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Original Investigation

Working Memory Training Reduces Cigarette Smoking Among Low-Income Individuals With Elevated Delay Discounting

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Abstract

Introduction: The competing neurobehavioral decision systems theory conceptualizes addictive behavior, such as cigarette smoking, as arising from the imbalance between stronger impulsive relative to weaker executive decision processes. Working memory trainings may enhance executive decision processes, yet few studies have evaluated its efficacy on substance misuse, with mixed evidence. The current study is the first to evaluate the efficacy of a working memory training on cigarette smoking. We consider the moderating role of delay discounting (DD), or the preference for smaller, immediately available rewards relative to larger, delayed rewards, which has been associated with smoking onset, progression, and resumption. The investigation focuses on individuals living in high-poverty, low-resource environments due high burden of tobacco-related disease they experience.

Aims and Methods: The study utilized a subset of data (N = 177 individuals who smoke) generated from a randomized clinical trial that is evaluating the efficacy of working memory training for improving health-related outcomes. Participants were randomized to complete up to 15 sessions of the active, working memory training or a control training.

Results: Findings showed that among participants who were randomized to the working memory condition, those with higher rates of baseline DD demonstrated decreases in cigarette smoking (p = .05). Conversely, individuals randomized to the control condition, who had higher rates of baseline DD exhibited increases in cigarette smoking (p = .025).

Conclusions: Results suggest that DD may be an important indicator of working memory training outcomes and a possible approach for effectively targeting treatments in the future.

Implications: DD is important indicator of working memory training outcomes on cigarette smoking. The findings suggest the possibility to effectively target treatments considering the impact of DD. Given that rates of DD tend to be higher among individuals from low-resource communities, and that computer-based working memory training programs are relatively low-cost and scalable, these findings suggest this approach may have specific utility for adults at heightened risk for cigarette use.

This study was registered with ClinicalTrials.gov (Identifier NCT03501706).

Introduction

Twenty percent of deaths per year in the United States are attributable to cigarette smoking, making it the leading cause of preventable mortality and morbidity in the country.[1] The prevalence of smoking has decreased in the past three decades from 25% to 16% in the general population,[2] but among individuals with low socioeconomic status (indexed by annual household income and educational achievement) currently surpasses 28%.[3] In fact, smoking disproportionally impacts individuals with low socioeconomic status, with evidence for greater rates of smoking onset, greater increases in smoking over time, and greater smoking duration.[4] Additionally, individuals living in high-poverty environments tend to smoke cigarettes for twice as long and have a higher risk of lung cancer.[5] Although individuals from low socioeconomic status backgrounds attempt to quit at similar rates to those found in the general smoking population, they are 40% less likely to achieve abstinence.[6]

Altogether, the existing research on low socioeconomic status and smoking intimates that there are specific risk factors that contribute to the significantly high prevalence of smoking rates and persistence. Specifically, individuals living in high-poverty, low-resource environments face unique and significant stressors including economic hardship, social and structural marginalization, and general neighborhood disadvantage, all of which have demonstrated associations with smoking.[7,8] Repeated exposure to these stressors has shown to lead to disruptions in cognitive processes fundamental to decision-making,[9] and particularly working memory. Working memory is a core cognitive function with close links to the chronic stress engendered by poverty and to the development, progression, and maintenance of addictive behaviors,[10,11] Working memory refers to one's capacity to focus on goal-related information and behavior while engaging in complex cognitive tasks such as reasoning, comprehension, and learning.[12] It has been documented

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that childhood poverty is inversely associated with working memory in adults, and that this relationship is mediated by elevated chronic stress experienced during childhood.[13] Further, the association between working memory and substance use is well researched and bidirectional: weaker working memory capacity predisposes individuals to misuse substances[14,15] and continued substance misuse has a detrimental effect on working memory.[16] Working memory also plays a role in smoking cessation; specifically, withdrawal symptoms in individuals with nicotine dependence leads to cognitive impairments (eg, difficulties with sustained attention, memory, and learning), which are then ameliorated by subsequent nicotine use.[17] Further, working memory may impact the success of quit attempts among smokers. An experimental study that involved a brief and planned abstinence period, showed that individuals with weaker working memory performance evidenced quicker resumption to smoking relative to those with better performance.[18]

