (including vision and hearing), 2) cognition (including comprehension and orientation, following directions, attention and working memory, and cognitive motor learning/abstract problem solving), 3) motor imagery (including explicit and implicit imagery ability), and 4) other BCI considerations that includes: fatigue, pain, motivation for using BCI, comfort with computers, motor function, positioning, literacy, and medical considerations (i.e., history of seizures, use of medications).

Rationales for selected screening tasks, feasibility and scoring
We identified three major requirements to ensure our screening tasks could be feasibly accomplished and used for assessment of individuals with neuromotor disorders based on our own experience and from prior BCI screening tool development (Fried-Oken et al., 2013):

(1) Tasks must be able to be completed by any form of reliable yes/no (binary) response,

(2) The whole protocol completion time is less than 60 minutes, and

(3) Tasks can be completed by individuals with severe visual or hearing impairments, or task scoring can be modified to account for sensory loss (i.e., if implicit imagery tasks cannot be completed due to visual impairments, explicit imagery ratings are multiplied by three to obtain the total motor imagery score of 15).

Assessment tasks that did not meet these criteria (e.g., those requiring non-binary physical responses) were not considered for inclusion. In order to be applicable to the widest range of individuals with neuromotor disorders, pictorial stimuli (with an orthographic label) were used throughout the screener to support individuals with minimal or emerging literacy skills. The following section describes each task selected per domain and summarizes their rationale and basis for scoring (as applicable). Importantly, EEG measurements are not required since the screener is intended to be used in a clinical assessment session with follow-up sessions for EEG measurements and BCI device trials.

Sensory. Individuals with sensory impairments may require modifications to communication device visual displays (e.g., item locations), or feedback type (auditory and/or visual) to ensure the BCI matches their unique strengths (Pitt & Brumberg, 2018). We chose a four corners task to screen for impairments in visual perception and visual neglect by examining whether individuals are able to confirm, via binary response, the presence of an image as it appears in random locations across a visual display. The rectangular stimuli are presented for 2 seconds at a distance of approximately 0.5 meters, and a visual angle of 0.48° (width) and 0.30° (height). Additional visual assessment is recommended prior to BCI trials to ensure the graphical display remains viewable after possible changes in positioning, presentation angle, and stimuli. Results from the four corners task should be compared to an evaluation of oculomotor function, as impairments in oculomotor control may indicate a covert attention strategy (e.g., peripheral vision) was used for task completion and may impair sensory attention modulated BCI performance (see BCI considerations section, below). We also included screener questions to explore other visual and/or hearing deficits, and for the use of corrective lenses and/or hearing amplification (see supplemental data A and B sections 3 and 4).

Section scoring. Only the objective four corners task is used for scoring in order to prompt for consideration of interface adaptations; one point per correct response is recorded by the examiner. The additional items that focus on specific sensory impairments are used to guide selection and other potential adaptations (e.g., visual display for profound hearing impairments).

Cognition. Tasks were grouped into four categories: (1) comprehension and orientation, (2) following directions, (3) attention and working memory, and (4) cognitive motor learning/abstract problem solving.

Comprehension and orientation. Understanding instructions is important when learning AAC and BCI device control; therefore, this category included a subset[1] of yes/no questions from the auditory verbal comprehension section of the Western Aphasia Battery (Kertesz, 2007; see supplemental data A and B section 8).

Attention and working memory. Successful control of sensory BCIs (e.g., P300 speller; Donchin et al., 2000) requires abilities for selectively attending to different items while ignoring others and holding items in working memory. In addition, an individual may have to attend to the presentation of dual feedback modalities (e.g., visual and/or auditory feedback) for sensory attention modulated (e.g., Belitski, Farquhar, & Desain, 2011) and motor imagery-based (Brumberg, Pitt, & Burnison, 2018) BCI learning and control. Thus, tasks for screening attention and working memory were modelled after the P300 BCI paradigm and test whether individuals can answer yes and no questions about items presented within a stream of rapidly presented stimuli (similar to prior assessment tasks; Fried-Oken et al., 2013; Riccio et al., 2013; supplemental data A and B section 11). To support individuals with sensory impairment, stimuli for tasks 11A and 11B are presented with concurrent audio and visual stimuli (e.g., picture of a cookie with the auditory word 'cookie'). For item 11C different auditory and visual stimuli are presented simultaneously (e.g., picture of a hotdog and the auditory word 'three'; see supplemental data B section 11C for task adaptions due to sensory impairment).

1. Items 8A, 8C, 8D, 8E, 8G, 8K and 8L are included in the Western Aphasia Battery.

Cognitive motor learning/abstract problem solving. Motor (imagery)-based BCIs use neural signals and control strategies related to imagined movements (simulation of an action without physical performance). Learning to perform motor imagery tasks has been likened to learning new physical motor actions, which is influenced by a range of factors (e.g., attention, working memory visuomotor and visuospatial skills, self-monitoring; Marinelli, Quartarone, Hallett, Frazzitta, & Ghilardi, 2017). Attention, engagement, and executive function are especially important during the early stages of motor learning for attending to and manipulating stored information (Marinelli et al., 2017; Sakai et al., 1998). For instance, during an n-back (e.g., 2-back) paradigm, individuals are asked to identify whether a presented shape in a sequence is the same as one given *n* turns back in the sequence, and requires individuals to monitor task performance, and update/remember information (Owen, McMillan, Laird, & Bullmore, 2005). Therefore, an n-back task was chosen for inclusion in the screening protocol to test attention, monitoring and recall (supplemental data A and B item 12A).

Abstract reasoning abilities are linked to motor imagery-based BCI learning (Wander et al., 2013); therefore, we included a task for individuals to indicate the way in which two items (i.e., gloves and scarves) are alike, which is similar to the abstraction items used in the Montreal Cognitive Assessment (Nasreddine et al., 2005, supplemental data A item 12B). Other similar abstraction items may also be used as appropriate to ensure task understanding. Attention modulated BCI paradigms do not require motor learning and rely less on abstract reasoning; therefore, a consideration of these factors is greater for possible selection of motor imagery BCIs. However, executive functions such as problem solving, monitoring and updating information are likely important across all BCIs to support skill learning.

Section scoring. Currently, the four categories are equally weighted with a total of six points per category. Items within each category are also weighted equally. Yes and no responses are balanced within each task and one point is lost for each incorrect response; however, at least one yes and no response must be correctly identified to achieve a score greater than zero to account for the possibility of habitual positive or negative responses. Future versions of this screener may alter the category weightings to reflect new findings of importance to BCI control.

Motor imagery. The neural signals used to control motor imagery-based BCIs depend on one's ability to perform imagined movements; specifically, first-person (kinesthetic) motor imagery leads to greater BCI success than third-person (visual) motor imagery (Neuper et al., 2005). Further, past work has found that self-ratings of first-person, explicit motor imagery (i.e., being aware of the imagined movement) using the Kinesthetic and Visual Motor Imagery Questionnaire (KVIQ; Malouin et al., 2007) can predict initial motor imagery BCI performance (Vuckovic & Osuagwu, 2013). Therefore, we included a self-report during which individuals rate their ability to imagine four generic BCI tasks and one familiar/ individualized task via first-person imagery. The four generic imagined movements are similar to those often used for BCI (e.g., wiggle your toes, make a fist). The familiar imagined movement was included to explore the effect of familiarity on first-person imagery ratings compared to generic tasks (e.g., strumming a guitar for a guitar player versus a simple fist clench). Two motor imagery tasks (upper and lower limbs) were included prior to the self-ratings to determine if individuals default to either a first or third-person imagery strategy (supplemental data A and B items 10A and 10C).

In contrast to explicit motor imagery, implicit motor imagery requires individuals to perform imagery without awareness. For example, motor imagery is required to successfully make laterality judgments (left or right hand) of pictured hand stimuli presented at varying angles in a hand rotation task (e.g., Craje et al., 2010) despite no instruction to imagine any movements. Object rotation paradigms also require implicit motor imagery. For example, when instructed to imagine picking up a rotated, fluid-filled, mug as if to take a drink, one must first mentally rotate their hand to match the mug's orientation; the (imagined) grip position can be reported and evaluated to assess how the individual interacted with the rotated object. In addition, mental rotation task performance has been linked to motor imagery BCI outcomes for neurotypical adults (Jeunet, Jahanpour, & Lotte, 2016); therefore, we included both a hand rotation task and an object rotation paradigm to assess implicit motor imagery in our screener (see Figures 1 and 2; supplemental data A and B items 10B and 10D).

Section scoring. All imagery tasks are weighted equally with a maximum of 5 points. The five explicit motor imagery tasks (4 generic

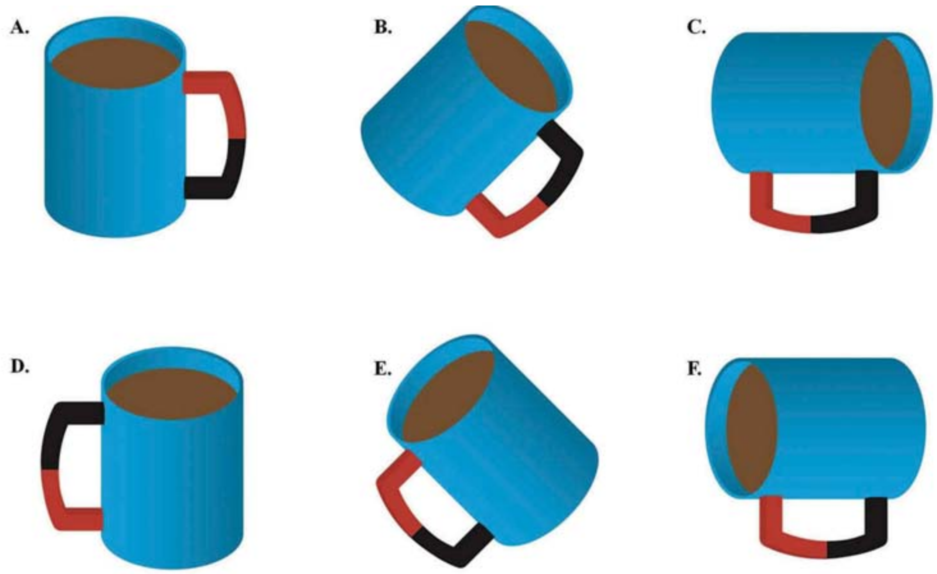

Figure 1. Stimuli used for the object rotation task. Images A-C demonstrate a right hand grip position with the mug rotated at A) 0 degrees, B) 45 degrees, and C) 90 degrees. Images D-F require a left hand grip position, rotated at D) 0 degrees, E) −45 degrees, and F) −90 degrees.

