SAFETY RESEARCH

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IMPROVING ATTENTIVENESS

Effect of Cognitive Training on Sustained Attention Measures

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INVESTIGATING THE CAUSAL FACTORS of electric line worker incidents is of high priority due to the decades-long record of incidents in the electric power industry. According to Bureau of Labor Statistics (BLS, 2018), 152 electrical line installer fatalities occurred in the U.S. in 2011 through 2016. For the individual years, the fatality numbers were 26, 27, 27, 25, 26 and 21, respectively. These rates often account for the ranking of electric line installers among the most dangerous professions in the U.S. Major contributors to electric line work incidents include electrocutions, machines, tools and vehicles (BLS, 2018). Closer inspection of these contributors reveals that their antecedents consist of attentional, strategic or knowledge factors (Reason, 1997). The study presented in this article investigates the role of sustained attention as a primary contributor to electric line worker incidents.

Little research exists concerning the safety of electric power line installers and, to the authors' knowledge, no research is available regarding attentiveness as a causal factor of installer incidents. Specifically, the effect of sustained attention and vigilance (cognitive skills of immediate relevance to incident prevention for these workers) has not been examined. Past studies of cognitive-training regimens have evaluated both the effect on the trained task and transfer of training benefit to related but untrained cognitive tasks.

The overall goal of our current work is to evaluate the effect of cognitive training on the sustained-attention ability of electric power line installers, examining impact on incident frequency and job function. This goal is approached in two phases. Phase I, the research described here, analyzes the effect of cognitive training of electric line installers on their performance on a sustained-attention task. This work evaluated a population that is distinct from that of previous research on sustained attention, which involved mostly older participants with neurological impairment (Chan, 2001; Manly, Robertson, Galloway, et al., 1999; Robertson, Manly, Andrade, et al., 1997). If statistically significant results are found in Phase I, Phase II of the research will be designed to determine if cognitive training results in reduced incident rates in electric power line installers. Phase II would also provide data regarding treatment duration and effects on job function.

It is safe to say that the problematic rate of incidents in the electric power industry is not due solely to worker inattentiveness. Non-human factors, such as organizational climate and decisions made upstream of the work site, also affect incident frequency (Behm, 2005; Garrett & Teizer, 2009; Mitropoulos, Abdelhamid & Howell, 2005). However, the primary focus of the literature concerns human error as the most significant cause of incidents (Krokos & Baker, 2007; Schmid, 2011; Wiegmann & Shappell, 1999). Singer (1966) was perhaps the first researcher to associate human error to an individual's inability to attend to the present. Subsequent studies have established the link between inattention and incidents (Baysari, McIntosh & Wilson, 2008; Blackmon & Gramopadhye, 1995; Edkins & Pollock, 1997; Klauer, Dingus, Neale, et al., 2006; Marcotte, Lazzaretto, Scott, et al., 2006; Owsley, Ball, Sloane, et al., 1991).

Many studies have reported success in strengthening attention, memory and other cognitive functions using widely available cognitive training computer programs (Smith, Housen, Yaffe, et al., 2009; Zelinski, Spina, Yaffe, et al., 2011). Other researchers have found that cognitive functioning can be improved with proper attention training as part of standard workplace practice, thus reducing incident rates (Koval & Floyd, 1998). Research conducted on attention training in different areas of psychology has shown that it is possible to increase attention, as measured by various tests. For example, Wexler, Anderson, Fulbright, et al. (2000), found that brain and behavioral problems associated with verbal memory in some patients with schizophrenia could be improved with cognitive exercises. Performance improvements were associated with increased task-related activation of the same brain region that is activated during verbal-memory tasks in healthy individuals.

The cognitive training routines used in the current study consisted of memory and attention activities from the BrainHQ program

KEY TAKEAWAYS

- **Building on prior studies that identified inattentiveness as a causal factor of incidents, this article discusses research to determine whether attentiveness of electric power line installers could be increased through cognitive training exercises.**
- **The authors used the sustained attention to response task (SART) to assess the effect of training.**
- **Researchers observed a statistically significant beneficial effect of cognitive training on SART performance.**
- **The power workers' 4-year incident histories subsequent to the study indicated safer on-the-job performance by those who had received cognitive training than for the control group. However, sampling concerns indicate the need for additional research to better evaluate the relationship between cognitive training and on-the-job incident rates.**

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(Posit Science, 2019). The memory exercises pair auditory and visual learning with order-dependent tasks to improve working memory. The attention exercises are intended to improve visual processing speed, divided attention and attentiveness by requiring participants to track and identify multiple objects and distinguish between similar objects as quickly as possible. For example, attention exercises include Divided Attention and Target Tracker.

