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Breathe Easy, Speak Easy: Pulmonary Function and Language Performance in Aging

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Abstract

Background—This study explored the association between pulmonary function (PF) and older adults' language performance accuracy. Study rationale was anchored in aging research reporting PF as a reliable risk factor affecting cognition among the elderly.

Methods—180 adult English native speakers aged 55 to 84 years participated in the study. PF was measured through forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio (FFR). Language performance was assessed with an action naming test and an object naming test, and two tests of sentence comprehension, one manipulating syntactic complexity and the other, semantic negation. Greater PF was predicted to be positively associated with all tasks.

Results—Unadjusted models revealed FVC and FEV1 effects on language performance among older adults. Participants with higher FVC showed better naming on both tasks and those with higher FEV1 had better object naming only. In covariate-adjusted models, only a positive FVC-object naming association remained.

Conclusion—Findings were discussed in terms of brain oxygenation mechanisms, whereby good PF may implicate efficient oxygenation, supporting neurotransmitter metabolism that protects against neural effects of cerebrovascular risk. Effects on object naming were linked to putative differential oxygenation demands across language tasks.

Keywords

lexical retrieval; sentence comprehension; spirometry; brain oxygenation; older adults

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Conflict of Interest

The authors declare no conflict of interest.

1. Introduction

Physiological changes in aging are known to alter pulmonary structure and function and lead to notable reductions in lung performance (Lalley, 2013). Decreases in pulmonary function (PF) begin at approximately age 25 (Emery, Pedersen, Svartengren, & McClearn, 1998), with non-smoking adults typically showing a one percent reduction in PF per year (Gore, Crockett, Pederson, Booth, Bauman, & Owen, 1995). These changes are usually measured via PF tests of forced expiratory volume in one second (FEV1) and forced vital capacity (FVC), often used to assist in diagnosis of asthma, emphysema, and more generally, chronic obstructive pulmonary diseases (COPD) and overall respiratory performance (Emery et al., 1998). In some studies, deterioration in older adults' PF has also been associated with reduction in FEV1/FVC ratio (FFR) (reviewed in Janssens, Pache, & Picod, 1999). FFR values have been considered in diagnosing clinically-relevant airway obstruction (Swanney et al., 2008).

Age-related declines in PF, captured by respiratory measures such as FEV1, FVC, and FFR, have been linked to coronary heart disease, stroke, and mortality (e.g. Gore et al., 1995; Hole et al., 1996). Impaired PF has also been shown to have adverse effects on cognitive functioning in specific clinical populations, such as individuals with chronic lung diseases (e.g., Emery et al., 2003; Grant, 1982). The impact of poor PF on cognitive performance has also been reported in the general population (e.g. Myint et al., 2005) and found to predict increased risk of dementia (Pathan et al., 2011; Schaub et al., 2000; Vidal et al., 2013). In a recent meta-analysis based on ten studies of PF and dementia and eight studies of pulmonary illness and dementia, Russ and his colleagues (2017) found that decreased FEV1 and FVC (as well as peak expiratory flow) doubled the risk of dementia. Pulmonary function (PF) is thus considered a reliable risk factor of age-related changes in physical and cognitive functioning (Albert et al., 1995; Cook et al., 1995).

The relationship between compromised PF and impaired cognition among older adults has been demonstrated in both longitudinal and cross-sectional studies (e.g. Albert et al., 1995; Anstey, Windsor, Jorm, Christensen, & Rodgers, 2004; Chyou et al., 1996; Cook et al., 1995; Weuve et al., 2008). It is difficult, however, to determine the extent to which PF measures uniquely influence cognitive performance, especially given differences in study design, measures of PF and cognition, and variability in statistical methods (e.g., Duggan, Graham, Piccinin, Clouston, Muniz-Terrera, & Hofer, under review). Nonetheless, small PF effects, if reliable, may reflect a gradual process by which lung health interacts with neural mechanisms across the lifespan (Anstey et al., 2004).