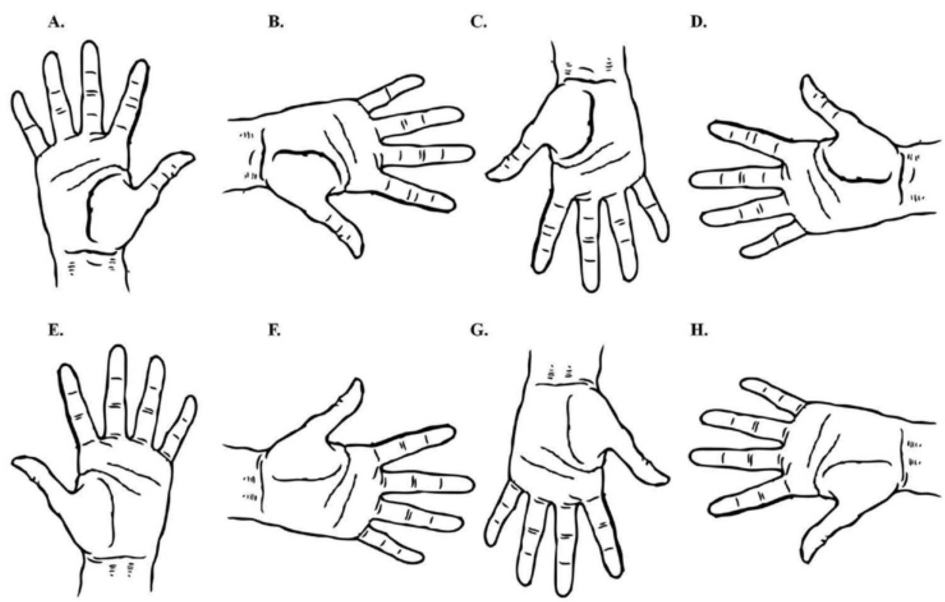

Figure 2. Stimuli used for the hand rotation task. Images A-D depict right hand images rotated at A) 0 degrees, B) 90 degrees, and C) 180 degrees and D) 270 degrees. Images E-H depict left hand images rotated at E) 0 degrees, F) 90 degrees, and G) 180 degrees and H) 270 degrees.

BCI tasks, 1 familiar) are scored using the KVIQ kinesthetic imagery 5 point sub-scale and averaged for a single explicit imagery score. Separate consideration may be given particular tasks for training purposes (e.g., imagined movements that are more meaningful, successful, or enhance motivation). Prior physical experience may be necessary to elicit brain activity changes while performing similar imagined movements (Olsson & Nyberg, 2010). Therefore, first-person imagery ratings for individuals with congenital motor impairments who have never physically performed the assessed actions should be interpreted with caution, and further exploration of individualized imagery tasks may be required.

For the implicit motor imagery tasks, one point is lost for each incorrect response and at least one yes and no response must be correctly identified in order to achieve a score of greater than 0. Identification of the default imagery modality (first versus third person) is a consideration though not scored since imagery modality may change with training (e.g., become more first person). The order in which the default imagery modality assessed is counterbalanced between the two blocks of imagery tasks to control for habitual positive or negative responses (see supplemental data A and B, item 10A subsections 1 and 2)

BCI considerations. Multiple considerations were incorporated into our screening tool to provide a more complete picture of an individual's motor and psychological profile, in addition to the suitability for specific types of BCI. For instance, many sensory BCIs rely on recordings from posterior EEG electrode locations that may be impeded by positional factors such as headrest compression (Daly et al., 2013). Additionally, greater performance for some sensory-based BCIs (e.g., P300 and steady state visually evoked potential) is facilitated by using overt attention strategies (i.e., moving the eyes to fixate on a target item on the screen; Brumberg, Nguyen, Pitt, & Lorenz, 2018; Brunner et al., 2010) as opposed to covert strategies (e.g., peripheral vision; Kelly, Lalor, Finucane, McDarby, & Reilly, 2005), which are often less useful than overt attention (e.g., Kelly et al., 2005; Pires, Nunes, & Castelo-Branco, 2011). Therefore, similar to current best practices in AAC, individuals with neuromotor disorders may require BCI display adaptions to account for lack of eye gaze control and support oculomotor strengths for maximum BCI performance (e.g., Brumberg et al., 2018; supplemental data A and B section 15). Physical experience with an action positively influences motor imagery performance (Olsson & Nyberg, 2010); therefore, cataloging individuals' overall physical motor capabilities may inform motor imagery BCI training. In addition, motor assessment allows for possible application of conventional, BCI-based, and hybrid AAC access methods that can be selected based upon factors such as location (indoors vs outdoors) and fatigue (Brumberg et al., 2018).

Other important BCI considerations include an individual's comfort level with computers (Burde & Blankertz, 2006, supplemental data A section 14), level of motivation (e.g., Nijboer, Birbaumer, & Kubler, 2010, supplemental data A section 13), handedness (supplemental data A and B section 1), and history of seizures due to an increased risk associated with the flickering stimuli used for some sensory BCIs (Brumberg et al., 2018; supplemental data A and B section 2). Additionally, literacy should be evaluated similar to traditional AAC; therefore, orthographic literacy is tested in our screener by asking individuals to read the instruction 'look up' (or a modified version, as appropriate) and to perform the action if possible, as well as to spell a short, target word in a binary decision format (supplemental data A and B section 5). Fatigue may impact cognitive performance and is commonly associated with neuromotor impairment (Lou, 2012). Therefore, we also evaluate the level of fatigue at the time of the assessment, and whether this is consistent with past general levels of fatigue (i.e., over the past two weeks) in order to aid with the overall interpretation of the screener results.

Section scoring. Questions to assess motivation, level of pain, fatigue, and comfort with computers are self-reported on a four-point scale (e.g., 1 low motivation, to 4 high motivation). For the oculomotor task, participants perform up, down, left and right eye movements, and one point is given for each direction for which there is a full range of stable oculomotor movement. For the other tasks (history of seizures, literacy and other motor-based considerations) a score is not given, though the information is provided to prompt assessment considerations and aid device selection, implementation, and adaptation.

Task instruction and protocol refinements

We used multiple review and refinement processes following initial screener development. First, all screener items were reviewed by two independent SLPs with experience in neuromotor impairments who reached a consensus with the research team on item content, administration, and scoring. Next, the revised screening materials were reviewed by five multidisciplinary professionals including two more SLPs, a physical therapist, an occupational therapist, and a psychologist trained in EEG, neuroscience, and behavior. All clinical reviewers currently work with individuals with neuromotor disorders, and one SLP and the occupational therapist are part of BCI teams at their institutions. Feedback from the review team was collected via Qualtrics survey software (Qualtrics, Provo, UT) and two rounds of review were needed for all team members to reach consensus that the screening protocol was feasible for completion by individuals with neuromotor disorders and was comprehensive for BCI assessment.

Pilot testing of the screening protocol

The initial screening protocol was piloted with four neurotypical college-aged adults (ages 20–27, mean 22 years; 4 female; 1 left handed), and one individual with ALS (43 years; F; 5 years from date of diagnosis). The pilot tests were focused on measuring completion duration, fatigue, and instruction clarity. Pilot results indicated the protocol could be completed in under 60 minutes by all participants, which suggests it is feasible for completion by individuals with neuromotor disorders (Fried-Oken et al., 2013). In addition, the individual with ALS reported minimal fatigue while completing the screener and further pilot participant feedback was incorporated to improve the clarity of task instructions.

Screening protocol evaluation

All study procedures were approved by the University of Kansas Institutional Research Board, and participants provided their informed consent prior to beginning study activities. Twelve individuals with a diagnosis of a neuromotor disorder (two with bulbar onset ALS, nine with spinal onset ALS, and one with primary muscular atrophy) completed the study (age: 46 – 80 years, mean 61 years; 5 female; all right handed). Participants completed the BCI screener as well as the ALS-CBS and ALSFRS for score comparisons. Completion times for the BCI screening protocol were timed via stopwatch, and presentation order of the BCI screener and ALS-CBS was counterbalanced across participants. Computer based tasks were administered using PsychoPy software (Peirce, 2008).

Results

Detailed participant information is provided in Table 1. All participants completed the protocol via binary response in under 60 minutes, which is the accepted benchmark in Fried-Oken et al. (2013). Completion times ranged from 24.08 to 34.88 minutes (M = 27.74, SD = 2.7).

Cognitive BCI screening protocol score comparisons to the ALS-CBS

The maximum score for the cognitive portions of our BCI screener and the ALS-CBS is 24 and 20, respectively. Scores less than 16 on the ALS-CBS raise suspicion for cognitive impairment, which is significantly increased for scores less than 12 (Woolley, 2014). Eleven of the twelve participants in this study scored consistently high on the cognitive portion of the BCI screener with scores ranging from 23 to 24 (M = 23.45, SD = .522), which indicates the presence of cognitive skills likely necessary for BCI control. The ALS-CBS was more sensitive to cognitive levels, as expected, for these eleven participants with scores between 13–19. One individual (participant 10) scored a 17 on the BCI screener, which was below the range of all other participants, and 11 on the ALS-CBS indicating a significant concern for cognitive impairment. Further correlation analysis to explore relative levels of cognitive ability for the BCI screener were not performed due to the lack of variance in screener scores, and an unclear relationship between level of impairment and BCI performance. Tables 1 and 2 provide a full summary of ALS-CBS and BCI screener scores, respectively.

Table 1. Participant demographics and commercial screening protocol scores.