Divided Attention requires the brain to focus on and react to particular details such as matching colors or shapes, or filling patterns. At the same time, the user must dismiss competing information. The task repeatedly shows two shapes on a computer screen, asking the user to press the left arrow key when the two meet certain criteria. Target Tracker requires the user to track multiple objects in an environment that contains several other objects that interfere with attentiveness. The intent of the exercise is to strengthen the ability to divide attention among multiple objects.

Working memory and selective attention can interact (Downing, 2000; Lépine, Bernardin & Barrouillet, 2005). Therefore, memory exercises are also part of the Posit Science cognitive training program (Figure 1). Memory exercises include Memory Grid, an auditory task requiring matching of one-syllable stimuli from a larger stimulus set, and To-Do List Training in which the user must listen to a set of instructions, then verbally repeat them in the order given. To adaptively train working memory, the instructions get longer and more complex as user performance improves.

Several studies confirm with positive cognitive outcomes the effectiveness of video training programs (Green & Bavelier, 2003; Li, Polat, Makous, et al., 2009). Concerned with mitigating age-related cognitive decline, most work validating the Posit Science cognitive training routines has evaluated the effect for older adults (Ball, Berch, Helmers, et al., 2002; Berry, Zanto, Clapp, et al., 2010; Mahncke, Bronstone & Merzenich, 2006; Rebok, Ball, Guey, et al., 2014; Smith, et al., 2009). As would be expected, study participants often demonstrated improvement on trained tasks. Two additional results from this work with older adults, specifically generalization and retention of training benefit, are of relevance to the design of the current study. Any potential benefit from cognitive training of electric line workers assumes generalization of performance benefits to the workers' on-the-job tasks, along with retention of the effect past the training period. Smith, et al. (2009), found that performance improvements of older adults did generalize to untrained measures of memory and attention, with this effect accompanied by self-reported improvements in function on everyday tasks. Furthermore, retention of performance improvements has been observed 2 to 10 years subsequent to training, with the duration of the effect dependent on the specific cognitive training task (Ball, et al., 2002; Rebok, et al., 2014).

While demonstrating features important for the utility of cognitive training of electric line workers, effects obtained with older adults cannot be assumed for a younger population. With older adults, the extent to which training primarily mitigates the rate of age-related cognitive decline, versus enhancing cognitive status, is not clear. Therefore, the present work evaluates the effectiveness of the Posit Science training program on the attentiveness of electric power line installers with a median age of 39 years. Unlike past work with older adults, the current study focused on task performance rather than mitigation of age-related cognitive impairment. As such, this study is a necessary first step in determining whether cognitive training can lessen on-the-job incident rates.

To measure attentiveness, the authors used the sustained attention to response task (SART; Robertson, et al., 1997). SART evaluates attentiveness by measuring the extent to which a participant can withhold responding to a random, infrequent false stimulus while responding correctly to rhythmically presented target stimuli. In SART, a false response to a distractor stimulus (which is presented less often than the target stimuli) is interpreted as an indication of an attention lapse (Manly, et al., 1999; Robertson, et al., 1997). Reaction time (the amount of time it takes to respond to the stimulus) can be measured for both correct and incorrect responses. Results from both Manly, et al. (1999), and Robertson, et al. (1997), indicate an inverse relationship between response time and error rate, a result consistent with the trade-off between accuracy and speed of response typical of reaction-time experiments. Across studies, researchers report that SART is an unbiased test with high reliability and validity, suitable for use with various types of subject populations (Chan, 2001; Robertson, et al., 1997; Sarter, Givens & Bruno, 2001; Smallwood, Riby, Heim, et al., 2006; Smilek, Carriere & Cheyne, 2010).

Of special significance to electric power line installers is the work of Robertson, et al. (1997), on induced attention slips, which they associate with absentminded errors. These kinds of errors take place during the performance of tasks that are highly practiced, such as stringing electric wire. With deficits in sustained attention acerbated by traumatic brain injury, SART performance was assessed by Robertson, et al., in both brain-damaged participants and a group of normal controls. Results showed that attention slips as measured by SART were significantly correlated to both the severity of impairment of brain-damaged participants and also the everyday attention mistakes of the control group. Furthermore, additional SART results suggest the test may be a reliable measure of an individual's general sustained attention ability (Manly, et al., 1999).

