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Education Shapes Executive Control: More Evidence from Turkish Literate and Illiterate Adults

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Abstract

Executive functions are known to be shaped by formal education, yet direct evidence from adult populations with minimal schooling remains scarce. The present study examines the effects of education and reading experience on inhibitory control by comparing literate and illiterate adults using a simple inhibition task. Participants also completed measures of reading fluency with real and nonce words. Results revealed significantly higher inhibitory accuracy in literate participants compared to illiterate participants. Importantly, inhibitory performance showed limited variability among literate adults, suggesting a ceiling effect, whereas illiterate adults displayed substantially large individual differences. These findings support the view that formal education and sustained engagement with written language contribute to the development of inhibitory control mechanisms. The study provides novel behavioral evidence that literacy-related experiences continue to shape executive functions in adulthood from a Turkish population, highlighting the cognitive consequences of unequal access to formal education.

Keywords: inhibitory control, adult, literacy, individual differences

Introduction

Executive functions refer to a set of domain-general cognitive control processes that support goal-directed behavior, including working memory, cognitive flexibility, and inhibitory control (Diamond, 2013). Inhibitory control, in particular, plays a central role in regulating attention and action by suppressing dominant, automatic, or contextually inappropriate responses. As such, it is foundational for a wide range of cognitive activities, from language processing and reasoning to learning and decision-making.

Although inhibitory control is often discussed in developmental terms, accumulating evidence indicates that it remains sensitive to experiential factors well into adulthood. Neurocognitively, inhibition is supported primarily by prefrontal networks that continue to undergo structural and functional reorganization across adolescence and early adulthood (Blakemore, 2008; Blakemore & Choudhury, 2006; Luna et al., 2010). This prolonged developmental trajectory suggests that environmental input, such as education and sustained engagement in cognitively demanding activities, may exert long-term effects on inhibitory control beyond childhood.

Literacy acquisition and formal education constitute two such sources of sustained cognitive engagement. Learning to read and write requires the coordination of attention, the suppression of competing interpretations, and the regulation of interference from irrelevant perceptual and linguistic information. For instance, in an alphabetic writing system, distinguishing mirrored letters (d vs b, q vs p) from one another at the beginning of literacy acquisition requires suppressing the incorrect phonological realization and providing the correct one. Moreover, literacy acquisition changes the overall connectivity of the brain (Dehaene et al., 2010), which may result in an improvement of overall inhibitory control as well.

Education, on the other hand, can help to improve inhibitory control in two ways. First, formal schooling requires doing activities improving inhibitory control such as following classroom rules, waiting for turn-taking, suppressing prepotent responses during instruction, and maintaining attention in the presence of competing perceptual and social distractions. Secondly, and more importantly, education has a preserving effect on inhibitory control, especially in old age through cognitive reserve (e.g., Staff et al., 2004; Stern, 2002). The capacity to manage age-related decline by optimizing or maximizing performance through differential recruitment of brain networks is known as cognitive reserve.

Correspondingly, several studies have reported associations between literacy or years of schooling and executive functions, including inhibition, working memory, and cognitive flexibility (Brodaty & Moore, 1997; Kim & Chey, 2010; Dorbath et al., 2013). These effects have been observed not only in children but also in adults, suggesting that literacy-related experiences may shape executive control throughout the lifespan.

While these findings are significant, we still do not fully understand how literacy specifically contributes to inhibitory control in adults. Much of the existing literature relies on samples with relatively homogeneous educational backgrounds, with few exceptions cited earlier, making it difficult to disentangle the effects of basic literacy from those of extended schooling. Moreover, to the researchers' knowledge, no study has investigated individual differences in inhibitory control in an illiterate population.

The present study addresses these gaps by examining inhibitory control in Turkish illiterate and literate adults. The use of a Turkish sample was entirely dependent on availability. Using an inhibition task with trial-level accuracy data, we investigate whether individual differences in reading fluency and years of education predict inhibitory performance, while controlling for age and participant-level variability. By focusing on inhibitory control as an outcome measure, this study aims to clarify the extent to which

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literacy and education contribute to executive functioning in adulthood, independent of broader cognitive or linguistic explanations.