Participant Number	*Age (years)*	*Sex*	*Diagnosis/Onset region*	*ALS-CBS Score (/20)*	*ALS-FRS Score (/40)*
1	47	F	Amyotrophic Lateral Sclerosis/Limb	18.0	16.0
2	68	F	Amyotrophic Lateral Sclerosis/Bulbar	19.0	38.0
3	56	M	Amyotrophic Lateral Sclerosis/Limb	16.0	34.0
4	61	M	Amyotrophic Lateral Sclerosis/Limb	18.0	21.0
5	80	M	Amyotrophic Lateral Sclerosis/Limb	13.0	34.5
6	75	M	Amyotrophic Lateral Sclerosis/Limb	15.0	27.0
7	64	F	Amyotrophic Lateral Sclerosis/Limb	19.0	32.0
8	46	F	Amyotrophic Lateral Sclerosis/Limb	17.0	28.0
9	67	F	Amyotrophic Lateral Sclerosis/Bulbar	17.0	27.0
10	71	M	Amyotrophic Lateral Sclerosis/Limb	11.0	8.0
11	49	M	Primary Muscular Atrophy/Limb	15.0	35.0
12	48	M	Amyotrophic Lateral Sclerosis/Limb	13.0	18.0

Table 2. Summary of BCI Screening Protocol Scores.

Participant Number	*Total Cognitive Score (/24)*	*Total Motor Imagery Score (/15)*	*Mean Explicit Imagery Rating Generic tasks (/5)*	*Explicit Imagery Rating Individual Task (/5)*	*Hand Rotation Score (/5)*	*Object Rotation Score (/5)*
1	23	11.2	4	3	3	5
2	23	12	3	3	5	5
3	23	11.7	2.5	4	5	5
4	23	9.8	2	3	4	5
5	23	10.8	2	3	5	5
6	24	12.8	4	5	5	4
7	23	10.3	3.25	3	3	5
8	24	10.7	4.75	5	0	5
9	24	12	2.75	4	5	5
10	17	10.3	3	4	3	5
11	24	12	3	3	5	5
12	24	13.1	4.25	5	4	5

Exploration of specific motor imagery tasks

All participants reported first-person imagery as their primary default modality and there were no significant differences between each of the self-rated generic imagery scores (related samples Friedman's two-way analysis of variance by ranks, $\chi2(3) = 6.90$ $p = .075$; see Table 3).

Table 3. Self-rated scores for the four generic imagery tasks. Increased ratings indicate improved first-person motor imagery performance.

Participant Number	*Making a Fist*	*Thumb to Index Finger Tapping*	*Foot Tapping*	*Wiggling Toes*
1	4	3	4	5
2	3	3	3	3
3	3	3	2	2
4	2	2	2	2
5	2	2	2	2
6	3	4	4	5
7	3	3	3	4
8	5	4	5	5
9	3	2	3	3
10	3	3	3	3
11	3	3	3	3
12	4	4	4	5
M (SD)	3.17 (0.83)	3.00 (0.74)	3.17 (0.94)	3.50 (1.24)
Range	2–5	2–4	2–5	2–5

Therefore, we compared the participant mean generic task scores to the familiar explicit motor imagery task scores using a related samples Wilcoxon signed-rank test to determine the influence of individualized versus generic motor imagery on first person imagery ratings. Shown in Figure 3, scores on the familiar imagery task ranged from 3 (moderately intense) to 5 (as intense as executing the action; M = 3.75, SD = .87), and were statistically significantly higher than the mean generic task scores that ranged between 2 (mildly intense) to 4.75 (intense to as intense as executing the action; M = 3.21, SD = .88, $Z = -2.067$, $p = .039$).

The effect of motor imagery modality (implicit or explicit) on imagery quality was assessed using a Spearman's rank order correlation between the hand rotation task scores (range: 0–5; M = 3.12, SD = 1.51) and the mean generic first-person explicit imagery ratings (range: 2–4.75; M = 3.31, SD = .89). The results of this test were not significant, but trended toward an inverse relationship between hand rotation scores and imagery ratings ($rs(10) = -.539$, $p = .070$). The second implicit motor imagery task, object rotation, resulted in scores with minimal variance (range: 4–5; M = 4.92, SD = .29); therefore,

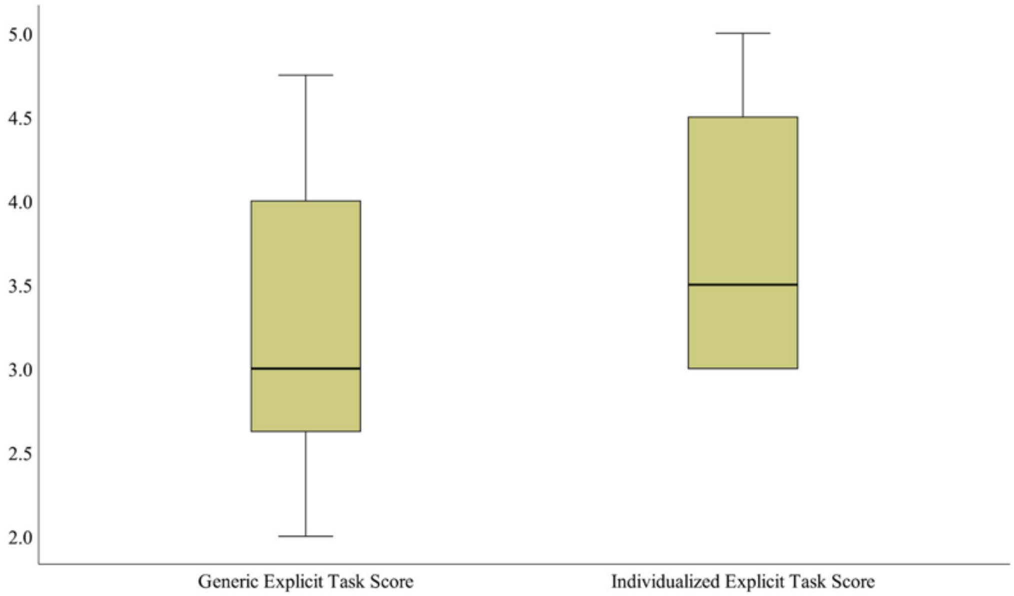

Figure 3. Box plot of self reported scores (1 = no sensation to 5, as intense as executing the action) for a) the mean score for the four generic imagery tasks, and b) the individualized explicit imagery task. Whiskers indicate maximum and minimum scores. A significant difference was found between groups ($Z = -2.067$, $p = .039$).

they were not included for comparisons with explicit motor imagery tasks. Within the implicit motor imagery tasks, however, a related samples Wilcoxon signed-rank test indicated that scores for the object rotation task were significantly higher than those for the hand rotation task ($Z = -2.058$, $p = .040$).

Motor imagery screening protocol score comparisons to the ALS-CBS & ALS-FRS

A Spearman's rank order correlation was used to assess the relationship between scores on the BCI screener motor imagery section, and both the ALS-CBS and ALS-FRS. The resulting correlations were not significant between the BCI screener and either the ALS-CBS ($rs(10) = .272$, $p = .393$) or ALS-FRS ($rs(10) = .178$, $p = .581$).

Sensory screening protocol scores & BCI considerations

All participants reported no history of seizures, achieved the maximum possible score of 6 for the visual perception (four corners) task, had hearing abilities sufficient for following verbal instruction and demonstrated unimpaired oculomotor control with other motor abilities ranging from mild (e.g., ambulatory with minimal impairment to fine motor skills) to severe (e.g., non-ambulatory, with restricted upper and lower limb movement). At the time of this study, the average reported current level of fatigue (1 not fatigued to 4 severely fatigued) was 1.83 (range: 1–4; SD = .94), and the average general level of fatigue over the prior two weeks was 2.33 (range: 1–4; SD = .78). Comfort with computers (1 very difficult to use to 4 very easy to use) was rated as an average of 3.5 (range: 2–4; SD = .67). Motivation was not evaluated as most participants indicated they needed more information about BCI to make an informed decision. Three participants reported having consistent pain in the prior two weeks, and rated pain interference on clarity of thinking (e.g., memory and concentration) and learning new tasks from 1–2 (M = 1.33, SD = .58; 1 never or rarely interferences to 4 frequently interferes). Only one participant missed any item in the literacy section (incorrectly identified ‘m’ as the fourth letter of comb).

Discussion

The purpose of this study was to develop and evaluate a foundational screening protocol specialized for BCI feature matching assessment to inform device selection(s) for BCIAAC trials. Past experiences in AAC suggest that initial assessments to ensure the appropriateness of specific technology (e.g., BCI type) for individuals who may use BCI will likely enhance performance outcomes (e.g., to ensure success and minimize device abandonment).

Sensory assessment & BCI considerations

No participants demonstrated hearing or visual impairments that would require protocol adaptions (i.e., item 11C in supplemental data B, and scoring adaptions to the motor imagery section if visual impairments prevent completion of implicit imagery tasks). Participants also reported low levels of fatigue and pain which are unlikely to impact assessment results, or BCI control and learning. In addition, participants largely reported a high level of comfort with computers (a mean score of 3.5/4) which may positively influence these participants' openness and motivation to pursue BCI use (Blain- Moraes, Schaff, Gruis, Huggins, & Wren, 2012). Regarding literacy, one individual made one error in this section of the protocol. While language impairments may be present for individuals with ALS (e.g., Taylor et al., 2013), additional assessments are needed to determine whether this error was due to literacy impairment or decreased attention to the task.

Cognitive domains

The cognitive portion of the BCI screening protocol was designed to be broadly capable of identifying the presence/ absence of cognitive abilities needed for BCI control, since current research has not yet identified the relationship between specific cognitive skill levels and BCI performance (cf. Geronimo et al., 2016). Therefore, we expected that scores on the cognitive portion of the BCI screening protocol would be high unless individuals had a preexisting significant concern for impairment. The results from our screening protocol matched our expectations with relatively high and consistent scores from all participants (except one) even as their ALS-CBS scores ranged from no concern to suspicion for cognitive impairment. However, one individual with an ALS-CBS score suggestive of a significant concern for cognitive impairment scored below his peers on the BCI screener. These results indicate that the BCI screener has the potential to modestly discriminate a significant concern of requisite cognitive ability for BCI control in this small sample of participants. Additional study is needed on a wider range of cognitive abilities to further evaluate the sensitivity of the cognitive section.

