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What would brain-computer interface users want? Opinions and priorities of potential users with amyotrophic lateral sclerosis

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Abstract

Objective—Universal design principles advocate inclusion of end users in every design stage, including research and development. Brain-computer interfaces (BCIs) have long been described as potential tools to enable people with amyotrophic lateral sclerosis (ALS) to operate technology without moving. Therefore the objective of the current study is to determine the opinions and priorities of people with ALS regarding BCI design. This information will guide BCIs in development to meet end user needs.

Methods—Telephone survey of 61 people with ALS from the University of Michigan's Motor Neuron Disease Clinic.

Results—Regarding BCI design, participants prioritized accuracy of command identification of at least 90% (satisfying 84% of respondents), speed of operation comparable to at least 15-19 letters-per-minute (satisfying 72%), and accidental exits from a standby mode not more than once every 2-4 hours (satisfying 84%). While 84% of respondents would accept using an electrode cap, 72% were willing to undergo outpatient surgery and 41% to undergo surgery with a short hospital stay in order to obtain a BCI.

Conclusions—People with ALS expressed a strong interest in obtaining BCIs, but current BCIs do not yet provide desired BCI performance.

Keywords

Brain-computer interface (BCI); Performance criteria; standards

1. Introduction

Individuals with amyotrophic lateral sclerosis (ALS) experience progressive loss of motor function with devastating consequences. Loss of speech and motor functions in late-stage ALS can render individuals powerless, force abdication of decisional control, and contribute to caregiver anxiety and frustration (1). Assistive technologies (AT) can ameliorate the effects of declining motor function. However, matching control interfaces to declining motor

function is a continuous challenge as commercial interfaces, including switch and eye-gaze operated technologies (2), can become inaccessible as ALS progresses.

Brain-computer interfaces (BCIs) utilize information directly from the brain, offering an AT interface that bypasses the need for movement. BCIs have enabled individuals to spell messages (3-5), operate an on-screen mouse (6-8), and control environmental features (9,10). However, most BCIs are used in laboratories, with few utilized for everyday needs (11).

Like all AT, BCIs are designed to improve function, enable participation and enhance independence (12). Improved function alone, however, does not ensure that the intended population will use an AT (13-15). The lack of clinical BCIs prevents specific study of BCI user satisfaction, however abandonment of other AT devices can be as high as 75% (12), which is costly both in dollars and outcome achievement. Abandonment can occur when users choose to forego function instead of deal with unsatisfactory technological solutions (16). Lack of user involvement has been identified as a significant factor in AT abandonment (15). Universal design principles strongly advocate for involvement of target users throughout the technological design process, including research and development (17). This principle has been incorporated into research for people with spinal cord injury (18), but has not yet been used for BCI research.

Therefore, this study investigates characteristics of people with ALS and their opinions about BCIs. As BCIs progress towards independent in-home use, this information will be critical in designing BCIs for everyday use by individuals with ALS.

2. Methods

A telephone survey of people with ALS, approved by our institutional review board, was conducted to determine characteristics of potential BCI users and their BCI design opinions. All people with ALS followed by the University of Michigan's Motor Neuron Disease Clinic between March 2008 and July 2009 were eligible.

The author-designed survey instrument consisted of BCI design topics and the following characteristics of potential BCI users: 1) demographics; 2) home computer use; 3) current AT use (reported in (19)), 4) caregivers and dwelling; and 5) functional impairments. Functional impairments were measured with the ALS functional rating scale-revised (ALSFRRS-R), validated for telephone administration (20).

Preferences and perceived cost/benefit on design topics important to acceptance of BCIs were explored through user opinions of the physical interface with the BCI, setup and training time, desired BCI performance, and user priorities for BCI tasks and design. Importance, interest, and expertise were evaluated on 10-point scales where 1 was always lowest, for example, "1=Not At All Important" and "10=Extremely Important." Other questions used multiple choice. For BCI design questions, respondents were instructed to assume that all BCI design issues previously discussed matched their preferred answers.