Methods

Participants

We collected data from 96 native Turkish speakers; 53 illiterate (mean age: 52.88, range: 21-80, SD: 13.05, mean years of education: 0.56, range: 0-5, SD: 1.26), and 43 literate (mean age: 44.39, range: 21-80, SD: 13.47, mean years of education: 17.23, range: 11-27, SD: 4.07), with at least primary school education or above. Illiterate participants were enrolled at the adult education center for the literacy course and were illiterate due to sociocultural reasons (i.e., financial hardships, religious beliefs, see Gedik, 2026 for a discussion). Literate participants were enrolled in other courses (i.e., pottery, handcraft, painting and so on). Along with subjects like math, basic history, and Turkish, the curriculum of the literacy course, which was broken up into 80 40-minute teaching units, included literacy instruction. A degree that is equivalent to a Turkish elementary school certificate is given to participants who successfully finish these courses. The literacy center assessed illiterate speakers for a range of cognitive and speech and communication impairments, including dyslexia, in collaboration with medical specialists from surrounding hospitals.

The fact that some of the study's illiterate participants could read a few words per minute is noteworthy (see findings). This might be because they were taught to read by family members or because they learned to read in the literacy course. These people would be considered functionally illiterate. Despite being able to read words, they are unable to comprehend longer texts and automate reading, therefore they enroll in literacy programs. Additionally, many of the participants could not read a single word in a minute due to their full illiteracy (see results). We therefore refer to this group as illiterate for convenience.

Inhibitory control task

To gauge inhibitory control, we adapted the Emotional Stroop Task (Lagattutta et al., 2011). Participants in this task are shown an emoji of a happy or sad face, and they were instructed to say the opposite of the stimulus: when a happy face is displayed, they must say sad, and vice versa (see the materials in the OSF link). As for the stimuli, we utilized emojis because, according to our first discussions with the illiterate participants, they all had smartphones and used social media sites like WhatsApp. We chose this task above other executive function tasks for two reasons: first, we needed to accommodate our illiterate participants, and standard tasks employ written language. Second, it has been shown that this task may capture individual differences and is a good measure of inhibition (Lagattutta et al., 2011).

The experimenter described the task as a "say the opposite" game before starting it. Four randomly selected happy and sad face stimuli were used in the testing phase. Participants were given feedback during the trial phase. Following the testing period, they randomly arranged five happy and five sad faces and received neither positive nor negative feedback. The experimenter reminded the participant of the game's rules if they made four consecutive mistakes during the testing phase.

1-Minute Word Reading Task

Since other literacy assessments (such as author recognition tests) would not be appropriate for illiterate speakers, we used the Turkish 1-Minute Word Reading Task (Gedik, 2026) to accommodate both literate and illiterate speakers to assess their orthographic decoding skills. This approach would offer a continuous variable of phonological decoding skills and speed (see Gedik, 2026 for details). One study revealed a reasonably large significant link between words read in a minute and text comprehension in youngsters (Yıldız et al., 2014) and a weak but substantial correlation between scores on such tasks and vocabulary size in adults (Simos et al., 2013).

There are 120 real words and 120 nonce-words in the task. Each real and nonce-word part has a one-minute time limit. Initially, the participants are given twenty additional words to practice correctly reading words aloud. They are then given a minute to read as many words properly as they can. For both real and nonce-words, this is repeated independently. One point is given for each accurate reading, and one point is deducted for each inaccurate reading. The participant receives one point if they correct their misreading. The two subcomponents are converted into z-scores and averaged to create the reading fluency measure which we call ReadComp.

Procedure

At adult education centers, literate and illiterate participants were tested in empty classrooms individually. Following informed consent, the sessions were recorded. The comfort of illiterate adults was given priority due to their vulnerable situation. After every task, the experimenter checked in to make sure the participants wanted to continue and provided encouragement. First, we collected demographic information (age, literacy duration, schooling, highest education level, prior literacy instruction), then we administered the 1-Minute Word Reading Task and the inhibitory control task. Prompts were neutrally repeated upon request.

Data analyses

All analyses were conducted in R (2025, version 4.5.0) using mixed-effects modeling. The dependent variable in the experimental task was trial-level accuracy, coded as correct (1) or incorrect (0). Because responses were binary and observations were nested within participants, accuracy was analyzed using generalized linear mixed-effects models with a binomial error distribution and logit link function.

Models were fit using the glmer function from the lme4 package, with parameters estimated by maximum likelihood using the Laplace approximation. To account for repeated measurements, all models included random intercepts for participants, allowing baseline performance to vary across individuals. No random slopes were included, as models with more complex random-effects structures failed to converge or did not improve model fit.

The primary predictors of interest were reading fluency and years of formal education, which were evaluated in separate models. Reading fluency was treated as a continuous predictor reflecting individual differences in literacy skill. Years of education was entered as a continuous variable indicating total years of formal schooling completed. Age was included as a covariate in all models to control for potential lifespan-related effects on inhibitory performance.