Some PF-cognition studies have shown that among middle-aged adults poor PF was associated with reduced psychomotor speed cross-sectionally and over 10 years (Richards, Strachan, Hardy, Kuh, & Wadsworth, 2005). Emery and colleagues (2012) found comparable results in an older cohort (ages 50–85 at baseline), where, over a span of 19 years, diminished PF was associated with decreased psychomotor speed and spatial abilities; memory, in contrast, was not impacted and verbal abilities evaluating vocabulary were only slightly modified.

These findings are consistent with most PF-cognition studies, which suggest that measures of fluid cognition assessing executive functions, such as sequencing and problem solving, but not those evaluating crystallized knowledge involving information retrieval from long-term memory (like the definitions of words measured in vocabulary tests), are particularly vulnerable to age-related reductions in older adults' PF (e.g. Emery, Finkel, & Pedersen, 2012). Examination of vocabulary measures may thus not be ideal for capturing age-related changes in language performance among the elderly, given that such verbal abilities appear to remain stable over the lifespan (Shafto & Tyler, 2014). In this study, we addressed this shortcoming by focusing on the potential effects of PF on language measures specifically known to be influenced by age, previously unexplored in PF-cognition studies.

Older adults' language problems typically involve difficulty with lexical retrieval (the ability to bring up the name of an item/person from one's memory storage without cue, etc.) (e.g., Connor, Spiro, Obler, & Albert, 2004) and auditory sentence processing in suboptimal conditions (e.g., increased syntactic complexity, reduced plausibility and/or predictability, high-level background noise) (e.g., Goral, Clark-Cotton, Spiro, Obler, Verkulilen, & Albert, 2011). The effects of PF on older adults' language abilities may thus be better characterized by investigating performance on tests assessing naming and sentence comprehension than vocabulary measures.

Evidence of the effects of PF on cognition suggest that a study exploring links between PF and language among the elderly is warranted. Only few studies have considered the potential relationship between PF and language (e.g., the Emery et al. (2012) study discussed above), making observations primarily on measures of vocabulary-definition. Given the shortcomings of these measures as reviewed above, in this study we examined the association between PF and older adults' accuracy performance on language tasks evaluating lexical retrieval and auditory sentence processing. We assessed lexical retrieval using tests of confrontation naming, and sentence comprehension through tests manipulating syntactic or semantic complexity.

In terms of PF, we selected three spirometric measures: forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio (FFR). In addition to being clinically related to the occurrence of conditions such as congestive heart failure (CHF), high systolic blood pressure, chronic bronchitis, pneumonia, emphysema, and asthma among the elderly (Griffith et al., 2001), FEV1 and FVC have been widely used in studies exploring the relationship between PF and cognition (Emery et al., 2012). FFR has been included, for example, in a study examining psychological and cognitive outcomes associated with exercise among older adults with Chronic Obstructive Pulmonary Disease (COPD) (Emery et al., 2003). We hypothesized that better PF would have a global and positive association with performance on both language tasks assessing lexical retrieval and sentence comprehension. This prediction was based on the findings reviewed above, which point to the influence of PF on a wide range of cognitive measures. Because not all cognitive measures seem equally sensitive to PF effects (e.g., Emery et al., 2012), we also considered the possibility that we would find differential patterns with our language measures.

2. Methods

2.1. Sample

Participants comprised 180 adult native speakers of English (61% female) aged 55 to 84 years (Mean 71.2; SD 8.1) who took part in the “Language in the Aging Brain” project (Cahana-Amitay et al., 2013; Cahana-Amitay et al., 2015; Goral et al., 2011). Recruitment was conducted by flyers, mail, and newspaper notices. Prospective participants were screened for eligibility by telephone; history of stroke, dementia, loss of consciousness, general anesthesia within the past 6 months, and radiation treatment within the past year served as exclusion criteria. Eligible participants were then mailed a Health and Behavior Survey (HBS) in which they were asked to provide demographic and health information (medical history, treatment and medication use, as well as health behaviors, such as smoking, alcohol, physical activity). Of the 355 recruited participants, 305 were aged 55–84 at the time of testing; of these, 52 were excluded due to suspicion of cognitive impairment (as indicated by scores < 24 on Folstein, Folstein & McHugh’s (1975) Mini-Mental State Exam), 44 were excluded due to incomplete pulmonary function data (i.e., data on fewer than 2 trials), and another 20 were excluded due to missing height data (to calculate height-adjusted FEV1 and FVC). All of the remaining 180 participants had data on two or more language outcomes (mean = 3.90, SD = 0.37), and formed the analytic sample for the current study.