Descriptive statistics were used to analyze survey results. Frequencies and percentages or medians and first (Q_1) and third (Q_3) quartiles were calculated as appropriate. Because participants could skip items, percentages are the percentage of respondents answering each question. Mode of response (verbal, caregiver relayed verbal, or caregiver relayed non-verbal) was considered as a surrogate for current BCI need and analyzed as a predictor of response to BCI design questions using Fisher's Exact test, ANOVA, or Non-parametric Kruskal-Wallis tests as appropriate for the level of measurement of the BCI design response. A respondent reporting both verbal and non-verbal relay was included in the verbal relay

group. Ratings of interest in different BCI tasks were grouped for analysis into three levels (low=1-5, medium=6-8, and high=9-10. Bhapkar tests were performed between pairs of variables to evaluate the significance of the distribution of respondent interest. Statistical analyses were done with SASⁱ.

3. Results

Of 96 eligible subjects, 31 (32%) were lost to follow-up and 2 (2%) excluded because a caregiver answered for them. The remaining 63 (66%) responded, with 61 (64%) answering BCI questions. Caregivers relayed answers for 30 (48%) respondents with 23 (77%) of these relaying verbal responses, 6 (20%) relaying non-verbal responses, and 1 (3%) relaying both verbal and non-verbal responses.

3.1. Characteristics of Potential BCI Users

Respondents demographics are reported in detail elsewhere (19) and in brief in Table 1. Impaired hearing, vision, and oculomotor function are reported in Table 1. Altogether, 92% reported some type of impairment. Home-computer use was common (Table 2). Respondents generally lived in single-family dwellings and had 1 or 2 caregivers, primarily family (Table 1).

3.2. Design Topics Involved in BCI Acceptance

3.2.1 Physical interface—Respondents (n=56) expressed interest both in commercial BCIs and BCI research participation with median values of 8 (Q₁=5, Q₃=10) and 7 (Q₁=5, Q₃=9) respectively. Acceptance of different electrode types for measuring brain activity was assessed through yes/no answers to the question: “Assuming that a BCI would let you independently operate any one device that you choose, which of the following ways of measuring brainwaves for a BCI would you be willing to select?” Fifty-one respondents (84%) would accept an electrode cap with an equivalent number, 50 (82%) accepting a dry electrodes cap. Interestingly, 44 (72%) would accept surgically implanted electrodes with outpatient surgery and 25 (41%) with a short hospital stay. Interest levels for an electrode cap and implanted electrodes were assessed separately (n=58) with median interest of 6 (Q₁=4, Q₃=8) for both.

3.2.2 Setup and training—Respondents were asked the maximum acceptable BCI setup time to obtain independent BCI use for 6-8 hours. The median response of 21-30 (Q₁=10-20, Q₃=46-60) minutes would satisfy almost three-quarters of respondents (n=40 or 74%, counting those willing to accept longer setup times). See Figure 1 for acceptable setup and training time investments.

3.2.4 Acceptable performance—BCI performance was assessed using three measures: “the minimum percentage of the time it [the BCI] would have to recognize your commands correctly for you to think that its performance was useful;” “the minimum letters-per-minute that the BCI could provide and you would still think that it was useful,” and “the most often that the BCI could accidentally leave standby mode and you would still think that its performance was useful.” Respondents were given wide ranges of options for accuracy and standby performance (Figure 2). For reference, subjects were told that current BCIs used for typing one letter at a time type at about 5 letters-per-minute. The option of selecting words or sentences instead of letters was also mentioned. Current performance was not described for accuracy or standby performance.

ⁱRelease 9.2 for Windows, SAS Institute, Inc., Cary, NC, USA.

3.2.5 Task and Feature Priorities—As reported in (19), the general areas of “communicate” and “use the bathroom” independently were rated highest with median scores of 10. Users rated “interest in learning to use BCI in order to perform the following tasks [Figure 3] independently without a caregiver.” All BCI tasks received median scores of 10 with distributions as shown in Figure 3. Distributions had $p < 0.05$ for 4 of the 45 pairs of variables. Overall, interest in motor wheelchair operation trended toward significantly more interest with p-values in the range 0.016-0.1026 when compared to 8 of the other tasks. Control of a robot arm for feeding also trended toward significance with p-values in the range 0.0006-0.1502 when compared to 6 of the other tasks. Only variable pairs including these tasks had significance values in this range.