Reading fluency and years of education were not entered simultaneously into the same model due to their strong correlation in the present sample, which would have resulted in severe multicollinearity and uninterpretable parameter estimates. Instead, each variable was evaluated in a separate, theoretically motivated model.

All data, code and materials are available at this link: https://osf.io/wq4rc/overview?view_only=8b03a831913046a7bd2ce51d816ad939

Results

Descriptive statistics

As expected, the two groups differed markedly in reading fluency. Illiterate participants read very few real words per minute (M = 9.6, SD = 14.7, range = 0–73) and almost no nonce words (M = 2.5, SD = 4.4, range = 0–20), whereas literate participants showed substantially higher reading rates for both real words (M = 100.1, SD = 17.5, range = 56–120) and nonce words (M = 61.4, SD = 15.9, range = 22–93).

Performance on the inhibition task also differed between groups. Illiterate participants responded correctly on average on 62% of trials (SD = .31), whereas literate participants performed near ceiling (M = .99, SD = .06), see Figure 1. These descriptive differences suggest a strong association between literacy and inhibitory control, which was evaluated statistically using mixed-effects models. Figure 1 shows the overlap of individual differences in inhibitory control between the two groups.

Beyond differences in mean performance, the groups differed markedly in performance dispersion. A Levene's test for homogeneity of variance (centered at the median) revealed significantly greater variance in the illiterate group compared to the literate group, $F(1, 92) = 71.33$, $p < .001$. While literate participants exhibited near-ceiling and highly stable performance across the lifespan (SDs ranging from .00 to .10 across age bins: 20-40, 40-60, 60-80), illiterate participants displayed substantial inter-individual variability at every age level (SDs ranging from .28 to .36). This pattern suggests that formal education may not merely elevate average performance but may also compress the performance distribution, yielding greater stability and resilience across adulthood, consistent with cognitive reserve accounts. Although reduced variance among literates partly reflects ceiling effects, the marked contrast in dispersion indicates that education may stabilize performance distributions across adulthood, consistent with cognitive reserve accounts.

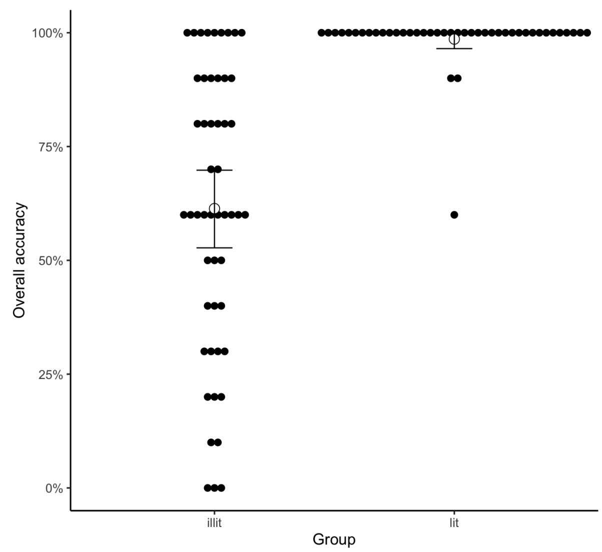

Figure 1: Overall accuracy (percent correct) in the inhibition task per group

Generalized linear mixed models

Accuracy on the inhibition task (correct vs. incorrect) was analyzed at the trial level using mixed-effects logistic regression, with random intercepts for participants to account for between-individual variability. All models were fit using maximum likelihood estimation. Reading fluency and years of formal education were strongly correlated in the present sample, reflecting the fact that literacy acquisition in this population is closely tied to schooling history. When both predictors were included simultaneously in the same model, neither could be reliably interpreted due to severe multicollinearity. For this reason, literacy and education were evaluated in complementary models rather than as competing predictors.

In the first model, reading fluency (ReadComp) and age were entered as fixed effects. This model revealed a strong and highly reliable effect of reading fluency on inhibitory accuracy (β = 2.65, SE = 0.42, z = 6.24, p < .001). Higher reading fluency was associated with a substantially increased likelihood of producing a correct inhibitory response. In contrast, age did not significantly predict performance (β = 0.01, SE = 0.02, z = 0.45, p = .65).

The magnitude of the literacy effect was large: a one-unit increase in reading fluency was associated with an approximately fourteen-fold increase in the odds of responding correctly. Figure 1 visualizes this effect by plotting predicted probabilities of correct responses across the observed range of reading fluency. As shown in the figure, predicted accuracy increases steeply with literacy, approaching ceiling levels at higher levels of reading fluency. The random-effects structure indicated substantial between-participant variability in baseline inhibitory performance (SD = 2.06), justifying the use of mixed-effects modeling.