Motor domains

All participants reported first-person imagery as their main default modality, with a 3.21 (on a 1–5 scale) average participant explicit imagery rating for the four generic imagery tasks. This result is consistent with Vuckovic and Osuagwu (2013) who found neurotypical adults reported a mean first-person imagery score of 3.4 (*SD* = .8).

Not only did we replicate this finding in individuals with neuromotor impairments, we also found a significantly increased rating for motor imagery of familiar actions. Past work has found increased motor cortical activity for motor imagery of proficient actions and visual cortex for novice actions, which may also reveal a first person (motor cortex) versus third person (visual cortex) imagery strategy (Olsson, Jonsson, Larsson, & Nyberg, 2008). Putting these results together, it is possible that familiar actions may facilitate first-person imagery, which is known to improve BCI performance (Neuper et al., 2005). Further work is needed to fully examine the effect of familiarity on BCI outcomes.

In contrast, there was a non-significant trend toward improved implicit imagery hand rotation task performance with decreasing first-person imagery scores, which is suggestive that a third-person imagery strategy was used for implicit motor imagery. Though not significant in our study, our results are supported by prior evidence indicating a visual (third person) imagery strategy was used by individuals with neuromotor impairments due to cerebral palsy when also performing hand rotation tasks (Craje et al., 2010). Further investigation with a larger sample size is needed to determine if a significant relationship between these variables exist, since our findings approached but did not surpass the significance threshold. The results from the object rotation task were mixed. Overall, there was a significant increase in object rotation scores compared to the hand rotation task, which implies that the use of a familiar object may help support motor imagery processes for individuals with neuromotor disorders. At the same time, there was only a limited range of scores for the object rotation component, possibly suggesting the object rotation task as administered was too easy, which limits its utility for assessing skills needed for BCI proficiency. Even though third person strategies are not as successful as first person for motor BCI control, the use of implicit motor imagery in this screener provides an objective measure of motor imagery ability. In contrast, explicit, first-person motor imagery can only be obtained by self-reports, which may be influenced by disease related factors (Heremans, D'hooge, De Bondt, Helsen, & Feys, 2012). Finally, correlations between the motor imagery portion of the BCI protocol and the ALS-FRS were not significant indicating the BCI screener likely assesses features not present in the ALS-FRS.

Together with the cognitive domain results, the motor domain findings indicate that the BCI screener is well-suited to broadly evaluate whether an individual possesses any level of the tested BCI-related skills which are needed across a range of BCI types and suggest possible BCIs for follow-up trial evaluation.

Using the screening protocol to guide clinical and research BCI trials

Currently, BCI research has focused on contrasting person-centered assessment factors for one or two BCI methods only (e.g., P300 and sensorimotor rhythm, Geronimo et al., 2016; sensorimotor rhythm and steady state visually evoked potential, Daly et al., 2013). Conventional AAC procedures seek to comprehensively assesses individuals across a full variety of devices, and to be successful in clinical applications BCI procedures should aim for assessment across the full range of possible BCI paradigms. Therefore, this BCI screener provides a method to identify that individuals who may use BCI demonstrate at least a minimal level of skill in various domains important for control over a large range of BCI devices not previously accounted for in prior published accounts. In addition, the screener formally identifies other medical and psychological considerations that may influence BCI use and learning. For instance, a history of seizures decreases an individual's suitability for sensory attention modulated BCIs (e.g., steady state visually evoked potential), impaired oculomotor control may require interface adaptions (e.g., rapid serial visual presentation of items in the center of the screen), and visual or hearing impairments disqualify related sensory- BCIs. Strengths in the assessed cognitive domains of selective attention, working memory support sensory attention modulated BCI success, with factors such as motor imagery and cognitive motor learning providing additional information for feature matching to motor imagery BCIs.

The screener also provides guidance for interpreting assessment outcomes for making decisions on proceeding with BCI trials. For example, BCI trials may be appropriate even if screener cognitive and motor scores are borderline, but only if the individual is highly motivated. In comparison, high levels of fatigue, and pain influencing cognition and skill learning may decrease the appropriateness of

BCI trials, especially for motor imagery based BCI devices given their often lengthy training times (e.g., Nijboer et al., 2010). Examiners should also consider individuals' self-report reliability when interpreting these and other screener results, as they may be influenced by cognitive status (e.g.., Geronimo, Stephens, Schiff, & Simmons, 2015). Finally, the BCI screener results may be used in conjunction with person-centered BCI-AAC feature matching frameworks (e.g., Pitt & Brumberg, 2018), to support and guide selection of BCIs for accessing AAC.

Comparison to the RSVP keyboard™ screener

The RSVP Keyboard™ screener outlined by Fried-Oken et al. (2013) provided a strong foundation for the development of the multi-BCI screening protocol discussed in the present paper, outlining screener requirements (e.g., maximum time for completion), and areas important for visual, RSVP-based BCI assessment such as visual perception, memory and speed of information processing, sustained visual attention, auditory comprehension, spelling, reading comprehension and literacy, levels of pain, current medications, motor function, and positioning. Our BCI screener builds upon the RSVP Keyboard™ protocol in multiple ways by 1) including assessment tasks and domains relevant to a range of BCI techniques (e.g., motor imagery, steady state visually evoked potential, auditory) that are designed to be accessible to individuals with and without severe visual or hearing impairments, and 2) providing assessment scores, which allows for comparison of participant performances across settings, and standardizes BCI assessment procedures for identifying person-centered factors influencing BCI control. As the RSVP Keyboard™ protocol does not provide a validated score, it is difficult to compare the effectiveness of the RSVP Keyboard™ screener with our own BCI screener though general comparisons can be made since both screening protocols overlap in some content. Overall, screener outcomes reported by Fried-Oken et al. (2013) are similar to those found in our protocol, as nine of twelve individuals with locked in syndrome achieved 100% RSVP screener accuracy across all tested domains, and the remaining three participants missed only a single item. For the sensory domain, across both protocols, all participants demonstrated functional hearing, and even though one individual who completed the RSVP protocol demonstrated impaired vertical oculomotor movement, all participants scored 100% accuracy on the four corners tasks. Regarding memory and attention, one participant scored 17 on the cognitive portion of our screener, and the RSVP protocol found only two participants (or their caregivers) reported a mild impairment in these areas. Finally, three participants in our study reported problems with pain as did six participants who completed the RSVP Keyboard™ screener, though both screeners suggest the level was not severe enough to interfere with participants' ability to remember, concentrate, or process new information. The RSVP Keyboard™ screener additionally found two individuals had pain that sometimes or rarely made them feel discouraged, with one participant who indicated their pain was rarely so severe it was all they could think about. The remainder of the BCI screening protocol described in this paper incorporates tasks that are relevant for assessment across a range of BCI techniques that are not included in the RSVP Keyboard™ screener, and therefore no further comparisons are possible.

Limitations

Further research is needed to evaluate the screening protocol described in this paper and its content areas in relation to long-term BCI performance across different methods in order to identify the critical factors most likely to facilitate communication success. The current BCI screener is a first step in this effort and provides a framework from which future BCI research can evaluate the factors involved in predicting long-term success. Further, this screener also serves as an initial comprehensive assessment specific to the selection of BCI devices for AAC that augments the relatively few other published screening tools developed for BCI applications (cf. Fried-Oken et al., 2013), and helps standardize BCI selection for clinical and research applications.

A strength of this screener in comparison to others is its ability to quickly assess a wide array of domains that may influence BCI performance across many different BCI types. In addition, the screener is designed for completion via binary response, and despite vision or hearing impairments. However, these stringent design requirements may limit the range of screener results due to adaptations needed to support the varied sensory-motor profiles of individuals with neuromotor disorders. For instance, to support individuals with sensory impairments, attention and working memory sections of the BCI screener incorporate auditory and visual stimuli (e.g., a picture of a cookie along with the auditory word). However, including simultaneous audiovisual presentation reduces the rate of stimulus presentation in comparison to visual stimuli alone, possibly decreasing cognitive demands related to speed of information processing, and ultimately lowering task difficulty and score variability. Therefore, for further assessment of these skills, future revisions of the screening protocol can be tailored for specific impairments (e.g., either hearing or visual loss, varied motor (dis)abilities) to improve assessment sensitivity by increasing task difficulty.

As BCIs transition into the clinical setting, future efforts will also aim to focus screener content to highlight the most important factors (while removing less important factors) for informing feature matching procedures and predicting BCI success, allowing for more comprehensive assessment of skill levels while still accounting for binary responses and potential sensory impairments. The current screener version, however, may be used as a first attempt to inform BCI trials, and as a starting point for feature matching assessment of BCI for accessing AAC. The ALS-CBS, or other cognitive-motor related skill assessments may be used as a follow-up for a more detailed assessment of cognitive function as needed.

Another limitation is the limited size and relatively homogeneous participant population primarily with a diagnosis of ALS in our study. Participants also did not present with a large range of cognitive or sensory impairments, which may have led to reduced variability in some of our measures. The homogenous population and relatively stable sensory and cognitive abilities of our participants was beneficial for developing this initial version of the BCI screening protocol, though future work should include larger sample sizes, and a more heterogeneous participant population (e.g., ALS, brainstem stroke, cerebral palsy) with a larger range of cognitive, sensory, motor and motor imagery abilities. Electrophysiological measures (e.g., sensorimotor rhythm amplitude; Blankertz et al., 2009) may also provide important information for BCI assessment; however, our protocol was designed to be completed in a short duration with minimal equipment demands for initial screening. Inclusion of these measures should be considered for future investigation particularly as follow-up evaluations for BCI selection. Finally, it is important to note that screening tools do not replace formal assessments of disease progression and ability, rather they are used here to determine the appropriateness of potential BCI devices; therefore, possible impairments noted through use of this screener require additional formal testing.