A leading theoretical model that reconciles the association between substance misuse and working memory is the competing neurobehavioral decision systems (CNDS) theory.[19] The CNDS posits that the neurological systems that promote impulsive behavior and the systems responsible for executive functions are interdependent and compete for relative control during decision-making. Consequently, addictive behavior is thought to occur when the executive decision systems are weaker relative to impulsive tendencies. Notably, these neurocognitive imbalances can also be a result of substance misuse, a risk factor for the onset of substance misuse or relapse after abstinence, or both.[20,21] Notwithstanding, numerous investigations lend evidence to the associations between the length of substance misuse and cognitive functions,[22,23] and strongly support the development of interventions to mitigate cognitive changes associated with substance misuse. Particularly, repeated trainings that target working memory may bolster executive decision systems to reestablish regulatory control over the impulsive system and subsequently, reinstate healthier decision-making.

Despite the strong theoretical support for the promise of working memory training in curbing substance use, few research efforts have evaluated the efficacy of working memory training in reducing substance use. To our knowledge, no study to date has examined the efficacy of working memory training specifically on cigarette smoking, which is notable considering the strong associations between working memory and cigarette smoking.[18,24] Of the existing literature that has considered this approach to substance misuse broadly, the extant findings are mixed. Relative to a control training, individuals assigned to a working memory training have shown reductions in problem-drinking,[25] mean number of drinks per drinking days,[26] and in tetrahydrocannabinol levels in adolescents enrolled in a cannabis use treatment.[27] However, two other studies did not yield significant effects of working memory training on substance use outcomes.[28,29]

Delay discounting (DD) may explain, in part, the inconsistent associations between working memory training and substance use outcomes. Elevated DD refers to the preference for smaller, immediately available rewards relative to larger, delayed rewards. DD is closely related to substance use, and particularly with the onset, progression, and maintenance of cigarette smoking.[30] The rationale for examining DD as a moderator of working memory training on substance use outcomes comes from a long line of research suggesting that people with higher DD who smoke tend to relapse more than those with lower DD levels after receiving a smoking cessation intervention.[31] Other research has shown that an online working memory training aimed at reducing problem-drinking decreased individuals' alcohol consumption, particularly when their baseline impulses (akin to DD) to prefer alcohol were higher.[25]

Consequently, the overarching aim of the study was to determine the efficacy of a working memory training on cigarette smoking, considering DD as a moderator of the training. We examined these relations in a low-income sample of mid-adult individuals because of the need to target high smoking rates and high burden of tobacco-related disease in this underserved subsample. We hypothesized that the working memory training would lead to favorable changes in smoking and that individuals with greater levels of DD who were randomized to the working memory training would show more benefits in reducing cigarettes smoked relative to those with lower levels of DD and those who were randomized to a control condition.

Methods

Participants

The data reported here come from a subset of participants (ie, individuals who smoke cigarettes) recruited from a larger intervention study that is ongoing in Baltimore, Maryland examining the efficacy of a computerized working memory training for improving health-related outcomes. All procedures were approved by the Institutional Review Board of the University of Kansas-Lawrence and meet the standards set forth by relevant national and institutional guidelines (ClinicalTrials.gov number NCT03501706). Participants (N = 646) were separately recruited from two community centers in medically underserved areas of Baltimore, Maryland, as defined by the Health Resources and Services Administration.[32] Participants were recruited using flyers/business cards visible to individuals participating in community outreach programs as well as by study staff, including a community liaison working for the project. Midlife individuals (40–60 years old) able to read at least at a fifth grade reading level were consented into the study and interviewed for eligibility—participants were deemed ineligible to participate if they (1) met criteria for a severe substance use disorder other than for tobacco, (2) had experienced a traumatic brain injury, (3) reported a diagnosis of dementia, (4) reported a significant learning disability, (5) endorsed psychosis symptoms, or (6) endorsed severe depression. Midlife individuals were specifically targeted for inclusion given that delayed consequences of unhealthy behaviors (eg, smoking cigarettes) tend to typically manifest during this age period. Only participants who reported smoking at the consent session were selected for analyses reported here.