In the present study, volunteer electric power line installers were randomly assigned to a treatment or control group. Attentiveness was measured for both groups at the start of the experiment (pretest) and after training was completed by the treatment group (posttest). The treatment group performed exercises for a period of 8 weeks. The 8-week regimen required 30-minute sessions of online cognitive training 3 days per week for 720 minutes of total treatment time. Existing Posit Science studies have used a similar approach (Willis, Tennstedt, Marsiske, et al., 2006; Wolinsky, Vander Weg, Howren, et al., 2011).

Method

Participants

Male electric power line installers volunteered to serve as subjects in this study.

The ages of the 28 participants who completed the study ranged from 21 to 56 (M = 38.8; SD = 10.0). The distribution of academic achievement showed that 18 (64%) had a high school diploma, 6 (21%) graduated from technical school, 2 (7%) had an associate's degree, 1 (3.5%) had a bachelor's degree and 1 (3.5%) chose not to respond. Participants were selected using convenience sampling from two electric utilities and two electric power contractors (Shakopee Public Utilities, Appalachian Power Co., Atkinson Power and Wilson Construction). Potential participants were identified by these four companies and were given information about the study. There was no compensation for participation.

Materials

SART performance of each participant was assessed in pre- and posttest sessions. The procedure involved presentation of a frequent target stimuli (=) and an infrequent foil or false stimulus (O) on a computer monitor. Stimuli were presented in a single block of 300 trials consisting of 267 target stimuli and 33 foils. Apart from the first six stimuli that were always targets, target and false stimuli were randomly distributed within the block and presented for 250 ms at a constant rate of one every 2,000 ms. Participants were instructed to respond by pressing the space bar of the computer keyboard as quickly as possible after presentation of the target and to withhold response to the foil. Response to any stimulus was allowed until presentation of the subsequent stimulus.

Cognitive training was conducted between the pre- and posttest sessions. The training was administered to the subjects by accessing the BrainHQ exercises at the Posit Science website. The subjects were provided passwords and participant codes from Posit Science. The treatment regimen consisted of 60% attention-building activities and 40% memory-building activities. Contacts at the two participating organizations monitored progress and communicated it to the lead researcher. Both contacts were direct supervisors of the electric power line installers. One of the participating companies was located more than 1,000 miles away from the lead researcher's office; therefore, the contact received training on how to access the exercises and administer the pre- and post-SART assessments. For the other company, the lead researcher administered the pre- and post-SART assessments. The research team also sent regular e-mails to the subjects and sponsor contacts to encourage them to maintain their adherence to the treatment regimen.

Procedures

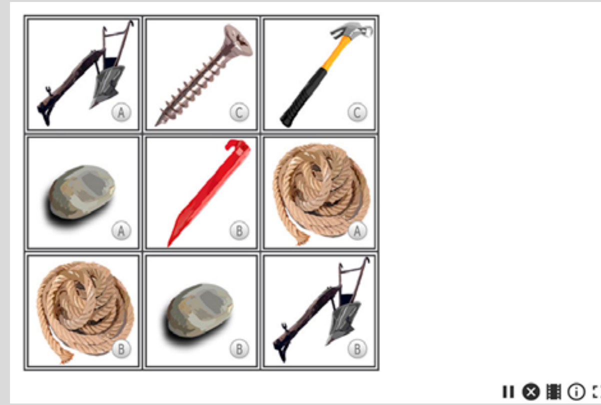
Employers provided computer access during company time in a quiet room for pre- and posttesting and cognitive training sessions. Participants signed a consent form before inclusion in any experimental activities. All participants next completed a pretest using the SART procedure. Of the 43 who completed the pretest, 24 were randomly placed in the treatment group. The treatment group was assigned 30 minutes of cognitive training 3 days a week for 8 weeks through a dedicated web portal, which most completed using company computers in dedicated private rooms and mostly on company time. The remaining 19 participants who did not receive training served as the control group. Both groups underwent posttest SART assessment 8 or more weeks after their pretest. Of the 24 participants who were in the treatment group, 15 dropped out during the course of the study. Their data were not included in the study results. Thus, 28 participants completed the entire study.

Results

SART produces two measures of performance: accuracy and reaction time. These two dependent variables were measured for all subjects at two times, pretest and posttest. To increase data normality, the Freeman/Tukey arcsine transformation was used in analysis of accuracy scores and reaction times were submitted to a logarithmic transformation. Since the researchers did not have a priori estimates of the underlying distributions for population performance on SART, a standard method based on interquartile range was used to determine outliers (Tukey, 1977). As a conservative approach to outlier rejection in this exploratory study, the researchers used three times the group interquartile range as the rejection criterion, rather than the more common multiplier of 1.5. The posttest accuracy scores of two control group subjects were deemed outliers with this conservative criterion and, thus, their data were omitted from further analyses.