Conclusions and future directions

The purpose of this study was to develop and evaluate a screening protocol to guide BCI selection across multiple BCI devices in a feature matching framework. The use of screening protocols helps to inform appropriate device matching for each individual, potentially increasing BCI performance and informing future clinical practices (e.g., minimizing device abandonment). The results of this study show our screening protocol has utility for ensuring individual factors are considered and assessed when selecting potential BCIs for trial evaluations. For example, we found in the motor domain that familiar explicit tasks increased self-ratings of first-person imagery, which may be important for BCI success.

The role of caregivers in the success of any AAC intervention must also not be overlooked (Beukelman & Mirenda, 2013). Therefore, we also developed a caregiver questionnaire in order to obtain new and/or clarifying information about individuals who completed the BCI screener. Though not the main focus of the present work, this questionnaire included the following topics: medication use, ability to provide accurate self-report, times of greatest and least fatigue, sensory ability, motor function, hobbies, changes in speech, language, swallowing, behavior (impulsivity, problem solving, emotional control, self-awareness) and cognition (attention and memory), common communication environments, daily activities, communication goals, and (any) prior AAC experience. Unfortunately, only five caregivers provided feedback on the questionnaire, which was not sufficient for a rigorous analysis and will be a focus of future study. With a screener in place, we anticipate and encourage future efforts to further refine protocol content, establish test-retest reliability, and further expand these initial findings in relation to other comprehensive cognitive and motor imagery assessment measures. These efforts will continue to advance work identifying those characteristics that have the greatest importance for selecting the most appropriate BCI through feature matching procedures, updating the protocol from evidence into practice.

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* * * * *

Supplemental data for this article follows.

Participant Name/ID: Gender: DOB/Age: Highest Education level:
Prior Occupation:

A Screening Protocol Incorporating Brain-Computer Interface Feature Matching Considerations for Augmentative and Alternative Communication

Kevin Pitt., CCC-SLP & Jonathan Brumberg., PhD.

Instructions on this form may be abbreviated. See manual for full guidelines.
Please record use of medications on a separate sheet.

Today's date: Given by (clinician): **Start time: ________** **End time: ________**

Introductory Information:

*Participant currently using mechanical ventilation? **Y / N** *Likely remaining with ventilation? **Y / N**
Primary Communication method:

Current AAC method, if applicable:

Communicational method used for screening protocol responses:

Diagnosis, and date of diagnosis: Date and region of symptom onset:

Date of last hearing test (pass/fail): Date of last vision test (pass/fail):

1) Handedness:

Do/did you primarily use your right / left hand to?
If applicable, prior to paralysis. If they have never been able to perform the selected actions due to congenital motor impairments, please individualize actions (see manual for examples) and record below. Select 'uncertain' if handedness cannot be ascertained.

1A) Throw a ball _Right hand _Left hand _Both hands equally well
1B) Draw _Right hand _Left hand _Both hands equally well
1C) Clarification: The subject is: _Right handed _ Left handed _Uses both hands _Uncertain

Modified task 1A: Modified task 1B:

____

____

2) History of Seizures:
2A) *Have you ever had a seizure?* **_ Yes _No**
If yes, please provide history in the general considerations section.

____

____

3) Vision:
3A) Four Corners. *Communicate whenever you seen an item appear.*
__Center __Right upper quadrant __Left lower quadrant __Right lower quadrant __ Blank
__Left upper quadrant __Unable to complete due to severe visual impairment
Score 1 point per correct response Enter score /6
3B) *Do you use contact lenses or glasses?* **_ Yes _No**

3C) *Do you have trouble seeing far away?* **_ Yes _No**
3D) *Do you have any other difficulties with your vision?* **_ Yes _No** (if yes, provide details as possible)

4) Hearing:
4A) *Do you use hearing amplification?* **_ Yes _No**
4B) *Do you have difficulty hearing in background noise (e.g., in a restaurant)?* **_ Yes _No**
4C) *Do you have any other difficulties with your hearing?* **_ Yes _No** (if yes, provide details as possible)

____
____

5) Literacy:
5A*) Are you able to read?* **_ Yes _No**. If no, *were you able to read in the past?* **_ Yes _No**
5B) Participant is to read/perform "*Look Up*" (see manual for stimuli and adapt to meet individual's voluntary motor, and visual capabilities as necessary)
_Accurate _Inaccurate _Unable to complete due to severe visual impairment

5C) *I will present a familiar object and ask you some questions about how to spell the word.*
Is the first letter c? **_ Yes _No**
Is the second letter o? **_ Yes _No**
Is the third letter r? **_ Yes _No**
Is the fourth letter m? **_ Yes _No**

____
____

6) Fatigue: Use visual scale in provided in the manual
6A) *I want you to indicate your* ***current*** *level of fatigue on a scale of 1 to 4, with 1 being not fatigued, to 4 being severely fatigued*: ____

6B) *I want you to indicate your* ***average*** *level of fatigue (e.g., over the past 2 weeks) on a scale of 1 to 4, with 1 being not fatigued, to 4 being severely fatigued*: ____

____
____

7) Pain:
7A) *Have you been in consistent pain over the past two weeks*? **_ Yes _No** If no, skip to section 7D

If yes*, I am going to ask you questions about your average level of pain (e.g., over the past two weeks). Communicate your answer using a scale of 1 (never or rarely interferes) to 4 (always interferes).*
7B) *At what level does your average level of pain interfere with your ability to learn new tasks?* _______
7C) *At what level does your average level of pain interfere with your ability to think (e.g., remember things, concentrate)?* _________

7D) *Are you currently in pain?* **_ Yes _No** If no, skip to section 8

If yes, *I am going to ask you questions about your current level of pain. Communicate your answer using a scale of 1 (never or rarely interferes) to 4 (always interferes).*
7E) *At what level does your current level of pain interfere with your ability to think (e.g., remember things, concentrate)?* _________

____
____

8) Comprehension & Orientation
I am going to ask you some more yes and no questions

8A) *Is your last name Smith?* (should be incorrect) **_ Yes _No**
8B) *Are you ______ years old?* (should be correct) **_ Yes _No**
8C) *Is your name ______?* (should be correct) **_ Yes _No**
8D) *Is this a hotel______?* (should be incorrect) **_ Yes _No**
8E) *Is this _______?* (should be correct) **_ Yes _No**
8F) *Do you live in Toronto?* (should be incorrect) **_ Yes _No**
8G) *Do you live in _______?* (should be correct) **_ Yes _No**
8H) *Is this month _________ ?*(should be correct) **_ Yes _No**
8I) *Is this month _________ ?(*should be incorrect, 1 month prior) **_ Yes _No**
8J) *Is this a restaurant?* (should be incorrect) **_ Yes _No**
8K) *Does March come before June?* (correct) **_ Yes _No**
8L) *Do you eat a banana before you peel it?* (incorrect) **_ Yes _No**
Score 6 points (12 corr), 5 (11 corr), 4 (10 corr), 3 (9 corr), 2 (8 corr), 1 (7 corr), else score 0
Enter score /6

---

9) Following Directions (Adapt to meet individual's voluntary motor capabilities as required).

9A) 1 step direction: *Look up* **_ Accurate _Inaccurate** /2
9B) 2 step direction: *Blink, look up* **_ Accurate _Inaccurate** /2
9C) 3 step direction: *Look down, move your finger, look up* **_ Accurate _Inaccurate** /2
Note any adaptions or task difficulties:
Score 2 points for each set of directions performed correctly, else score 0
Total Score /6

---

10) Motor Imagery (MI)

10A) **Default Preference** for First-Person/Kinesthetic versus Third-Person/Visual Motor Imagery. After participant has performed tasks via motor imagery, ask in the order presented which modality was used.

1A	Tapping foot:	__ First person (kinesthetic)	__Third person (visual)
1B	Making a fist:	__ Third person (visual)	__ First person (kinesthetic)
2A	Curling Toes:	__Third person (visual)	__ First person (kinesthetic)
2B	Tapping your finger:	__ First person (kinesthetic)	__Third person (visual)

3) *Generally, is it more natural for you to use first person imagery during all these tasks?*
__Yes __No

10B) **Hand Rotation** (See manual for a scoring modification if the participant cannot complete this task due to a sensory impairment). **Right/left** (below) denotes the laterality of the presented hand. **Yes/No** denotes the correct binary answer.

I will ask you if the picture is of a right or left hand

- Practice: Right (yes)

Are you ready to continue? I will ask you if the picture is of a right or left hand.

- Experimental: Left (no), Left (yes), Right (yes), Left (yes), Right (yes), Right (no), Left (no), Right (no)

Score 5 points (8 corr), 4 (7 corr), 3 (6 corr), 2 (5 corr), else score 0 Enter score /5

10C) **Self-Rating of First-Person Imagery**

After demonstrating a movement overtly (sitting position), the participant is to perform all tasks via first-person (kinesthetic) motor imagery. As possible, a physical practice should precede imagery performance. Use the corresponding 5-point number scale (1 = no sensation, to 5 = as intense as executing the action) for scoring. If the participant has never been able to perform a task physically due to congenital paralysis, interpret results with caution.

	Imagery rating:		
1) Making a fist:	__	Overt: __	Time since physical task performance:
2) Foot tapping:	__	Overt: __	Time since physical task performance:
3) Thumb to index finger tapping:	__	Overt: __	Time since physical task performance:
4) Wiggling toes:	__	Overt: __	Time since physical task performance:
5) ________________________	__	Overt: __	Time since physical task performance:

(Note individualized task used for item 5)

Mean imagery rating /5

10D) **Object Rotation** (See manual for a scoring modification if the participant cannot complete this task due to a sensory impairment).

Red/black below denotes the correct tip of thumb location. **Yes/No** denotes the correct binary answer.

*I will ask you if the **TIP** of your thumb is resting on the **red or black** part of the handle.*

- Practice: Red (yes) *Are you ready to continue?*

- Experimental: Black (no), Black (yes), Red (yes), Red (no), Red (yes), Black (yes)

Score 5 points (6 corr), 4 (5 corr), else score 0 Enter score /5

NOTE: If the participant could not complete rotation tasks due to a visual impairment then multiply the mean imagery rating by 3, and do not score any other tasks in the motor imagery section.