2.2. Procedure

Participants were scheduled to come in for two study visits, held within a 6-week period. During the initial visit, they underwent a standardized physical exam and a neurological examination conducted by a registered nurse, who also verified the information reported in the HBS. Participants then underwent a 2–3 hour test battery evaluating cognition and language. They then returned for a second 2–3 hour visit to complete the remainder of the cognitive and linguistic tests, which were administered by trained research assistants. The study was approved by the Institutional Review Boards of (1) the Veterans Affairs Boston Healthcare System and (2) the Boston University Medical Campus. All participants provided written informed consent.

2.3. Respiratory Measures

Multiple measures of pulmonary function (PF) were obtained, including forced expiratory volume in 1 second (FEV1), forced vital capacity (FVC), and FEV1/FVC ratio (FFR), using a SpiroLab II computerized machine. FEV1 is the volume of air exhaled forcefully in one second, FVC is the volume of air that can be maximally exhaled in an expiration, and FFR is their ratio. Participants were seated and nose clips were used to block their nasal passages. They then filled their lungs with air and exhaled as forcefully as possible for 6 seconds. Three acceptable trials were performed and recorded. Outlying values of FEV1 and FVC (i.e., >10 liters/second) were removed. For individuals with at least two acceptable trials, mean values of FEV1 and FVC were computed and divided by height (in meters) squared to obtain height-adjusted values, which serve as key independent variables in the analysis. For FFR, the raw values (without height adjustment) of FEV1 and FVC were used.

2.4. Language Measures

Language measures were obtained from two confrontation-naming tests and two auditory sentence comprehension tests (recently described in (Cahana-Amitay et al., 2015)). The confrontation naming tasks included the (1) Boston Naming Test (BNT) (Kaplan, Goodglass, & Weintraub, 1978) and (2) Action Naming Test (ANT) (Obler & Albert, 1979). The auditory sentence comprehension tests evaluated comprehension of (1) sentences that varied in syntactic structure and plausibility (S) and (2) sentences with zero-, one-, and two-negative markers (N) (see Goral et al., 2011). All four tests were administered on a computer using E-Prime software (Psychology Software Tools, Inc.).

Picture naming required labeling visually presented black and white line drawings of objects (60 items, in the BNT test) and actions (57 items, in the ANT test), shown on a computer screen one at a time. If participants did not respond within 20 seconds, or produced an incorrect response, the examiner provided a semantic and then a phonemic cue, if the semantic cue failed to elicit a correction. To avoid ceiling effects, only responses with no cueing were included in the analysis.

Sentence comprehension involved judging the plausibility of auditorily presented pre-recorded sentences by pressing a response button (to indicate whether the content of the sentence was likely or unlikely). In the S test, syntactic structure (presence and placement of relative clauses) and plausibility were manipulated. Stimuli comprised 96 sentences (object-relative: *The jogger identified the robber that the policeman arrested*; subject-relative: *The violinist listened to the conductor that directed the orchestra*; no-relative sentences: *The student filed a complaint when the professor fired the assistant*, distractor, per sentence type), equally divided between plausible and implausible and controlled for length (in terms of number of propositions and content words). In the N task, plausibility and number of negative markers were manipulated. Stimuli comprised 50 sentences (zero-negative: *Tyler had been smiling, so we believe he was happy*; one-negative: *Because the book was long, I could not read it quickly*; two-negative sentences: *Because the ceiling light is not off, the room is not dark*, as well as eleven- and twelve-word non-negative sentences, matched for sentence length of the target sentences). As in the S test, half the sentences were plausible and half implausible.