In a second model, years of formal education replaced reading fluency as the primary predictor, with age again included as a covariate. This model also revealed a robust positive effect of formal education on inhibitory performance ($\beta = 0.32$, $SE = 0.05$, $z = 6.32$, $p < .001$). Each additional year of education increased the odds of a correct response by approximately 37%. As in the literacy-focused model, age did not significantly predict performance ($\beta = 0.02$, $SE = 0.02$, $z = 0.73$, $p = .46$). Between-participant variability remained substantial (SD = 1.98).

Model fit indices slightly favored the education-focused model (AIC = 650.6) over the literacy-focused model (AIC = 655.4), indicating that years of education accounted for marginally more variance in inhibitory accuracy at the population level.

Given the wide age range of the sample (21–80 years), we also tested whether age-related effects might follow a non-linear trajectory. A model including a quadratic age term did not improve fit relative to the linear model ($\Delta AIC = 1.62$; $\chi^2(1) = 0.37$, $p = .54$), and neither the linear nor quadratic component was significant. These results suggest that the absence of an age effect is not attributable to linear model misspecification.

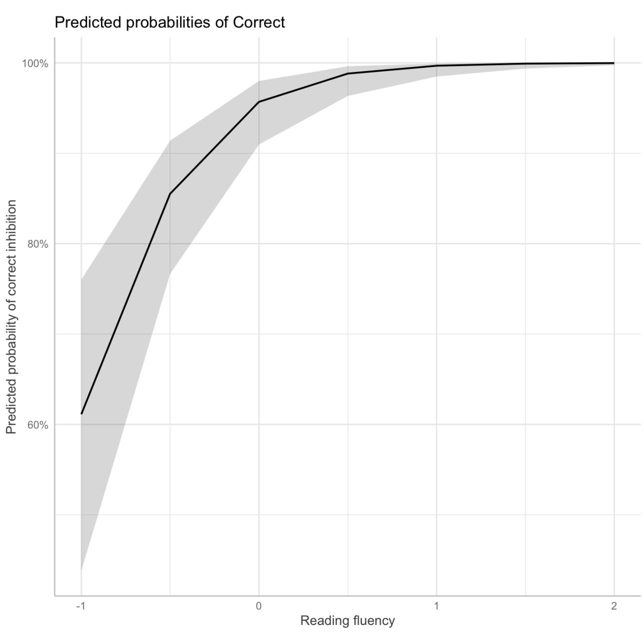

Figure 2: Predicted probabilities of reading fluency and correct inhibition

Discussion

The present study examined whether literacy and formal education are associated with inhibitory control in adulthood, using an adapted inhibition task administered to literate and illiterate adult speakers. By combining trial-level modeling with continuous measures of reading fluency and years of education, this study provides novel evidence that inhibitory control in adults is strongly shaped by experiential factors rather than chronological age alone. To our knowledge, this is the first study to document systematic individual differences in inhibitory control within an illiterate adult population.

The results showed that the two groups differed in their inhibitory control, with literate speakers being at ceiling (see limitations) and illiterate speakers showing large individual differences. Our findings also reveal a robust association between education-related variables and inhibitory performance. Both reading fluency and years of formal schooling significantly predicted the likelihood of producing a correct inhibitory response (in separate models), whereas age did not contribute reliably once these factors were taken into account. This pattern supports the view that inhibitory control remains experience-sensitive well into adulthood, consistent with neurocognitive accounts emphasizing the prolonged development and plasticity of prefrontal control networks (Blakemore, 2008; Luna et al., 2010). Our findings also align with previous studies that tested adults differing in educational experience (e.g., Dorbath et al., 2013).

Crucially, the effects observed here cannot be attributed to childhood development alone. All participants were adults, and age-related variance was minimal relative to the explanatory power of literacy and education. This suggests that inhibitory control does not simply plateau after adolescence, but continues to reflect cumulative experience with cognitively stimulating environments or activities, particularly those associated with schooling and literacy. However, given the cross-sectional nature of the present data, these findings should be interpreted as reflecting associations rather than definitive causal effects of education or literacy.

When modeled separately, both reading fluency and years of education were strong predictors of inhibitory success. However, years of education provided a better-fitting model overall, and the effect of reading proficiency was attenuated when education was included. While these patterns suggest that formal education may capture broader and more cumulative sources of inhibitory demand than reading proficiency alone, the strong correlation between these variables in the present sample limits the extent to which their unique contributions can be definitively disentangled.