Figure 4 shows importance of BCI design features. “Accuracy of BCI operation” had the highest median value of 10 ($Q_1=8$, $Q_3=10$) followed by “simplicity of BCI setup” with a median of 9.5 ($Q_1=6$, $Q_3=10$). “Functions the BCI provides” and “reliability of BCI standby mode” were also rated highly with medians of 9 ($Q_1=8$, $Q_3=10$). Appearance was least important.

3.3. Relationship of impairment and responses

Participants’ survey response mode (verbal, verbal-relay, and non-verbal relay) was significantly related to some BCI design preferences. The importance of appearance during BCI use was significantly related to response mode ($p < 0.001$) with people who used caregiver-relay reporting appearance as less important. Desired BCI performance was not significantly related to response mode. However, the reported importance of every BCI feature was significantly related to response mode ($p < 0.05$) with the verbal response group rating importance higher than the verbal-relay group; and the verbal-relay group rating importance higher than the non-verbal relay group.

4. Discussion

These preferences and characteristics of individuals with ALS as potential BCIs users can inform BCI development during the crucial transition from laboratory to in-home BCI use. Giving voice to participants’ preferences minimizes the chances that a well-intentioned product will fail to meet intended users’ needs (21). Operating a motorized wheelchair and a robot arm were tasks of particularly widespread interest, but the high interest expressed in all BCI-operated tasks emphasizes the importance of BCI compatibility with existing AT to enable users to select personal top priority tasks.

4.1. Functional characteristics and BCI design

Most BCIs rely on the user’s ability to perceive and process visual information (22). Over 25% of respondents, however, reported difficulties controlling blinking and 13% reported difficulties controlling eye gaze. These results encourage the development of auditory, tactile, and multimodal methods of BCIs interaction to ensure that the majority of individuals with ALS can access BCIs.

4.2. User preferences and BCI design

User opinions on six BCI design features are presented in juxtaposition with the performance standards of typical existing BCIs in Table 3, illustrating that, while current BCIs are approaching the performance desired by potential users with ALS, the minimal criteria have not yet been met. Interestingly, respondents indicated equal interest in invasive and non-invasive electrodes, but their willingness to accept implanted electrodes was dramatically reduced when the implant surgery involved a hospital stay (41% compared to 72% who would accept an outpatient procedure). Thus, an electrode implantation approach

such as subdermal EEG electrodes (23) or epidural screw electrodes (24) that enabled placement of BCI electrodes with an outpatient surgery could be well accepted.

4.3. Limitations

While this is the first study on BCI design preferences of potential BCI users, several limitations must be considered when interpreting results. First, the task list grouped communication under computer use, a grouping that may not have been apparent to respondents. Second, priorities may have been clearer if respondents had been asked to rank tasks and BCI features. Third, references to setup time did not mention other daily maintenance requirements; therefore setup time was likely interpreted as the total daily time investment respondents felt willing to tolerate. Fourth, BCI rarity means that answers are probably not based on experience, but instead on performance imagined to be acceptable. Results should therefore be interpreted as initial goals that potential users perceive necessary to try a BCI; but this performance may actually be unacceptable in daily use. Fifth, cognitive function was not measured, and it is important to note that cognitive dysfunction can be an issue for many people with ALS (25) and may therefore affect BCI preferences. Finally, respondents were from a single clinic in the United States, therefore results may not generalize to people with ALS in other clinics or countries because of known variability in attitudes toward mechanical ventilation (26) and associated assumptions about future functional need.

5. Conclusions

People with ALS have a great interest in BCIs for many tasks. Accuracy, setup simplicity, standby mode reliability, and available functions are considered important design features.

Like all AT users, people with advanced ALS can decide whether the effort of a specific technological solution is worth the functional gain. The significantly lower ratings of feature importance for those in the response relay groups may indicate a willingness to accept less performance as impairment increases, but desired performance levels did not vary by response group. Survey respondents reported desired BCI performance as providing at least 90% accuracy, accidental standby mode exits only once every 2-4 hours, and speed of at least 15-19 letters-per-minute. The common co-incident occurrence of visual and auditory impairments and the prevalence of impaired gaze control should be considered during BCI design.