Enter score /15

---

11) Attention / Working Memory

11A) Experiential: *Pay attention, I will ask you how many times the "ice cream" was presented.*

A) Was the ice cream presented four times? **_ Yes _No**

B) Was the ice cream presented five times? **_ Yes _No**

Score 2 if the response to only question B was YES, else score 0 Enter score /2

11B) *You will see and/or hear numbers and objects. Pay attention, at the end of the sequence I will ask you if the number one and/or the cookie was presented.*

A) Was the number one presented? **_ Yes _No**

B) Was the cookie presented? **_ Yes _No**

Score 1 point per correct response, A= yes, B= no Enter score /2

11C) If the participant has a severe visual or hearing impairment please see the manual for task modifications.

You will see different objects on the screen and at the same time hear different numbers. Pay attention, at the end of the sequence I will ask you about whether you saw the cheese and/or heard the number 5.
- Experimental: Fires (1), Hotdog (3), Fries (5) [*A], Hotdog (2), Popcorn (3), Hotdog (2), Popcorn (1), Cheese (2)[*v], Popcorn (3), Fires (2).

A) Did you hear the number 5 (or feel left side tap for hearing modification)? **_ Yes _No**
B) Was the cheese presented (or feel left side tap for visual modification)? **_ Yes _No**
Score 1 point per correct response, A & B both = yes Enter score /2

---

12) Cognitive Motor Learning / Abstract Problem Solving

12A) **Circle/square** below denotes the shape presented. **Yes/No** denotes the correct binary answer. **X** denotes no answer required.

Is the shape the same as the one shown two turns back?
- Practice: Triangle (X), Circle (X), Triangle (yes) *Continue?*
- Experimental: Circle (X), Triangle (X), Circle (yes), Triangle (yes), Triangle (no), Circle (no)
Score 3 points (4 corr), 2 (3 corr), else score 0 Enter score /3

12B) *Which of the following three options best describes how **GLOVES & SCARVES** are alike?*
1. Made of leather (incorrect) 2. Winter clothing (correct) 3. Both worn near the head (incorrect)
Score 0 if incorrect, 3 if correct. Enter score /3

---

13) Motivation for BCI use:
13A) *I want you to indicate your level of motivation to use a brain-computer interface for communication using a scale of 1 – 4, with 1 being unmotivated to, 4 highly motivated.:* _________

13B) *I want you to indicate how helpful you think brain-computer interfaces will be for communication in your daily life, on a scale of 1 – 4 with 1 unhelpful to 4, very helpful:* _________

Enter score /8

14) Comfort with Computers:
14A) *I want you to indicate on a scale of 1 – 4, your comfort level with using computers, with 1 being computers are very difficult to use to 4, very easy to use:* _________

---

15) Motor functionality: In relation to brain-computer interface use, a screening of voluntary motor control including the: upper and lower limbs, face, tongue, horizontal/vertical eye movement, presence of uncontrolled, or impulsive movements, and posture should be completed. Describe findings below, continuing on a separate page if needed. See manual for further guidance of motor assessment.

15A) **Oculomotor movement**, describe findings including; vertical and lateral range of motion, pursuit (following an object/finger), speed, effort, stability), and reliability (reproducibility of task). Score 1 point for each direction which they demonstrate a full range of stable oculomotor movement (up, down, left and right).

Enter score /4

15B) **Facial, and tongue movements,** describe findings including; range of motion, speed, effort, stability (e.g., tremor), and reliability (reproducibility of task).

15C) **Upper, lower limb, and trunk** motor function, describe findings including; range of motion, speed, effort, stability (e.g. tremor), and reliability (reproducibility of task).

15D) **Posture/ positioning for device access**, describe findings including; areas where the headrest may compress the electroencephalography (EEG) cap (as applicable), and how the participant may be most comfortable, and be afforded best access to the device.

Is there a concern for the participants' reliability to provide an accurate self-report?

Yes (provide details below) ____ No____ Unable to ascertain (provide details below) ____

Concern may be based on, but is not limited to; clinical observations, unclear responses to self-report based tasks (e.g., an unclear self-report for explicit imagery ratings), and caregiver input.

Total Screening Scores

Practice items are not included in scoring.

Level of Current Fatigue	/4	Oculomotor:	/4
Level of Average Fatigue	/4	Visual Acuity	/6
Mean KI score (generic tasks #1-4)	/5	Comfort with Tech.	/4
KI score for individualized task #5	/5	Motivation for BCI	/8
		Cognitive	/24
Check if participant was NOT able to complete rotation imagery tasks: __		Motor Imagery:	/15

Was the individual currently in pain (**Yes / No**) and/or have habitual pain (**Yes / No**)?

Does the individual have a history of seizures? **_ Yes _No**

Is the self-rating for the individualized explicit imagery task higher than the mean of the four other generic tasks? **_ Yes _No**

Self-Report Details, General Considerations & Medications.

If the information has not been provided by the caregiver (see caregiver questionnaire), a list of primary medications (especially: sedative, anti-depressant, anti-epileptic, psychiatric or pain medications) should be noted. Please discuss any difficulties in completing tasks, strengths and weaknesses noted during performance of protocol tasks, etc. Continue on a separate page if needed.

A Screening Protocol Incorporating Brain-Computer Interface Feature Matching Considerations for Augmentative and Alternative Communication

Instruction Manual

Kevin Pitt., CCC-SLP & Jonathan Brumberg., PhD.

General Instructions

For items requiring performance of a specific motor task (e.g., following directions), the tasks provided are designed to be appropriate for individuals with advanced paralysis. However, task modifications can be made if necessary to match the individuals voluntary motor capabilities. Any task modifications should be recorded on the screening form.

- Identify a reliable form of yes/no response.
- For all individuals without visual impairment, number scales should be provided during the task for reference. Ensure the participant can view and read all number scales.
- Provide task instructions via visual and/or auditory modalities, as appropriate.
- If the participant does not provide a clear response for items requiring self-report, or following directions, indicate 'unclear' next to task.
- See screening protocol form for more information on task scoring.

- No practice items are included in scoring.

- Full task instructions are given *in italics* within this document. Abbreviated instructions given on the scoring sheet are for examiner reference only.

For more information about the screening protocol and how it may be used to guide device selection BCI-AAC trials see:

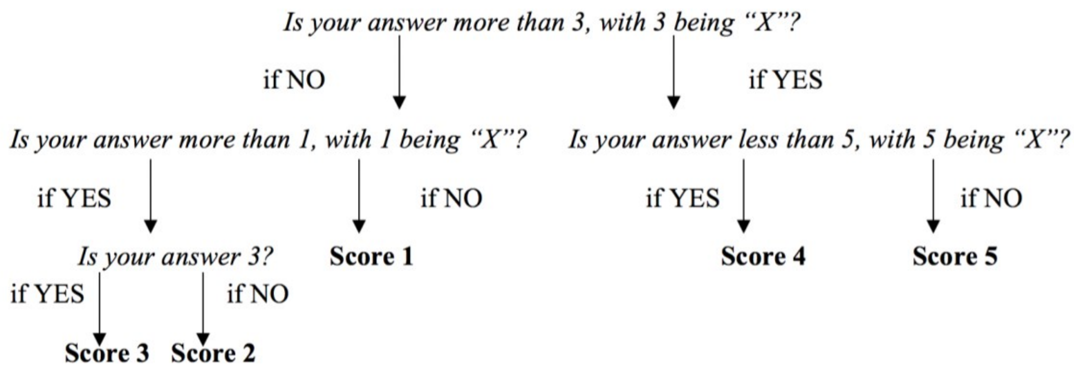
1) Pitt, K., & Brumberg, J. (in review). *A Screening Protocol Incorporating Brain-Computer Interface Feature Matching Considerations for Augmentative and Alternative Communication.*

2) Pitt, K. M. and Brumberg, J. S. (2018). Guidelines for Feature Matching Assessment of Brain-Computer Interfaces for Augmentative and Alternative Communication. *American Journal of Speech-Language Pathology,* 1–15. doi:10.1044/2018_AJSLP-17-0135

Binary formats for presenting number scale response choices

"X" = Explanation for each scoring item (e.g., is your answer more than 3, with 3 being moderately intense?)

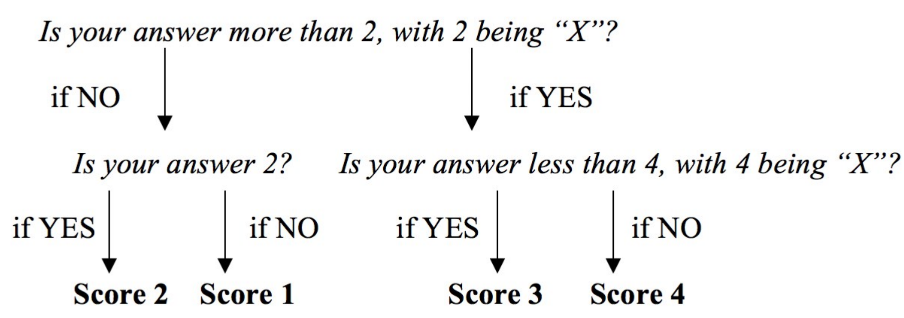
A) Five-point number scales



Clarify answer once each score is obtained (e.g., so, your score is a 3 which is moderately intense?). If 'no' is indicated during clarification question repeat answer tree.

If the participant does not answer, seems confused, or asks for clarification following the first prompt explain "if your answer is 3, then state no. This question is asking if your answer is **more than 3". Then repeat prompts. Provide this instruction as needed.*

B) Four-point number scales



Clarify answer once each score is obtained (e.g., so, your score is a 3 which is moderately intense?) If 'no' is indicated during clarification question repeat answer tree.