Figure 2 (p. 34) shows the mean raw scores (i.e., without transformation) for accuracy and reaction time for target detection. Overall, accuracy was quite good, varying between roughly .955 and .970 across groups and conditions. Mean reaction times varied from 332 ms obtained in the posttest results of the trained subjects to 394 ms from the control subjects in the pretest condition.

FIGURE 1
SAMPLE FROM TRAINING EXERCISE



Note. Screenshot from BrainHQ software by Posit Science, 2019, www.brainhq.com.

The authors used a multivariate analysis of covariance (MANCOVA) to test for the effects of training on SART performance. In the MANCOVA, posttest accuracy and target-detection reaction time were the dependent variables. Pretest accuracy and target-detection reaction time were used as covariates in the analysis to control for group differences that may have been present at the pretest. The authors found a significant group difference attributable to training [$F(2,21) = 4.57$, $p = .022$, Wilks's $\Lambda = .697$, partial $\eta^2 = .303$]. The partial η^2 indicates that roughly 30% of the multivariate variance in the dependent variables was associated with training, a result generally interpreted as representing a large effect size (Cohen, 1988). Examination of the parameter estimates for the weighting of the dependent variables in the linear combination used to distinguish groups in the analysis indicated much greater weight for reaction time (.041) than accuracy (.001), with only the contribution of the former significant ($p = .040$). The interpretation of these results is that the treatment group differed from the control group in terms of reaction time after training, but not in terms of accuracy.

The researchers performed additional analyses to test for other trends in the data. In reaction-time tasks, a trade-off is typically observed between reaction time and accuracy. In this trade-off, shorter reaction times are associated with poorer accuracy. Evidence of a trade-off was found in the present data. For the entire subject cohort, the correlation between accuracy and target-detection reaction time was significant in both the pretest ($r = .511$, $p = .009$) and posttest ($r = .638$, $p = .001$) conditions. However, no significant difference existed between groups in the magnitude of the effect. In addition, different subjects in the treatment group spent varying amounts of time completing the training, so the possibility of a relationship between training time and both reaction time and accuracy was examined. Weak relationships were found between training time and reaction time ($r = -.654$, $p = .056$; Figure 3, p. 34) and training time and accuracy ($r = -.366$, $p = .332$); however, the correlations were not statistically significant.

Discussion

The significance of these results demonstrates that it is possible to increase sustained attention ability in electric power line installers through cognitive training. The treatment group that completed cognitive training performed the sustained attention task with lower reaction times to target stimuli when compared to the control group. Figure 2 (p. 34) shows that the overall accuracy of the control and treatment groups are both high. These high performance levels are anticipated by the high proportion of presentations of the target stimuli in SART such that a naive observer who simply always

FIGURE 2
SART RESULTS

Mean accuracy (left) and mean reaction time (right) for control and treatment groups in pretest and posttest. Error bars denote the 95% confidence interval.

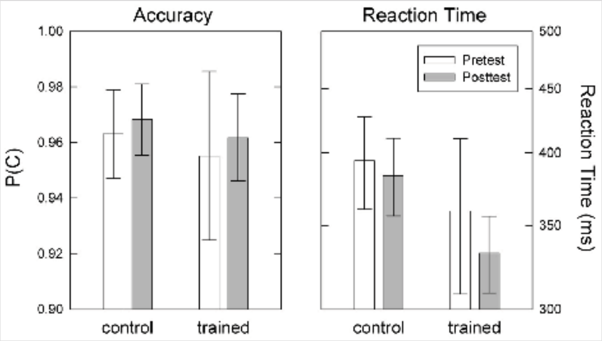
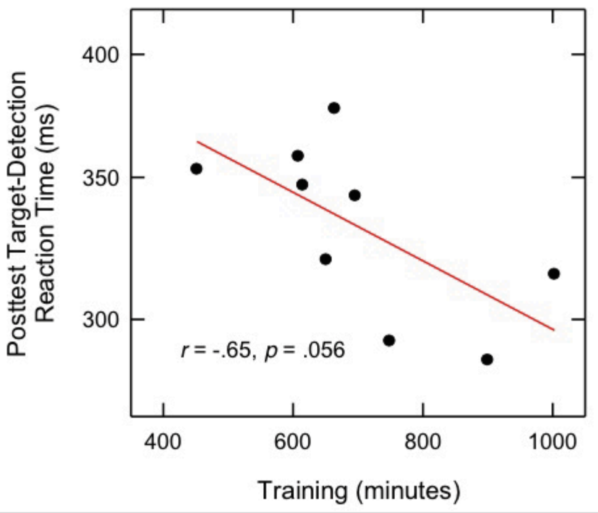