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References

1. Happ MB. Interpretation of nonvocal behavior and the meaning of voicelessness in critical care. *Social Science & Medicine*. 2000; 50:1247–1255. [PubMed: 10728845]
2. Ball L, Nordness A, Fager S, Kersch K, Mohr B, Pattee G. Eye-Gaze Access to AAC Technology for People with Amyotrophic Lateral Sclerosis. *Journal of medical speech-language pathology*. 2010; 18:11–23.

3. Kennedy PR, Bakay RA, Moore MM, Adams K, Goldwithe J. Direct control of a computer from the human central nervous system. *IEEE Trans.Rehabil.Eng.* 2000; 8:198–202. [PubMed: 10896186]
4. Nijboer F, Sellers EW, Mellinger J, Jordan MA, Matuz T, Furdea A, et al. A P300-based brain–computer interface for people with amyotrophic lateral sclerosis. *Clinical Neurophysiology.* 2008; 119:1909–1916. [PubMed: 18571984]
5. Kubler A, Furdea A, Halder S, Hammer EM, Nijboer F, Kotchoubey B. A brain-computer interface controlled auditory event-related potential (p300) spelling system for locked-in patients. *Ann.N.Y.Acad.Sci.* 2009; 1157:90–100. [PubMed: 19351359]
6. Wolpaw JR, McFarland DJ, Neat GW, Forneris CA. An EEG-based brain-computer interface for cursor control. *Electroencephalogr.Clin.Neurophysiol.* 1991; 78:252–259. [PubMed: 1707798]
7. Kim SP, Simeral JD, Hochberg LR, Donoghue JP, Black MJ. Neural control of computer cursor velocity by decoding motor cortical spiking activity in humans with tetraplegia. *J.Neural Eng.* 2008; 5:455–476. [PubMed: 19015583]
8. Schalk G, Kubanek J, Miller KJ, Anderson NR, Leuthardt EC, Ojemann JG, et al. Decoding two-dimensional movement trajectories using electrocorticographic signals in humans. *J.Neural Eng.* 2007; 4:264–275. [PubMed: 17873429]
9. Cincotti F, Mattia D, Aloise F, Bufalari S, Schalk G, Oriolo G, et al. Non-invasive brain–computer interface system: Towards its application as assistive technology. *Brain Research Bulletin.* 2008; 75:796–803. [PubMed: 18394526]
10. Xiaorong G, Dingfeng X, Ming C, Shangkai G. A BCI-based environmental controller for the motion-disabled. *IEEE Transactions on Neural Systems and Rehabilitation Engineering.* 2003; 11:137–140. [PubMed: 12899256]
11. Sellers EW, Vaughan TM, Wolpaw JR. A brain-computer interface for long-term independent home use. *Amyotroph Lateral Scler.* 2010; 11:449–455. [PubMed: 20583947]
12. Scherer MJ. Outcomes of assistive technology use on quality of life. *Disability and rehabilitation.* 1996; 18:439–448. [PubMed: 8877302]
13. Scherer MJ, McKee B. High-tech communication devices: what separates users from non-users? *Augmentative & Alternative Communication.* 1990; 6:99.
14. Scherer, MJ. *Living in the State of Stuck: How technology impacts the lives of people with disabilities.* Brookline Books; Cambridge, MA: 1993.
15. Phillips B, Zhao H. Predictors of assistive technology abandonment. *Assistive Technology.* 1993; 5:36–45. [PubMed: 10171664]
16. Neumann N, Kubler A. Training locked-in patients: a challenge for the use of brain-computer interfaces. *IEEE Trans.Neural Syst.Rehabil.Eng.* 2003; 11:169–172. [PubMed: 12899265]
17. Preiser, WFE.; Ostroff, E. *Universal Design Handbook.* 2nd ed. McGraw-Hill; New York: 2010.
18. Anderson KD. Targeting recovery: priorities of the spinal cord-injured population. *J.Neurotrauma.* 2004; 21:1371–1383. [PubMed: 15672628]
19. Gruis KL, Wren PA, Huggins JE. *ALS Patients' Self-Reported Satisfaction with Assistive Technology.* Muscle and Nerve. 2010 in press.
20. Kaufmann P, Levy G, Montes J, Buchsbaum R, Barsdorf AI, Battista V, et al. Excellent inter-rater, intra-rater, and telephone-administered reliability of the ALSFRS-R in a multicenter clinical trial. *Amyotroph Lateral Scler.* 2007; 8:42–46. [PubMed: 17364435]
21. Peterson W. Role of persons with a disability in the design process. *Topics in Stroke Rehabilitation.* 2008; 15:87–96. [PubMed: 18430672]
22. Schreuder M, Blankertz B, Tangermann M. A new auditory multi-class brain-computer interface paradigm: Spatial hearing as an information cue. *PloS one.* 2010; 5:e9813. [PubMed: 20368976]
23. Ives JR. New chronic EEG electrode for critical/intensive care unit monitoring. *J.Clin.Neurophysiol.* 2005; 22:119–123. [PubMed: 15805811]
24. Drury I, Schuh L, Ross D, Pennell P, Varma N, Henry T. Ictal patterns in temporal lobe epilepsy recorded by epidural screw electrodes. *Electroencephalogr.Clin.Neurophysiol.* 1997; 102:167–174. [PubMed: 9129571]