For all four tests, accuracy performance was assessed. Total number of correct responses divided by total number of properly administered items was calculated and converted into percent correct. Because accuracy variables for the S and N tasks were negatively skewed (skewness = -3.4 and -2.2, respectively), scores (0–100) were subtracted from 101 and then natural-log transformed prior to the analysis; higher values indicate worse performance. In unadjusted models where language outcomes were regressed on pulmonary variables without covariates, model fit was improved when the S and N accuracy variables were log-transformed, compared with using the raw scores (AIC and BIC = 1683). Of note, higher scores on the transformed S and N variables denote *worse* performance.

2.5. Covariates

Age, education, gender, history of smoking and respiratory conditions, and current physical activity were included as covariates. *Education* was measured in years. Due to the low prevalence of current smokers (<4%), *smoking* was coded as 1=current or former smokers and 0=never smoked. *Respiratory conditions* were coded as a dichotomous variable (1=yes, 0=no) indicating whether participants endorsed lifetime occurrence of any of the following conditions: chronic bronchitis, emphysema, asthma, chest illness, and sleep apnea. Current physical activity was indicated by two self-reported variables: *Frequency of engaging in sports or vigorous exercise*, coded as 1=never to 5=five or more times per week; and *number of city blocks* (or their equivalent) walked daily. The latter variable was top-truncated at 50 to handle outliers. A *physical activity* z-score was computed as the mean z-score of the two indicators and used in the analysis.

2.6. Analyses

We computed descriptive statistics for all variables. Across covariates, data were missing for less than 7% of the sample. We generated maximum likelihood estimates of missing covariates based on participants' responses to all variables in the analytic model (Graham, 2012). This approach is based on the assumption that the data were missing at random (MAR).

Next, three separate multivariate regression models were conducted, each with a different pulmonary measure as the key predictor of accuracy performance on the four language tasks. Analyses were conducted using Mplus version 7.4 (Muthén & Muthén, 2012). First, for each of the three PF measures, we examined an unadjusted model where the four language outcomes were simultaneously regressed on PF (i.e., FEV1, FVC, FFR). Then we tested a fully-adjusted model that included all the covariates. We report the unstandardized regression coefficients (*b*) for model predictors, which represent the absolute difference in the language outcome for each unit of difference in the predictor. We also report the standardized regression coefficients (β) to facilitate comparison among predictors. For continuous predictors, β was standardized against both the predictor and outcome; each β is interpreted as the difference in each language outcome (in *SD* units) for each 1*SD* difference in the continuous predictor. For binary predictors, β was standardized against the outcome only; each β is interpreted as the difference in each language outcome (in *SD* units) between the two categories of the predictor. Of note, due to the aforementioned transformations of the S and N task accuracy scores to handle skewness (as described in Section 2.4), positive regression coefficients correspond to predictors associated with *worse* accuracy on the S and N tasks. We also report fit indices Akaike Information Criterion (AIC; Akaike, 1974) and Bayesian Information Criterion (BIC; Schwarz, 1978) for each model.

Missingness in the language outcomes was handled with full-information maximum likelihood. In the unadjusted model, covariates were included as auxiliary variables (i.e., treated as correlates of missing data) to facilitate maximum likelihood estimation of the language outcomes. Variable skewness was handled via robust estimation.

3. Results

3.1 Descriptive Findings

Descriptive statistics are shown in Table 1. Skewness and correlations among all variables are presented in Table 2. Participants' mean respiratory values (FEV1: 2.11 liter per second; FVC, 2.81 liters) were slightly lower than those for older adults in the National Health and Nutrition Study (NHANES, FEV1: 2.67 liters/sec; FVC: 3.53 liters) (Hankinson, Kawut, Shahar, Smith, Stukowsky, & Barr, 2010). The NHANES cohort was somewhat younger than the participants in our sample (mean 65 years vs. mean 72 years). However, in a study by Emery et al. (2012), which compared PF effects on older adults' cognitive performance, participants with a mean age of 72 years had FEV1 and FVC values closer to ours (FEV1: 2.04; FVC: 2.14).