FIGURE 3
REACTION TIME

Linear regression (solid red line) of the correlation of time spent training and response time for trained participants.



responded that the target was present would obtain a proportion correct of 0.89. Results also showed a relationship between accuracy and speed, such that the more a participant focused on accuracy, the longer their reaction time became and vice versa, leading to a significant positive correlation between these two variables. The MANCOVA indicated that 30% of the difference in scoring between the control and treatment groups was attributable to cognitive training. The final analysis evaluated the effect on SART performance of differences in the length of time it took treatment group participants to complete the 8-week training. Although not statistically significant, the results suggest a trend in which greater training time may be associated with quicker SART performance without a reduction in accuracy. With a larger group size, these positive effects may reach the level of statistical significance.

On-the-job incident records were available for 27 of the 28 electric power line installers who completed this study, covering the roughly 4 years since their study participation. There were no reported on-the-job incidents for 5 of the 8 workers (62.5%) who had previously received cognitive training. For the workers who had been assigned to the control group and thus did not participate in cognitive training, only 3 of the 19 (15.8%) were incident free. This difference in incidence by worker of on-the-job incidents was statistically significant ($p = 0.027$, Fisher's exact test). As a measure of effect size, the significant odds ratio of 8.89 ($z = 2.27$, $p = 0.023$) indicates workers from the control group were nearly nine times more likely to have been involved in an incident than those who had undergone cognitive training. These incident records are categorized according to OSHA's protocol as either recordable (those requiring medical treatment) or nonrecordable (those not requiring medical treatment; OSHA, 2001). If eliminating nonrecordable incidents from the analysis, trends remain the same, but the difference in percentage of incident-free workers (87.5% who had received cognitive training vs. 63.2% from the control group) was no longer statistically significant ($p = .365$, Fisher's exact test), nor was the odds ratio of 4.08 ($z = 1.20$, $p = .229$).

This analysis of incident records subsequent to study participation was both unplanned and exploratory. That is, the authors had access to limited information regarding workers' on-the-job activities, their actual tally of incidents and possible presence of other confounds (e.g., participation in other trainings of relevance to safety performance). However, the researchers also had no indication that any of these factors affected one subject group more than the other. As such, the authors believe that the analysis of workers' poststudy incident histories offers support for pursuing a more controlled evaluation of the effect of cognitive training results on incident rates by electric power line workers in Phase II of the overall study.

Along with concerns regarding poststudy analysis of incident records, there are limitations to the central research of the current work. Most important was the high drop-out rate, which decreased intended sample sizes. Although results from the primary analysis (the MANCOVA) exhibited a large effect size, the reduced group sizes adversely affected statistical power. The high drop-out rate may also have biased results. Specifically, participants who did not drop out may have been in some way more amenable to positive effects of training than those who left the study. In terms of incident history subsequent to training, participants who did not drop out of the treatment group may have been less incident prone than those who quit treatment due to factors unrelated to training benefits. Consequently, the unbalanced drop-out rates between treatment and control groups may have biased posttreatment incident rates. Additionally, large time gaps during the course of the cognitive training of some subjects may have influenced results due to a dilution of the training effect.

Current research represents the authors' preliminary results in the study of whether cognitive training can reduce incident rates for electric power line installers. With the established link between inattention and incidents across occupations and activities (Baysari, McIntosh & Wilson, 2008; Blackmon & Gramopadhye, 1995; Edkins & Pollock, 1997; Klauer, et al., 2006), a beneficial effect of cognitive training on incident rates should not be limited solely to electric power line workers. Presumably, this benefit would vary with the specifics of on-the-job task demands across occupations. Regarding electric power line workers, additional research is needed to link more fully the improvement obtained in sustained attention or vigilance through cognitive training in the present work to on-the-job safety. If it is found that enhanced cognitive abilities positively affect job safety, further research is needed to estimate both the amount of cognitive training needed to produce a significant result and the point at which additional training no longer significantly contributes to a beneficial effect.

Along with estimates of requisite training duration, future work would evaluate the utility of adding cognitive-training booster treatments as part of employees' work readiness activity. For electric power line installers, this could mean completing a 30-minute booster treatment once a month (Rebok, et al., 2014; Willis, et al., 2006). Results from future research should aid the development, with minimal time and monetary commitment, of worthwhile safety programs by electric companies. **PSJ**

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