Nevertheless, this statistical finding (education over reading fluency) is informative. While literacy acquisition itself places substantial demands on inhibitory control, such as suppressing competing phonological, orthographic, or semantic representations, formal education encompasses a broader and more sustained set of inhibitory demands. This finding aligns well with education acting as a crutch for cognitive reserve (see introduction).

Schooling systematically requires individuals to regulate attention, suppress impulsive responses, follow explicit rules, and maintain task goals over extended periods. These demands are repeated across years and across domains, likely producing more generalized and durable effects on executive control than literacy alone. From this perspective, reading proficiency may reflect one manifestation of this training, whereas years of education capture the cumulative exposure to inhibitory demands more comprehensively.

One of the most striking findings of the present study is the substantial variability in inhibitory performance among illiterate adults. Unlike literate participants, who performed near ceiling, illiterate participants showed large individual differences with overlap with the literate sample. Importantly, this pattern suggests that formal education may elevate both mean levels of inhibitory performance and reduce individual differences, effectively compressing the performance distribution. Although reduced variance among literate participants is partly attributable to ceiling effects, the magnitude of the difference in dispersion between groups indicates that sustained educational experience may stabilize inhibitory control across individuals, consistent with cognitive reserve accounts. At the same time, the near-ceiling performance of literate participants limits the extent to which reduced variability can be unambiguously attributed to enhanced stability, and future work using more demanding inhibition tasks will be necessary to disentangle genuine distributional compression from task-related ceiling constraints.

These individual differences in inhibitory control are theoretically important because inhibitory control is important for the deployment of theory of mind skills (Carlson & Moses, 2001) as well as metaphor comprehension (George & Wiley, 2016).

The results suggest that inhibitory control may remain underdeveloped or inconsistently recruited in the absence of sustained educational experience. Importantly, this does not imply a deficit inherent to illiteracy, but rather reflects differences in experiential input. Clearly, some illiterate speakers could perform at ceiling performance. Illiterate adults are often excluded from experimental research, and as a result, models of executive functioning may be implicitly biased toward educated populations. The present findings highlight the need to broaden empirical samples in order to better understand the true range and determinants of executive control in adulthood.

Across all models, age did not significantly predict inhibitory performance. Rather than chronological age per se, it appears to be engagement in cognitively demanding activities, such as formal education and its concomitant effects, that supports inhibitory control across the lifespan. This absence of an age effect remained robust even when non-linear age terms were considered, suggesting that the null finding is unlikely to reflect model misspecification.

This result also has methodological implications. Studies that attribute adult differences in executive functioning primarily to aging may overestimate age effects if educational and literacy-related variables are not adequately controlled. The present findings suggest that education may buffer against age-related decline in inhibition, consistent with cognitive reserve accounts, although longitudinal data would be needed to test this claim directly.

Several limitations warrant consideration. First, the inhibition task consisted of a limited number of trials, which may constrain the reliability of individual-level estimates. Future studies should incorporate multiple inhibitory paradigms or longer task versions to assess the generality of the observed effects. Second, although education and reading fluency were measured directly, other experiential factors, such as occupational complexity, numeracy, or daily cognitive demands, were not assessed and may also contribute to inhibitory control. Third, the inhibitory control task was arguably too easy for literate participants, resulting in near-ceiling performance and consequently larger performance gaps between the two groups. However, given that this study represents a first attempt to document inhibitory control differences between literate and illiterate adults, the use of a simple and highly accessible task was a deliberate methodological choice. Importantly, despite potential ceiling effects in the literate group, the task was sufficiently sensitive to capture substantial variability among illiterate participants and to reveal robust associations with education- and literacy-related measures at the trial level.

Future research should also examine whether literacy acquisition later in life longitudinally leads to measurable improvements in inhibitory control, which would provide stronger causal evidence for the experience-dependent nature of executive functions. Longitudinal and intervention-based designs will be especially important in this regard.

Conclusion

This study provides clear evidence that formal education is associated with individual differences in inhibitory control in adulthood. Literate participants outperformed illiterate participants on a basic inhibition task, suggesting that schooling-related activities and sustained engagement with written language support the development of executive control mechanisms beyond childhood. While inhibitory performance among literate adults approached ceiling levels, illiterate adults showed both lower accuracy and greater variability, underscoring the long-term cognitive consequences of limited educational exposure. These findings complement previous work linking literacy to broader cognitive and neural outcomes and extend it to inhibitory control specifically. Taken together, the results highlight education as a powerful experiential factor shaping executive functions across the lifespan and emphasize the importance of considering literacy background when studying adult cognition.

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