Our participants' object naming was also age-appropriate, as their BNT scores were comparable to those described in other language and aging studies (e.g. Connor et al., 2004). Their performance on the other language measures could not be directly assessed for age-appropriateness because reports describing older adults' action naming, comprehension of syntactically complex sentences, and comprehension of negation used different tasks. All but two participants were at least high school graduates, and 60% had at least college-level education. Less than 4% of the sample were current smokers, but 45% identified as former smokers. About one-fifth of the sample had a history of respiratory disease. The sample reported exercising 1–2 times per week on average.

3.2. FEV1

In the unadjusted regression model with FEV1 as the key predictor, higher FEV1 was associated with better performance on the BNT test. Individuals with 1 liter/second higher FEV1 were estimated to have 10% greater accuracy on this confrontational naming task. FEV1 was unrelated to action naming or sentence comprehension performance. After adjusting for the influence of demographic variables, history of smoking and respiratory conditions, and physical activity on language outcomes, the association between FEV1 and BNT was no longer significant.

Results from the final model for FEV1 are shown in Table 3: Women performed better than men on both sentence comprehension tasks. Assuming mean values of FEV1, age, education, physical activity, a history of smoking but no respiratory disease, the estimated sex difference is 1.6% on the S task (94.9% for females vs. 93.3% for males) and 2% on the N task (96.9% for females vs. 94.9% for males). Younger participants performed better than older participants on the S task, ANT, and BNT. Compared with individuals at the sample mean age of 71, those a decade older were estimated to have 1.7% lower accuracy on the S task, 1.2% lower accuracy on the ANT, and 2.1% lower accuracy on the BNT. More education lent an advantage across all language tasks. Greater physical activity was linked to lower N task accuracy; individuals scoring 1 SD higher on physical activity were estimated to have 1% lower accuracy on the N task compared to those at the sample mean level of physical activity. The final model provided excellent fit to the data: $\chi^2 = 12.08$, $df = 21$, $p = .94$, AIC = 8643, BIC = 8919, RMSEA = .00, CFI = 1.00, TLI = 1.11, SRMR = .02.

3.3 FVC

Results for FVC as the key predictor of language outcomes are shown in Table 4. The associations with language performance were stronger for FVC than FEV1. In the unadjusted model, each liter higher in FVC corresponded to 4.6% higher accuracy on the ANT and 11.0% higher accuracy on the BNT, but FVC was not related to performance on the S and N tasks. After adjusting for covariates, the association between FVC and ANT became non-significant. However, the association between FVC and BNT, although attenuated, remained significant: Each liter higher in FVC was associated with 7.9% improvement in BNT accuracy. There was a marginal association between FVC and S (better FVC, higher S) in unadjusted model, which became nonsignificant after adjusting for covariates.

3.4 FFR

Results on the association between FFR and language outcomes are shown in Table 5. The aforementioned relation between pulmonary function, as indicated by FEV1 and FVC, and naming performance was not observed for FFR. In both the unadjusted and fully adjusted models, FFR was not related to either sentence comprehension or confrontation naming (all p 's > .05).

3.5 Summary of Findings regarding PF and Language

In terms of the covariates, across the models reported in Tables 2–4, women outperformed men on sentence comprehension. Older participants had worse performance on one sentence comprehension task (S) and both naming tasks. Higher education was consistently linked to better naming performance, and had a marginal association with better performance on the N task. Greater physical activity was related to worse performance on the N task.

4. Discussion and Conclusion

Findings from this study show that older adults' pulmonary function (PF), as measured by forced vital capacity (FVC), is positively associated with language performance, especially with a task evaluating object naming (BNT). That is, those with greater PF were better able to handle the task performance demands of accurate noun retrieval. FVC was also marginally positively associated with a task assessing comprehension of syntactically complex sentences (S).

