Preliminary Evidence for using
Heart Rate Variability as a Measure of Cognitive Effort

Abstract

Researchers have suggested that language deficits in individuals with aphasia may result from an inability to adequately allocate effort to verbal tasks (e.g. Clark & Robin, 1995). Heart rate variability has been used as a physiological measure of cognitive effort (e.g. Aasman et al., 1987). The purpose of this study is to establish baseline data and verify the utility of HRV as an indicator of cognitive effort on tasks used with IWA. Relationships among neurologically intact participants' accuracy on verbal and spatial *n*-back tasks, the physiological measure of effort (HRV), and perceptions of task difficulty will be reported.

Introduction

Researchers have suggested that language deficits in individuals with aphasia (IWA) may be the result of an inability to adequately allocate effort or cognitive resources to verbal tasks (e.g. Murray et al., 1997; Clark & Robin, 1995). If individuals with aphasia are not able to properly adjust the effort they invest to tasks that vary in their cognitive demands, this could influence current theories of aphasia.

In a previous study, Christensen et al. (2011) investigated effort allocated by IWA to a verbal working memory tasks using a physiological measure- Heart Rate Variability (HRV) measured via an electrocardiogram. HRV is the amount of fluctuation around the mean heart rate. It has been shown to reflect the mental workload required during cognitive tasks (Hansen et al., 2003) and has been used as a physiological measure of effort (Aasman et al., 1987). Five IWA completed three *n*-back working memory tasks – 0-back, 1-back, and 2-back. The stimuli in the n-backs included pictures of common fruit. The n-back task required participants to decide whether each fruit, presented one at a time on a computer screen, matched the one that appeared *n* items ago; thus requiring temporary storage and manipulation of information while continuously updating the contents in working memory (Jonides, et al., 1997). Accuracy on the *n*-back tasks was compared to participants' ratings of task difficulty and to the physiological measure of effort (change in HRV from baseline to task performance). The IWA accurately rated task difficulty based on their behavioral performance on the *n*-back task (i.e. as performance declined, perceived difficulty increased). In addition, participants' HRV decreased from baseline to task conditions as expected. However, according to the HRV data, the IWA did not differentially allocate effort according to the task demands (i.e., 1-back v. 2-back). These results seem to provide support for the literature suggesting language deficits in IWA may be related to an impaired ability to properly allocate cognitive resources to verbal tasks (e.g. McNeil et al., 1991). According to the HRV data, although behavioral performance declined with increased task difficulty, participants did not allocate additional effort to the more difficult task (i.e. 2-back). In contrast, their ratings of task difficulty were consistent with their behavioral performance (accuracy on the *n*-back tasks) indicating that participants were able to perceive the difficulty of the tasks, but were not able to adjust their allocation of effort to meet the task demands.

There were several limitations to this study that need to be considered to better understand the findings and determine the utility of HRV as a physiological measure of cognitive effort in IWA. First, a control group was not included. It is possible that the HRV measure is sensitive to differences between rest (baseline) and task conditions but is not sensitive to differences between tasks of differing difficulty levels (i.e., 1-back v. 2-back). Second, only verbal stimuli were used (pictures of common fruit). Therefore, conclusions about whether any decreased ability to allocate effort is specific to verbal processes known to be impaired in IWA, or a domain-general cognitive deficit could not be determined. The purposes of the current study were to address these limitations by (1) enrolling neurologically intact participants and (2) including both verbal and non-verbal stimuli. By comparing neurologically intact participants' behavioral performance with their perceptions of task difficulty and with the physiological measure – HRV, the current study will establish baseline data and verify the utility of the measure of HRV as an indicator of cognitive effort on tasks used to assess working memory in IWA. This data is needed in order to establish the sensitivity and utility of HRV as an indicator of physiological effort for IWA.

Method

Participants

Currently 18 neurologically intact participants have been tested. Participants ranged in age from 36 to 85 (Mean = 67.11, SD = 11.34). All participants passed a vision and hearing screening prior to the experimental tasks, and reported a negative history of TBI, stroke, or other neurological conditions. Data collection for IWA is in progress but will not be reported in this study.