25. Phukan J, Pender NP, Hardiman O. Cognitive impairment in amyotrophic lateral sclerosis. *Lancet Neurol.* 2007; 6:994–1003. [PubMed: 17945153]
26. Smyth A, Riedl M, Kimura R, Olick R, Siegler M. End of life decisions in amyotrophic lateral sclerosis: a cross-cultural perspective. *J.Neurol.Sci.* 1997; 152(Suppl 1):S93–6. [PubMed: 9419063]
27. Guger C, Daban S, Sellers E, Holzner C, Krausz G, Carabona R, et al. How many people are able to control a P300-based brain-computer interface (BCI)? *Neurosci.Lett.* 2009; 462:94–98. [PubMed: 19545601]
28. Farwell LA, Donchin E. Talking off the top of your head: toward a mental prosthesis utilizing event-related brain potentials. *Electroencephalogr.Clin.Neurophysiol.* 1988; 70:510–523. [PubMed: 2461285]
29. Sellers EW, Donchin E. A P300-based brain-computer interface: Initial tests by ALS patients. *Clinical Neurophysiology.* 2006; 117:538–548. [PubMed: 16461003]
30. Piccione F, Giorgi F, Tonin P, Priftis K, Giove S, Silvoni S, et al. P300-based brain computer interface: reliability and performance in healthy and paralysed participants. *Clin.Neurophysiol.* 2006; 117:531–537. [PubMed: 16458069]
31. Furdea A, Halder S, Krusienski DJ, Bross D, Nijboer F, Birbaumer N, et al. An auditory oddball (P300) spelling system for brain-computer interfaces. *Psychophysiology.* 2009; 46:617–625. [PubMed: 19170946]
32. Townsend G, LaPallo BK, Boulay CB, Krusienski DJ, Frye GE, Hauser CK, et al. A novel P300-based brain-computer interface stimulus presentation paradigm: moving beyond rows and columns. *Clin.Neurophysiol.* 2010; 121:1109–1120. [PubMed: 20347387]
33. Donchin E, Spencer KM, Wijesinghe R. The mental prosthesis: assessing the speed of a P300-based brain-computer interface. *IEEE Trans.Rehabil.Eng.* 2000; 8:174–179. [PubMed: 10896179]
34. McFarland DJ, Sarnacki WA, Vaughan TM, Wolpaw JR. Brain-computer interface (BCI) operation: signal and noise during early training sessions. *Clin.Neurophysiol.* 2005; 116:56–62. [PubMed: 15589184]
35. McFarland DJ, Krusienski DJ, Sarnacki WA, Wolpaw JR. Emulation of computer mouse control with a noninvasive brain-computer interface. *J.Neural Eng.* 2008; 5:101–110. [PubMed: 18367779]
36. Blankertz B, Losch F, Krauledat M, Dornhege G, Curio G, Muller KR. The Berlin Brain--Computer Interface: accurate performance from first-session in BCI-naive subjects. *IEEE Trans.Biomed.Eng.* 2008; 55:2452–2462. [PubMed: 18838371]

Figure 1.

Maximum time investments acceptable to respondents. First column shows numbers of responses with * indicating median response. Second column shows percentage of respondents who would be satisfied with each answer.

Figure 2.
BCI performance answers.

Figure 3.