The PF effects on older adults' language performance that we observed involved FVC but not FEV1, suggesting that these PF indices implicate related but distinct physiological mechanisms. This idea is consistent with findings reported by Pathan et al. (2011), who found that FVC-based restrictive ventilatory pattern, rather than an FEV1-related obstructive pattern, was associated with poorer cognitive function and greater risk of dementia among the elderly. In the current context, we would argue that the physiological differences between restrictive and obstructive patterns may underpin the differential PF effects on language performance in the elderly.

The PF effects we observed influenced only a subset of our language measures, primarily object naming. This pattern is consistent with findings from the PF-cognition literature, in which many, but not all, cognitive measures are shown to be sensitive to PF effects. The absence of a generalized PF effect on language performance is likely not attributable to particularly high PF values in our sample. The PF values reported here are consistent with the predicted respiratory values of the general US population (see Hankinson et al., 2010). They are also similar to values published in PF-cognition aging studies reviewed in the introduction (e.g. Emery et al., 2012). In addition, we do not think these results can be explained in terms of increased level of physical activity in our sample, or lower levels of smoking, which were controlled in our analysis. The significant association between FVC and BNT in the fully-adjusted model (Table 4), as well as similar patterns of findings for FVC-ANT and FEV1-BNT, suggest that the observed PF effects on language performance cannot be reduced to demographic or lifestyle differences, and deserve more thorough investigation using larger samples, to allow for clearer differentiation of covariate, as compared to PF effects.

Thus, the PF-object naming association we report here, although small, is non-negligible. As such, it could represent cumulative lifelong interactions between respiratory function and neural mechanisms (Antsey et al., 2004). Therefore, to explain the potential link between PF and object naming, we suggest considering the relationships among PF, brain oxygenation, and neural mechanisms in aging. A common assumption is that older adults' declining PF compromises brain oxygenation, which alters the central nervous system by either impairing neurotransmitter metabolism (e.g. Dustman, Emmerson, & Shearer, 1994; Grant, 1982), or creating subclinical cerebral abnormalities associated with increased cardiovascular risk and pro-inflammatory processes (Guo et al., 2006; Liao et al., 1999). This idea is supported by epidemiological data that point to an association between age-related reduction in lung function and dysregulated glucose metabolism (e.g. McKeever, Weston, Hubbard, & Fogarty, 2005). Similar associations have also been reported for older adults' compromised PF and increased inflammation (Shaaban et al., 2006). In fact, in some studies, older adults' decreased lung function has been linked to both glucose abnormalities and presence of inflammation (Dennis et al., 2010).

However, with such a neural mechanism in place, other cardiovascular risk factors that predict cognitive decline in aging may come into play (for a related comment, see Russ et al., 2017), suggesting that the naming performance observed in this study may reflect the effect of cardiovascular disease rather than that of pulmonary function *per se*. Because pulmonary function is related to coronary disease (see Introduction), and because we did not control for cardiovascular risk in our analysis, we cannot rule out this possibility. Indeed, in earlier studies exploring the effects of cerebrovascular health on language and aging, we have shown that increased cerebrovascular risk impairs older adults' language performance (e.g., Albert et al., 2009; Cahana-Amitay et al., 2013; Cahana-Amitay et al., 2015). Thus, future studies exploring the impact of PF on language performance in aging should consider health, and cerebrovascular risk factors (e.g., hypertension, diabetes, and metabolic syndrome) as possible mediators of these effects.

Interestingly, the influence of cerebrovascular risk on older adults' linguistic performance also demonstrated differential patterns, reminiscent of our current findings. For example, in one such study (Cahana-Amitay et al., 2013), we showed that hypertension and type II diabetes both contribute to older adults' difficulties in sentence comprehension, but that their relative contributions to poor performance were distinct: Hypertension was linked to accuracy in comprehending sentences with negative markers, while diabetes was related to impaired comprehension of syntactically complex sentences. In another study, we compared language performance among older adults with and without metabolic syndrome and found disease presence impairs (1) action but not object naming and (2) comprehension of sentences that manipulate syntactic structure but not negation (Cahana-Amitay et al., 2015).