If the participant does not answer, seems confused, or asks for clarification following the first prompt explain "if your answer is 2, then communicate no. This question is asking if your answer is **more than 2. Then repeat prompts. Provide this instruction as needed.*

Introductory Information:

Provide information regarding the individuals current communication method(s), and reliance on mechanical ventilation. In addition, provide information about the individuals medical diagnosis (including date), and describe onset of symptoms. If known, provide dates of the last hearing and vision test and results.

---

1) **Handedness**

If applicable, evaluate handedness prior to paralysis. Select 'do' or 'did' based on individuals current level of motor function. If they have never been able to perform these actions due to congenital motor impairments, individualize actions (and record on the testing form), or state 'uncertain' if there is no functional motor movement. Examples of modified actions include: Using a spoon, holding a brush, using a computer mouse, etc.

Instructions:

1A) *Do/did you primarily use your **right hand** to throw a ball?*
Do/ did you routinely use both hands equally well in performing this task?

1B) *Do/did you primarily use your **left hand** to draw?*
Do/ did you routinely use both hands equally well in performing this task?

1C) Clarify handedness
- So, you are (left or right) handed?
- So, you are/were able complete tasks equally well using both your left and right hands?

---

2) **Seizure History**

Have you ever had a seizure?

---

3) **Vision**

3A) Four Corners
Instructions: *During this task an image may or may not appear on the screen. After a short duration I will ask you if an image appeared. Are you ready?*

After each image presentation:
Did an image appear on the screen?

3B – 3D) Instructions: *I am going to ask you some yes and no questions about your vision.*
See scoring sheet for question instructions.

---

4) **Hearing**

4A-4C) Instructions: *I am going to ask you some yes and no questions about your hearing.*
See scoring sheet for question instructions.

---

5) **Literacy**

5A) Instructions: *Are you able to read?* If no, *were you able to read in the past?*

5B) Adapt to meet individual's voluntary motor and visual capabilities, as appropriate. If modification to the given task is required a simple one step movement should be selected (e.g., lift your thigh, move your foot, move your arm, move hand). Instructions should be provided on a sheet which contains no other distracting information.

Instructions: *Perform this task* (show task instructions for participant to read).

Look Up

5C) Instructions: *I will present a familiar object and ask you some questions about how to spell the word for that object. The object is* (an image of a comb is presented on the screen, or in the case of participants that may have visual difficulties, the auditory word 'comb' is given).
To spell the word for this object:

- *Is the first letter c?*
- *Is the second letter o?*
- *Is the third letter r?*
- *Is the fourth letter m?*

---

6) **Fatigue**, use the following scale:

1	2	3	4
Not fatigued	Mild	Moderate	Severe

6A) Instructions: *I want you to indicate your current level of fatigue on a scale of 1 to 4, with 1 being not fatigued, to 4 being severely fatigued*

6B) Instructions: *I want you to indicate your average level of fatigue (e.g., over the past 2 weeks) on a scale of 1 to 4, with 1 being not fatigued, to 4 being severely fatigued.*

---

7) **Pain**, use the following scale:

1	2	3	4
Rarely Interferes	Sometimes Interferes	Often Interferes	Always Interferes

7A) Instructions: *Have you been in consistent pain over the past two weeks?* If no, skip to section 7D

If yes, **Instructions:** *I am going to ask you questions about your average level of pain (e.g. over the past two weeks). Communicate your answer using a scale of 1 (never or rarely interferes) to 4 (always interferes).*

7B) *At what level does your average level of pain interfere with your ability to learn new tasks?*
7C) *At what level does your average level of pain interfere with your ability to think (e.g. remember things, concentrate)?*

7D) *Are you currently in pain?* If no, skip to section 8.

If yes, **Instructions:** *I am going to ask you questions about your current level of pain. Communicate your answer using a scale of 1 (never or rarely interferes) to 4 (always interferes)*

7E) *At what level does your current level of pain interfere with your ability to think (e.g. remember things, concentrate)?*

---

8) Comprehension & Orientation

8A-8L) Instructions: *I am going to ask you some more yes and no questions.*
See scoring sheet for question instructions.

---

9) Following Directions:

If necessary, adapt to meet individuals voluntary motor capabilities. If modification(s) are required a simple one step movement should be selected (e.g. lift your thigh, move your foot, move your arm, move hand), to replace the given item(s). Repeat instructions only once. If instructions are repeated score 0, but allow for task completion. The individual is to wait until all commands are given before completing the task. If necessary (e.g., depending on impulsivity) further clarify this requirement to the individual, and following sequence instruction inform them to start.

An example of a modified protocol for an individual who cannot look up, but can move their foot, is provided in steps 1-3 (below).

9A) *Look up*	1) *Move foot*
9B) *Blink, look up*	2) *Blink, move foot*
9C) *Look down, move your finger, look up*	3) *Look down, move your finger, move foot*

Instructions*: I am going to give you some directions, when I am finished, complete the directions, exactly as I presented them to you*. If necessary, following command sequence: *Please start.*

---

10) Motor Imagery

10A) Default preference for first person (kinesthetic) versus third person (visual) motor imagery. Pause for approximately 5 seconds after task instruction to allow for imagery performance.

Instructions: *Imagine you are tapping your foot, and now imagine making a fist. I want to know if when you imagined these tasks you imagined them in* ***first person****, like you were actually tapping your foot, "feeling" the sensations associated with the task, or* ***third person****, like you were watching yourself from across the room.*

1A) *For tapping your foot, did you use first person?*
(if no) -- *Did you use third person?*

1B) *For making a fist, did you use third person?*
(if no) -- *Did you use first person?*

2) Instructions: *Now imagine curling your toes and tapping your finger*

2A) *For curling your toes, did you use third person?*
(if no) -- *Did you use first person?*

2B) *For tapping your finger, did you use first person?*
(if no) -- *Did you use third person?*

3) *Generally, is it more natural for you to use first person imagery during all these tasks?*

10B) Hand Rotation
See item 10C if the participant cannot complete task due to visual impairments. As possible, the participants hands should be in a neutral position (e.g., resting in front of them) versus an unusual posture (e.g., behind back, fingers intertwined).

Allow approximately 2 seconds after image presentation before asking for a response.

Practice Instructions: *I am going to show you some rotated left and right-hand pictures. After, I will ask you if the image is of a right or left hand. Let's practice.*

After image presentation 1:
Is the image of a ***right*** *hand?*

If participant **responds correctly** (yes) state "*yes, that is a right hand*".
If participant **responds incorrectly** (no) state "*No, that is a right hand*".

Experiment Instructions: *I will ask you if the image is of a right or left hand. Are you ready?*
After image presentation 1:
Binary question: *Is the image of a* ***right*** *hand?*
After image presentation 2:
Binary question: *Is the image of a* ***left*** *hand?*

Continue to alternate response options following each presentation to account for the possibility of habitual positive or negative responses.

10C) Self-Rating of First-Person Imagery

Beginning with task 1, the examiner demonstrates the target movement physically from a sitting position. Following demonstration, if possible, the participant physically practices the same movement for approximately 5 seconds, and then perform the task via kinesthetic (first person) motor imagery (for approximately 5 seconds). Following imagery task performance, the participant self-rates imagery performance using the 1-5 kinesthetic number scale (below). These steps will be completed for each item (1 thru 5) sequentially.

Tasks may be completed using limb of preference, or bilaterally as preferred. If the participant can perform the action physically the limb with most movement, or their dominant limb should be chosen. If the participant is able to perform a physical practice prior to imagery, check 'overt' on the screening form next to the corresponding task(s). If the participant cannot perform the physical action, perform imagery task only and record the length of time since the participant lost motor ability.

If necessary, provide further instruction to ensure the individual understands how to perform first person imagery.

Task 1: Make a fist
Task 2: Foot tapping
Task 3: Thumb to index finger tapping
Task 4: Wiggle Toes
Task 5: Individualized

5 = As intense as executing the action

4 = Intense

3 = Moderately intense

2 = Mildly intense

1 = No sensation

Individualized task 5: The selected task should be familiar to the participant (e.g., an activity of daily living, playing an instrument, hobbies). It is recommended that the clinician incorporates participant and caregiver input into the selection of this task. Record the task that was selected on the evaluation form. Performance and self-rating of this task follows the same procedure as generic BCI tasks 1 thru 4. Practice physically if possible, depending on the suitability of the chosen task.

Instructions: *I am going to demonstrate a movement; after I have demonstrated it you will (*if applicable: *perform it once physically, and then…) "imagine" performing the same movement using first person motor imagery, like you are actually performing the action, "feeling" the sensations associated with the movement. I will then give you a scale to rate your imagined performance.*

1) Examiner demonstrates tasks physically and states task (e.g., *first we will make a fist*)

1B) If applicable, the examiner instructs the participant to physically perform the action.

2) Following physical performance by the examiner (and possibly participant) state: *Now imagine performing the same task in first person motor imagery.*

3) After completion of the imagery task state "*Now I want you to rate your imagined performance using a 1 to 5 scale, with 1 being no sensation to 5, as intense as executing the action.*

*If appropriate, after accurate completion of the first couple of tasks the examiner may state, *"Now I want you to rate your imagined performance using the same 1 to 5 scale."*

Repeat instructions obtaining self-ratings of first person kinesthetic imagery performance for all 5 tasks sequentially. Place reported scores in the corresponding kinesthetic imagery (KI) column.

Scoring

- If the participant has never been able to perform a task physically due to congenital paralysis, interpret self-ratings of first person imagery with caution.
- **For participants without severe visual deficits:** Average all reported KI scores.
- **<u>For participants WITH severe visual impairments</u>:** Only if the visual impairment is severe enough to prevent completion of rotation-based motor imagery tasks (10B and 10D), average the reported KI scores and multiply by 3 to obtain the imagery section score of 15. Do not score any other tasks in the motor imagery section. However, their imagery preference should still be ascertained and considered.

10D) Object Rotation
See item 10C if the participant cannot complete task due to visual impairment.
Allow approximately 2 seconds after image presentation before asking for a response.