Tasks

All participants completed a serial reaction time task prior to the experimental tasks that included the verbal and spatial stimuli. The experimental tasks included three verbal and three spatial *n*-back tasks that varied in processing load: 1-back, 2-back, and 3-back. The verbal stimuli consisted of eight letters presented visually that varied in case. The spatial stimuli included black circles presented on a white background in 8 different locations spaced in an octagon fashion around a central fixation point. One location appeared on the screen at a time.

Prior to each *n*-back, participants viewed task instructions and sample stimuli on Microsoft PowerPoint. All participants received the same number of practice trials and all participants verbalized and demonstrated understanding of the practice items. In the experimental task presented via E-Prime 2.0, each *n*-back again contained a practice block of 10 items with two targets. The test conditions included 33 targets presented in a single block containing 100 stimuli.

Task difficulty order and presentation order for stimuli type was counterbalanced within the difficulty levels. For example, a participant may receive the 2-back first, but would complete both verbal and spatial stimuli for the 2-backs together before moving on to a difficulty different level (i.e., 1-back or 3-back). Each n-back was preceded and followed by a five minute baseline rest period during which baseline HRV data were recorded.

Procedures

Participants were instructed to avoid smoking, caffeine, alcohol, and strenuous exercising on the day of testing because it could affect their baseline HRV. They completed a brief questionnaire describing any deviations from that request upon their arrival. Prior to testing, three surface electrodes were placed on their torso to record ECG activity during testing. ECG activity was recorded using BIOPAC Student Labs (BSL) PRO MP35 recording unit with

BSLPro software (500 samples/second, Filter .05 - .35 Hz). Participants sat in a comfortable, high back chair during recording.

During 5 minute post-task baseline conditions, participants were instructed to rest quietly with their eyes open. The difference between n-back task HRV and post-task HRV recording was the measure used as the dependent variable in the data analysis (HRV Change).

Results and Conclusions

The relationship between perceived task difficulty and performance accuracy was assessed using Spearman's rho correlation for ordinal data. As expected, a significant negative relationship between performance accuracy and perceived task difficulty was found ($\rho = -.67$, $p < .01$). As accuracy decreased, ratings of task difficulty increased demonstrating participants were able to accurately rate the difficulty of the working memory tasks.

A repeated measures ANOVA was conducted to assess performance of neurologically intact participants on the verbal and spatial *n*-back tasks. There was a significant working memory load main effect, F (2, 16) = 303.22, $p < .01$ with the 1-back being significantly easier than 2-back, and 2-back being significantly easier than 3-back. There was also a significant main effect for stimulus type, F (1, 17) = 9.95, $p < .01$, with verbal n-backs eliciting higher accuracy scores than spatial *n*-backs. However a significant interaction was also found, F (2, 16) = 4.11, $p<.05$. The difference between the verbal and spatial stimuli was only significant in the 1-back condition. Analysis of HRV data may shed additional light on this finding and are currently being extracted and processed. The comparison of verbal and spatial working memory in neurologically intact participants, combined with perceptions of task difficulty, and a physiological measure of cognitive effort (HRV) will provide the normative data which can be used to understand verbal and non-verbal working memory processes in IWA.

References

Aasman, J., Mulder, G., & Mulder, L. J. (1987). Operator effort and the measurement of heart rate variability. *Human Factors*, *29*, 161-170.

Christensen, S. C., Wright, H. H., & Spahr, A. (2011, May). Cognitive Effort and Aphasia. Poster presented at the Clinical Aphasiology Conference, Fort Lauderdale.

Clark, H. M. & Robin, D. A. (1995). Sense of effort during a lexical decision task: resource allocation deficits following brain damage. *American Journal of Speech-Language Pathology, 4,* 143-147.

Hansen, A. L., Johnsen, B. H., Thayer, J. F. (2003). Vagal influence on attention and working memory. *International Journal of Psychophysiology*, *48,* 263-274.

Jonides, J., Lauber, E. J., Awh, E., Satoshi, M., & Koeppe, R. A. (1997). Verbal working memory load affects regional brain activation as measured by PET. *Journal of Cognitive Neuroscience, 9,* 462–475.

McNeil, M. R., Odell, K. & Tseng, C. H. (1991). Toward the integration of resource allocation into a general theory of aphasia. *Clinical Aphasiology, 20,* 21-39.

Murray, L.L., Holland, A.L., & Beeson, P.M. (1997). Accuracy monitoring and task demand evaluation in aphasia. *Aphasiology*, *11*, 401-414.