Of the total sample recruited as part of the larger trial, 182 individuals reported smoking. Of those 182, one participant disqualified because they self-reported a history of severe traumatic brain injury and two participants had never begun the computer intervention. Participants were predominately Black/African American (demographic information for participants is reported by treatment condition in Table 1). Differences in demographic variables and smoking status (average number of self-reported cigarettes smoked in the 7 days prior to baseline session) were observed between community centers, which may partly be explained by one site

Table 1. Demographics by Treatment Group and Intervention Site

Variable	Active condition	Control condition
Sex (male)	51.1%	38.2%
Mean age (*SD*)	50.2 (5.4)	51.9 (6.0)
Race/ethnicity		
White	21.1%	13.5%
Black/African American	73.3%	78.7%
Native American/American Indian	4.4%	3.4%
Other	1.2%	4.4%
Highest level of education		
Less than high school degree/General Educational Development exam	21.1%	33.7%
High school degree/General Educational Development exam	61.1%	55.0%
Associates degree or trade school	12.2%	7.9%
Bachelors or advanced degree	5.6%	3.4%
Current employment status		
Unemployed	46.7%	31.5%
Part-time	7.8%	6.7%
Full-time	4.4%	4.5%
Unable to work	38.9%	56.2%
Student/other	2.2%	1.1%
Current annual household income		
$0–9999	50.0%	48.3%
$10 000–19 999	21.1%	16.9%
$20 000–29 999	11.1%	4.5%
$30 000+	6.7%	5.6%
Don't know/refused to answer	11.1%	24.7%
Smoking status (*SD*)	50.7 (37.3)	48.1 (29.3)

SD = standard deviation. Smoking status denotes average number of self-reported cigarettes smoked in the 7 days prior to the baseline session.

being located near multiple medication assisted treatment centers.

Procedures

Participants Completed All Study Procedures at the Community Centers

Participants completed a screener session (to determine eligibility), baseline session, up to 15 sessions of the computer intervention (active or control condition) session, and a post-training follow-up session. Participants were randomized into either the active (ie, working memory) or control condition further discussed in Computer Intervention section. However, initial participants were assigned only to the active condition to determine incentive schedules for fully finished participants (ie, those who completed 15 computer training sessions). Subsequent participants were randomized into either the active or control condition.

Computer Intervention

The program in the active intervention condition consisted of 15 sessions with four modules, each presented in a counterbalanced fashion across sessions. Previous research has shown working memory improvements using these modules.[10] Modules included:

1. Sequenced Recall of Digits—Auditory: participants heard a series of increasingly long strings of numbers and were asked to memorize and recall them immediately after.
2. Sequenced Recall of Reversed Digits—Auditory: participants heard a string of numbers but were asked to recall the series in the reverse order.
3. Sequenced Recall of Words—Visual: participants were presented with an increasingly longer list of four-letter words to memorize and were asked to recognize these words from a larger list after a 3-second delay.
4. Verbal Memory—Categorizing: participants were given a word bank containing 20 words, each of which fell into one of four categories listed in boxes above the word bank. Participants were instructed to categorize each word and then identify these words from a larger list.

Across all modules, five incorrect attempts ended the modules.

If assigned to the control condition, participants were presented with the same modules without having to engage their working memory. Instead of having to recall or categorize, correct answers were presented on the screen and participants were told to select those accordingly.

Participants in the active condition were compensated via gift cards: $2.50 for each session attended and an additional $2.50 for improvement on each module, with payments ranging from $2.50 (no improvement within session) to $12.50 (improvements on all four modules within session). Control condition participants were compensated $2.50 for each computer training session and were randomly yoked to active condition participants who had completed training to receive payment based on their yoked counterpart's compensation schedule.

Scheduled computer training sessions occurred approximately 3 days per week and were completed over the course of 5–7 weeks. Participants discontinued the training if they did not complete it by week 7 and they were counted as having completed training if they took part in at least 12 sessions. Each training session lasted approximately 30 minutes. Of the current sample, 90 participants were randomized to the active condition (*M* = 7.5, *SD* = 6 computer training sessions; 35 completing training) and 89 in the control condition (*M* = 8.5, *SD* = 6 computer training sessions; 41 completing training).

Measures

Demographics

Participants were asked to self-report their age, biological sex, race/ethnicity, educational status, employment status, annual household income, and smoking status (see Table 1).

Cigarette Use

The Timeline Followback (TLFB)[33] was used to assess point prevalence of tobacco use at baseline and post-training sessions. Participants were asked to report number of cigarettes smoked for each day in the past 7 days retrospective to each study session. Results were summed across respective weeks. The TLFB has proven reliability and validity when used to assess retrospective cigarette smoking[34] for much longer timeframes than past 7 days. The TLFB was administered at the baseline session and at the post-training follow-up, after completing the computer intervention (active or control condition) session.