Practice Instructions: *I am going to show you pictures of a mug. I want you to imagine picking up the mug by its handle, gripping it like the example mug shown here,* (thumb at the top; show picture below), *as if you are going to take a drink. The mug I am about to show you has a red and black handle, and after you have imagined picking up the mug, as if to take a drink, I will ask you if the **TIP** of your thumb is closest to the red or black part of handle. Let's practice.*

After image presentation 1:
*Is the tip of your thumb closest to the **red** part of the handle?*

If participant **responds correctly** (yes) state "*yes, the tip of your thumb was closest to the red part of the handle"*, and then make an action as if picking up the red and black handled mug, using a grip where the thumb is resting against the middle and/or index finger, and points to the thumb tip.

If participant **responds incorrectly** (no) state "*The tip of your thumb was closest to red part of the handle",* and then make an action as if picking up the red and black handled mug, using a grip where the thumb is resting against the middle and/or index finger, and points to the thumb tip.

Experiment Instructions*: Are you ready to continue*? *Pick up the mug by its handle, as if you are going to take a drink. After I will ask you if the **TIP** of your thumb is closest to the red or black part of handle.*

After image presentation 1:
Binary question: *Is the tip of your thumb was closest to the **red** part of the handle?*
After image presentation 2:
Binary question: *Is the tip of your thumb closest to the **black** part of the handle?*
Continue to alternate response options following each presentation.

11) Attention / Working Memory

11A) Instructions: *Varying objects will be presented in sequence. I want you to count how many times the ice cream is presented. This is what you are looking for* (target image to be visually presented with simultaneous auditory stimuli; i.e., picture of ice cream and auditory word 'ice cream'). *At the end of the upcoming sequence, I will ask you how many times the ice cream was presented. Are you ready?*

Stimuli presentations will depict the ice cream on 5 occasions (no, no, no, yes, no, no, yes, no, no, no, yes, no, no, no, yes, no, yes, no)

Following presentations ask:
A) Was the ice cream presented four times?
B) Was the ice cream presented five times?

11B) Instructions (for those without sensory impairment): *You will see and hear a sequence of numbers and objects. Pay attention, at the end of the sequence I will ask you if the number one* ***and/or*** *the cookie was presented. The items will be presented separately. Here is what you are searching for* (targets are separately presented with simultaneous visual and auditory stimuli; e.g., picture of cookie and auditory word 'cookie').

Following presentation sequence ask:
A) Was the number one presented?
B) Was the cookie presented?

<u>Sensory modifications:</u>
* **Instructions for individuals with visual impairments:** Replace first sentence above with: *You will hear a sequence of numbers and objects.*
* **Instructions for individuals with hearing impairments**: Replace first sentence above with: *You will see a sequence of numbers and objects.*

11C) See sensory modifications below.

Auditory and Visual presentations:
Instructions: *You will see different objects on the screen and, at the same time, hear different numbers. Pay attention, at the end of the sequence I will ask you about whether you* ***saw*** *the cheese* ***and/or heard*** *the number 5. The items will be presented separately. Here is what you are searching for* (target stimuli are separately presented including an image of a cheese, and the auditory word 'five').
Following presentation sequence ask:
A) Did you hear the number 5?
B) Was the cheese presented?

For individuals with severe hearing impairment:
Instructions: *You will see different objects on the screen. At the same time, you may feel me lightly tap your right or left shoulder. Pay attention, at the end of the sequence I will ask you about whether you* ***saw*** *the cheese* ***and/or felt*** *me tap your LEFT shoulder. The stimuli will be presented separately. Here is what you are searching for…* (target image is presented, in addition to separately demonstrating a light tap on the participants left shoulder). Ask permission before touching participant.

Tap the participant's RIGHT shoulder in conjunction with each visual presentation. Only when **[*A]** is indicated on the screening form tap the participants LEFT shoulder.

Following presentation sequences ask:
A) Did you feel me tap your left shoulder?
B) Was the cheese presented?

For individuals with severe visual impairment:
Instructions: *You will hear different numbers. At the same time, you may feel me lightly tap your right or left shoulder. Pay attention, at the end of the sequence I will ask you about whether you* ***heard*** *the number 5* ***and/or felt*** *me tap your LEFT shoulder. The stimuli will be presented separately. Here is what you are searching for…* (auditory word 'five' is presented, in addition to separately demonstrating a light tap on the participants left shoulder). Ask permission before touching participant.

Tap the participant's RIGHT shoulder in conjunction with each visual presentation. Only when *v is indicated on the screening form tap the participants LEFT shoulder.

Following presentation sequence ask:
A) Did you feel me tap your left shoulder?
B) Did you hear the number 5?

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12) Cognitive Motor Learning / Abstract Problem Solving

12A) Practice Instructions: *I will present a circle or a triangle in the center of the screen. After I have shown you the shape, I will ask you if it is the same as the one shown* ***two*** *turns back. First, we will practice. Do not respond to the first two presentations*. Allow approximately 3 seconds between presentations of image 1-2, and 2-3. An 'X' prompt will be given on the screen to indicate moving to the next stimuli.

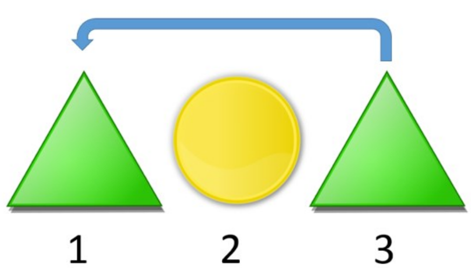
Allow approximately 3 seconds after presentation of the third image before asking:
Is the shape the same as the one given two turns back?

If participant **responds correctly** (yes) state "*yes that is the same shape as the one given two turns back. The third shape is the same as the first, which was two turns ago"* visually point to the diagram (below) to draw attention how presentation 1 and 3 are the same (below).

For individuals with visual difficulties only, verbally state "*yes, that is the same as the shape given two turns back. The first shape was a triangle, the second was a circle, and the third is another triangle. The third shape is the same as the first, which was two turns ago."*

If participant **responds incorrectly** (no) state "*no, that is the same shape as the one given two turns back. The third shape is the same as the first, which was two shown two turns ago"*. Visually point to the diagram to draw attention how presentation 1 and 3 are the same (below).

For individuals with visual difficulties only, verbally state "*no, that is the same shape as the one given two turns back. The first shape was a triangle, the second was a circle, and the third is another triangle. The third shape is the same as the first, which was two turns ago"*



Experiment Instructions: *Ready to continue? Now we will start again, and after the first two presentations, I will ask you if the shape presented is the same as the one shown **two** turns back. Do not respond to the first two presentations.* Allow approximately 3 seconds between image presentations. An 'X' prompt will be given on the screen to indicate moving to the next stimuli.

Allow approximately 3 seconds after presentation of the third image before asking:
Is the shape the same as the one given two turns back?

Continue to ask this question following presentation of each subsequent stimuli.

12B) Instructions: *Which of the following three options best describes how **GLOVES & SCARVES*** are alike, *1) They are made of leather, 2) They are winter clothing, 3) They are both worn near the head*

Answer options should be displayed visually for reference while the binary questions (below) are given.

Is the best answer "They are made of leather?"
Is the best answer "They are winter clothing?" (Correct)
Is the best answer "They are worn near the head?"

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13) Motivation for BCI use:

13A) Instructions: *I want you to indicate your level of motivation to use a brain-computer interfaces for communication using a scale of 1 to 4, with 1 being unmotivated to, 4 highly motivated.*

1	2	3	4
Unmotivated	Mildly Motivated	Moderately Motivated	Highly Motivated

13B) Instructions: *I want you to indicate how helpful you think brain-computer interfaces will be for communication in your daily life, on a scale of 1 to 4 with 1 unhelpful to 4, very helpful:*

1	2	3	4
Unhelpful	Mildly Helpful	Moderately Helpful	Extremely Helpful

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14) **Instructions:** *I want you to indicate on a scale of 1 to 4, your comfort level with using computers, with 1 being computers are very difficult to use to 4, very easy to use:*

1	2	3	4
Very Difficult to Use	Quite Difficult to Use	Quite Easy to Use	Very Easy to Use

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15) **Motor functionality:** In relation to use of the brain-computer interface and conventional AAC techniques, a physical motor screening including upper and lower limbs, face, tongue, horizontal/vertical eye movement, presence of uncontrolled, or impulsive movements, spasticity/muscle tension, and posture should be completed, including:

15A) Oculomotor movement; speed, effort, stability and reliability (reproducibility of task).

- Vertical and lateral range of motion.
- Visual pursuit (following an object/finger).
- Decreased stability (e.g., due to Nystagmus).

15B) Face and tongue movement; range of motion, effort, stability reliability (reproducibility of task).

- Eyelid ptosis.
- Ability to blink (once, and on multiple consecutive occasions), and/or excessive blinking
- Other facial movements (smile, tongue movement, etc.)
- Presence of uncontrolled or impulsive movements.

15C) Upper limb, lower limb and trunk; range of motion, effort, stability (e.g. tremor), reliability (reproducibility of task).

- Bilateral leg and foot motor movements.
- Presence of uncontrolled or impulsive movements.
- Bilateral hand and arm motor movements.
- Levels of muscle tension and spasticity in neck and shoulders.

15D) Posture/ positioning for device access

- Postural adjustments, and environmental adaptations possibly needed for device use, including providing a stable base of support, limiting the influence of atypical muscle tone, extraneous movements, and reflexes, in addition to providing support for rest.
- Does posture need frequently changing?
- If applicable, does the participants head support apply pressure to the back of the head? This positioning may possibly impede recordings from Occipital electroencephalography electrode locations.

<u>Scoring</u>

See participant protocol form for scoring guidelines. No practice items are included in scoring.

Self-Report
Concern may be based upon, but is not limited to; participant observations, unclear responses given for self-report tasks, caregiver input, etc.

General Considerations & Medications
If the information has not been provided by the caregiver (see caregiver questionnaire), a list of primary medications including sedative, antidepressant, anticholinergic, antiepileptic and psychiatric or pain medications should be noted. General considerations are provided to assist in clinical interpretation of scores. For instance, if screener scores are marginal but the participant is extremely motivated to use BCI as a communication modality, further BCI-AAC evaluation may still be warranted.