Interest rating for BCI-operated tasks. Graphs were generated using the SAS boxplot procedure. The box extends from Q₁ to Q₃ with the vertical line indicating median. The narrowing around the median measures the significance of differences between medians. The diamond indicates the mean and the whiskers indicate the range of answers. Outliers, when present, are indicated by circles.

Figure 4.

A) Importance of different BCI design features (n=56). B) Importance ratings from verbal response group (n=31); C) from verbal-relay group (n=19); and D) from non-verbal relay group (n=6). * indicates one less response.

Table 1
Characteristics of Respondents as Potential BCI Users

Male	60%			
Median Age (years)	62 (Q ₁ =52, Q ₃ =72)			
Median time since symptom onset (months)	50 (Q ₁ =31, 74)			
Median time since diagnosis (months)	26 (Q ₁ =17, Q ₃ =50)			
Median ALSFRS-R (months)	25 (Q ₁ =18, Q ₃ =33)			

Hearing, Vision, or Eye Movement Impairments				
Impairment	Yes	Cumulative		
Hearing Impairment	26 (42%)	27 (44%)		
Hearing Aides	12 (19%)			
Reading glasses	50 (81%)	52 (84%)	56 (90%)	
Glasses for TV	35 (56%)			

	No Difficulty	Some Difficulty	No Control	Cumulative
Blinking Difficulty	45 (74%)	12 (20%)	4 (7%)	16 (26%)
Eye Gaze Difficulty	53 (87%)	4 (7%)	4 (7%)	

Caregivers and living situation		
Caregivers per week	0	11 (17%)
	1	24 (38%)
	2	17 (27%)
	3 or more	11 (17%)
Caregiver Relationship	Family members	48 (92%)
	Friends	19 (37%)
	Employees	20 (38%)
	respite caregivers	5 (10%)
Living situation	Single family home	40 (63%)
	Apartment	14 (22%)
	facility that provides assistance	5 (8%)
	multi-family or group home	3 (5%)

Table 2**Computer Use Characteristics**

Computer Use (n=63)	Current	40 (63%)
	Past	10 (16%)
Frequency of computer use (n=40)	Daily	19 (48%)
	Multiple per week	15 (38%)
	once a week or less	5 (13%)
	never	1 (3%)
Computer expertise (n=61)	median 6 of 10 (Q1=3, Q3=8)	
Home internet available (n=56)	cable modem	13 (23%)
	DSL	22 (39%)
	Dial-up	5 (9%)
	Unknown type	9 (16%)
	None	3 (5%)
	No answer	7

Computer Devices Used	Yes, without difficulty	Yes, with difficulty	No	No answer
Desktop Computer	15 (38%)	24 (60%)	1 (3%)	
Laptop Computer	9 (24%)	14 (36%)	16 (41%)	1
Keyboard	13 (33%)	26 (65%)	1 (3%)	
Computer mouse	12 (30%)	21 (53%)	7 (18%)	
Joystick	7 (18%)	7 (18%)	24 (63%)	2
Voice-activated computer access	2 (6%)	1 (3%)	31 (91%)	6

Table 3

BCI features: User preferences and current BCI characteristics. Percentages of respondents are cumulative numbers who would be satisfied by this performance.

Feature	Desired BCI performance	Current BCI performance
Accuracy	90% (satisfy 84% of respondents)	About 90% (27,28) for controls, lower for people with ALS (e.g. (4,29,30)).
Speed	15-19 letters-per-minute (satisfy 72% of respondents)	About 5 letters-per-minute (31-33)
No control	1 unintentional standby mode exit in 2-4 hours (satisfy 84% of respondents)	Largely unreported Calculations ¹ show a 23% chance of an accidental standby mode exit more than once in 4 hours. Experimental testing showed 4 unintentional standby mode exits in 6 hours (unpublished data)
Training	2-5 sessions (satisfy 95% of respondents)	P300 BCIs need a single session; Sensorimotor BCIs usually need 10+ sessions (34,35); one group reports only one session (e.g. (36)).
Electrode types	Equal interest in invasive and non-invasive electrodes	Invasive and non-invasive electrodes
Setup times	21-30 minutes (satisfy 74% of respondents)	Not generally reported, dependent on number and type of electrodes. About 30 minutes in our lab.

¹ using probability formulas in (33), 36 choices, 5 letters-per-minute, and 2 sequential commands to exit.