Delay Discounting

Participants were given a computerized binary choice task to assess DD at baseline and post-training sessions. Trials asked participants to choose between smaller, immediate amounts of money and larger, delayed amounts (either \$50 or \$1000), with delayed amount available at one of seven possible delays (1 day, 1 week, 1 month, 6 months, 1 year, 5 years, and 25 years). A computerized algorithm[35] adjusted the amount of the smaller, immediate amount across seven trials to determine an indifference point for each delay. Indifference points were used to derive *k* values, which were natural log transformed to approximate normality.

Data for only the \$1000 delayed amount are reported here because small magnitude conditions in DD tasks may not be sensitive enough to detect within- or between-group differences.[36] Moreover, monetary choices in the task were hypothetical, although previous research has shown comparable results between real and hypothetical rewards as well as reliability,[37] with one study showing statistical equivalence and reliable estimates across time.[38] Furthermore, using monetary DD tasks to study cigarette use is justified given its robust associations with substance use and addiction broadly[39] and cigarette smoking specifically.[40]

Data Analysis

We first compared participants who completed both pre- and postintervention assessments to those who completed only preassessment and found they did not differ on any demographic or study variables (p values >.10). Data were then examined to ensure they met univariate assumptions. Two cases were above the criterion of $z = 3.29$ and were deleted as univariate outliers, yielding a final sample size of 177. All analyses were conducted in M*plus* 8.0,[41] which utilizes full information maximum likelihood estimation models to account for missing data in computing parameter estimates. This approach is preferable to listwise or pairwise deletion which can yield biased estimates and allows for inclusion of participants who contributed data at either assessment point in the sample. Descriptive data and bivariate correlations among all key variables are reported in Table 2.

In order to examine the effect of the working memory training on postintervention cigarette use, we evaluated a linear regression model, examining the main effect of treatment on changes in smoking across the intervention period, adjusting for the impact of theoretically and empirically related covariates, including age,[42] sex,[43] initial levels of DD, and recruitment site. We then assessed whether levels of initial levels of DD moderated the relation between intervention condition and smoking outcomes by including an interaction term. Post hoc probing of any significant interaction terms was conducted by estimating the conditional effects of baseline DD on changes in cigarette use for the intervention conditions.

Results

Bivariate correlations between measures suggested that recruitment site was significantly associated with the likelihood of ending up in the control condition, being male, and smoking more at postintervention.

Next, we ran a series of linear regression models. The first model evaluated the main effect of intervention condition on cigarette use at postintervention, controlling for initial levels of smoking, age, sex, recruitment site, and baseline levels of DD. Results suggested that the model was significant ($R^2 = 0.40$, $p < .001$) and that only recruitment site ($b = 0.21$, $p = .001$, 95% confidence interval = 0.06–0.37) was a significant predictor of changes in smoking.

Our next model added an interaction term to the adjusted model to evaluate whether baseline DD moderated the effect of intervention condition on changes in cigarette use. This model was also significant ($R^2 = 0.42$, $p < .001$) and indicated that the interaction term was a significant predictor of changes in smoking (see Table 3 for path estimates). Post hoc probing of the interaction suggested that for participants in the control condition, higher (more problematic) rates of baseline DD were associated with greater increases in smoking ($b = 0.31$, $p = .025$, 95% confidence interval = 0.04–0.58). In contrast, among participants in the active condition, higher rates of baseline DD were associated with greater decreases in cigarette use ($b = -0.22$, $p = 0.050$, 95% confidence interval = −0.44 to −0.001), see Figure 1.

Discussion

The goal of the current study was to evaluate the effects of a computerized working memory training on cigarette out-

Table 2. Correlations, Means (*M*), and Standard Deviations (*SD*s) of Key Variables

	1.	2.	3.	4.	5.	6.	7.
1. Age							
2. Sex (female)	0.03[b]						
3. Recruitment site	0.09[b]	−0.22**[,a]					
4. T0 DD (\$1000)	0.07	−0.06[b]	−0.05[b]				
5. T0 cigarettes	−0.06	−0.06[b]	0.01[b]	−0.01			
6. T1 cigarettes	0.01	−0.12[b]	0.26**[,b]	0.02	0.55**		
7. Intervention condition (active)	−0.15*[,b]	0.11[a]	−0.16*[,a]	0.12[b]	0.01[b]	−0.16[b]	
M (*SD*)	51.08 (5.78)	0.45 (0.51)	1.44 (0.50)	−3.98 (3.85)	48.49 (31.35)	39.46 (32.71)	0.50 (0.50)

Intervention condition is coded 1 = active, 0 = control; sex is coded 1 = female, 0 = male; T0 = baseline, T1 = post-training. DD = delay discounting (*k* values natural log transformed), \$1000 denotes LL amount.
[a]Phi correlation coefficient.
[b]Point-biserial correlation coefficient; all other correlations are Pearson product-moment correlation coefficients.
*$p < .05$.
**$p < .01$.

Table 3. Path Estimates for the Final Interaction Model Predicting Postintervention Smoking

Variable	*B*	*SE* (*B*)	*β*	*p*
Cigarette use at baseline	0.57	0.09	0.67	.000**
Intervention condition (active)	−18.07	7.44	−0.29	.015*
Delay discounting at baseline	1.61	0.96	0.20	.091
Site	13.85	5.32	0.21	.008**
Age	0.00	0.03	0.00	.980
Sex (female)	0.89	5.28	0.02	.866
Delay discounting × condition	−2.97	1.47	−0.28	.043*

Intervention condition is coded 1 = active, 0 = control; sex is coded 1 = female, 0 = male.
*$p < .05$.
**$p < .01$.

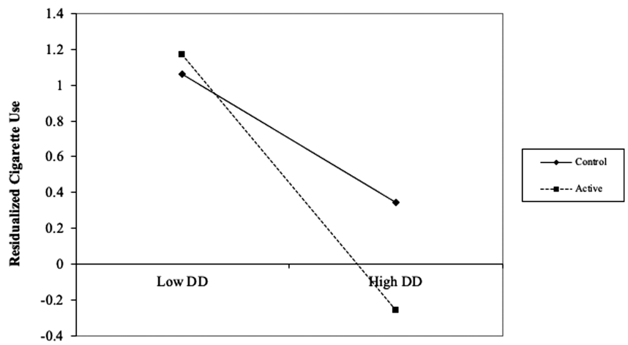

Figure 1. Interaction between delay discounting and intervention condition predicting changes in cigarette use.

comes and to examine the moderating role of DD in these relations. Results from our study suggested that DD influences the relation between working memory training and changes in smoking, such that individuals with elevated (more problematic) rates of DD who took part in a working memory intervention experienced the greatest decreases in cigarette use. These findings and their implications are discussed below.

This study is the first to show the important role of DD in working memory training for reducing rates of smoking. The utility of a working memory training program for reducing nicotine use is consistent with other studies indicating the efficacy of this approach across samples of individuals who use other substances, for example, methamphetamine,[44] hazardous alcohol use,[25] and stimulants.[10] However, our finding that the intervention was effective at reducing rates of cigarette use only for individuals with higher levels of baseline DD is particularly novel. These results align with and add to research suggesting that working memory is closely linked to both DD[45] and smoking status,[24] yet are the first to suggest that therapeutically manipulating working memory may drive decreases in cigarette use among a subset of vulnerable individuals. DD may then represent a potentially important target for future smoking cessation efforts, especially among individuals from low-resource communities. Thus, the current findings provide preliminary evidence that the mixed evidence surrounding working memory training and its impact on substance misuse could be in part explained by not considering predisposing and moderating variable of DD, which is related to the onset and persistence of cigarette smoking.[30] The current investigation also provides preliminary evidence for whom working memory training would be most effective, suggesting that these types of interventions may be best targeted at groups of individuals that research suggests may have elevated DD (eg, individuals with reinforcer pathologies such as substance use or gambling disorders). Future research will be needed to examine pathways by which these individuals experience benefit, and whether these pathways differ from individuals with lower immediacy biases. The investigation also begins to address *for whom* working memory training may bring about positive health outcomes, suggesting that this approach is specifically impactful for individuals focused on immediate rewards. Working memory trainings may enhance executive decision processes, yet few studies have evaluated its efficacy on substance misuse, with mixed evidence. Given that elevated DD scores at baseline tend to predict smoking onset and progression during adolescence,[46] and that greater DD has been associated with less likelihood of remaining smoke-free after receiving empirically supported smoking cessation interventions relative to those with lower levels of DD,[31,47] the working memory training could have clinical utility in serving groups of individuals who smoke who need it the most. A future and important avenue of investigation constitutes *why* individuals with lower rates of DD did not benefit from the working memory training. This finding may suggest that individuals with higher DD are especially able to decrease their smoking because the working memory training tapped into core executive functioning processes related to DD, which in turn were able to decrease cigarette smoking. Future research is warranted to test this hypothesis using a mediated moderation model. Another noteworthy finding was that participants who were assigned to the control condition who had higher DD rates at baseline increased their smoking over time, even during a relatively short study duration. This is consistent with prior research findings that demonstrated that baseline levels of DD predicted smoking uptake.[30]

Our examination of research on the efficacy of working memory training within a low-resource sample is particularly important, given that very low-income and unstably housed adults smoke at significantly higher rates than adults from more affluent settings.[48] Indeed, smoking-related mortality accounts for more deaths than alcohol or other drugs in homeless older adults and are three times higher than rates of similarly aged stably housed individuals.[49] Moreover, research suggests that individuals from low-resource communities are particularly likely to have higher rates of DD.[11] A robust literature also highlights health disparities in access to evidence-based treatment for nicotine reduction, indicating that predominantly Black and low-income individuals are significant less likely to have access to these interventions.[50] Thus, the development of a cost-effective and easily scaled intervention (such as a computer training program) has particular promise. Specifically, computer-based working memory training programs can be implemented in community-serving settings without the need for professional interventionists or costly infrastructure, suggesting an important avenue for reaching vulnerable populations who are most likely to use cigarettes. The use of a working memory training to assist with smoking cessation maintains the specificity necessary for high impact, parsimony, and replicability necessary to be disseminatable through publicly available services and has a high degree of innovation and potential to benefit the communities that need tend to disproportionately suffer the negative health consequences associated with smoking. Furthermore, the current results constitute a first step to identifying *for whom* a treatment like this is most impactful, allowing us to improve our future ability to provide personalized smoking interventions.

Limitations and Future Directions

While this research has a number of strengths, including its implementation in a vulnerable population and the use of a behavioral task to assess DD, several limitations of the current design point to avenues for future research. First, the current study did not examine biological indicators of smoking, such as expired-air carbon monoxide monitoring or cotinine measures. Although self-reported rates of smoking correlate with biological measures[51,52] and the methodology used (a computer training that does not include any smoking-related content) decreases concerns regarding demand characteristics, future studies should evaluate more objective indicators of nicotine intake. Second, the current study only examined pre- to postintervention changes in cigarette use and are, thus, not able to ascertain longer-term changes. Given research indicating the relation between working memory deficits and smoking lapse following abstinence,[18,53] longer-term follow-up studies are needed to evaluate sustained changes in cigarette use. While the mechanism behind the study findings is unknown, consistent with the CNDS theory, individuals who misuse substances may demonstrate other executive function deficits including working memory, which may contribute to substance use, which could be tested in future investigations in a mediated moderation model. Future research should explore the extent to which working memory capacity underlies changes in smoking cessation over time. Third, the current study used a subsample of individuals who reported smoking taking part in a larger randomized control trial. Importantly, these individuals were not selected based on interest in smoking cessation and future research is needed to evaluate the utility of this approach among adults seeking to reduce cigarette use. Relatedly, the question remains of whether a 12–15 session working memory training may lead to participant burden and dropout, specifically among individuals with higher DD who smoke. Although the current study did not find an association between DD with dropout ($r = -.04$; $p = .68$) or number of working memory training sessions completed ($r = -.02$; $p = .84$), a feasibility study is warranted to determine the utility of this working memory training tool in community settings in our sample of interest. Finally, one last limitation is that we only recruited individuals who were between 40 and 60 years old, thus limiting the generalizability of the findings to the general population of smokers.

Conclusions

Results from this study suggest that DD may be an important indicator of working memory training outcomes and a possible approach for effectively targeting treatments in the future. Given that rates of DD are higher among individuals from low-resource communities, and that computer-based working memory training programs are relatively low-cost and scalable, these findings suggest this approach may have specific utility for adults at heightened risk for cigarette use.

Supplementary Material

A Contributorship Form detailing each author's specific involvement with this content, as well as any supplementary data, are available online at https://academic.oup.com/ntr.

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Declaration of Interests

None declared.

Data Availability

Data are being collected as part of an ongoing clinical trial. For the current study, we are using a subset of the data (from individuals who reported smoking cigarettes) and are examining a different research question from the aims of the original trial. Data will be available upon request to the corresponding author.

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