These cumulative findings have led us to propose a neural model in which age-related language impairments implicate at least two separate, biologically modifiable, pathogenic mechanisms that act on the brain simultaneously to influence linguistic functions (Cahana-Amitay et al., 2015). One involves inflammation-linked microvascular changes in brain systems mediated primarily by frontal white matter. The other implicates metabolic neuronal dysfunction associated with insulin resistance and reduced glycemic control affecting neuronal networks underlying language and cognition in widely distributed fields, altering the brain in a multifocal manner. Compromised PF as a gateway to inefficient brain oxygenation could be easily incorporated into such a model, given the presumed relationship between older adults' poor respiratory health, glucose abnormalities, and inflammatory processes mentioned earlier in the discussion.

However, the notion that changes in older adults' PF negatively affects brain oxygenation and in doing so impairs language performance still leaves open the question of why these effects might be differential with respect to language. We speculate that older adults' accuracy on some language tasks may draw on oxygen more heavily than others, because of greater energy demands of the neural networks engaged in the specific cognitive-linguistic tasks. This idea was inspired by evidence from studies examining the impact of exercise on language performance, showing PF effects on cognitive measures comprising verbal components, such as verbal fluency (Colcombe & Kramer, 2003). Our data clearly do not allow us to develop and evaluate this idea further, as we did not include cognitive measures in the current analysis. Future studies should include both cognitive and linguistic measures to help determine whether cognitive performance does, in fact, mediate linguistic patterns, as related to older adults' PF.

Nonetheless, our proposal is in line with studies linking older adults' difficulties with language performance to cognitive changes in the aging brain (Shafto & Tyler, 2014). For example, older adults' slow processing speed can impede action naming (e.g. Szekely et al., 2005). The common assumption is that aging adults with preserved cognitive abilities, use them as a performance-enhancing support mechanism for deteriorating language functions (e.g. DeDe, Caplan, Kemtes, & Waters, 2004; Goral et al., 2011).

In addition, emerging evidence from the cognitive aging literature, especially those focused on older adults' picture naming accuracy (Conner et al., 2004), suggests a potential dissociation between the cognitive supports involved in noun versus verb retrieval processes.

For example, a small number of studies have explored whether older adults' word retrieval is related to cognitive processing, as measured by verbal fluency (McDowd et al., 2011; Piatt, Fields, Paolo, & Tröster, 1999). In this context, fluency was taken as a measure of word-access efficiency from long-term memory (e.g., Fisk & Sharp, 2004). Results showed that category fluency is linked to older adults' naming accuracy (McDowd et al., 2011), and that action fluency fails to correlate with object naming (Piatt et al., 1999).

The finding we report here, while specific, is consistent with independent claims from the cognitive-linguistics literature regarding the grammatical and conceptual distinctions between action and object naming (e.g., Shao et al., 2012). It supports a lexicalist views of language production (e.g., Levelt, 1989), whereby grammatical class is an integral part of lexical representation, which would predict noun-verb word dissociations even when words are produced in isolation. Finally, it is also aligned with longstanding findings from the aphasia literature, which have demonstrated distinct neuroanatomical patterns associated with the lexical properties, such as imageability, abstractness, and animacy, of nouns as compared with verbs (e.g., Caramazza & Hillis, 1991).

We acknowledge that the proposal we outlined above is highly speculative and that our findings may derive from altogether different factors. The simplest explanation would be that our sample size was not large enough to show PF-language effects comparable to the PF-cognitive effects described in the larger aging studies we reviewed in the introduction. Another possibility is that PF and language performance in aging are simply not tightly related. Support for this scenario comes from a systematic review of longitudinal studies of PF effects on older adults' cognition (Duggan et al., under review), which suggests limited evidence for a link between changes in respiratory measures and cognitive performance among aging adults over time. This conclusion, combined with our findings (or lack of), might suggest that a re-evaluation of the presumed link between PF and cognitive aging is warranted.

In summary, this study demonstrates that object naming is positively associated with changes in older adults' respiratory health. The mechanism by which preserved forced vital capacity contributes to naming accuracy remains underspecified, but we propose that it may involve efficient oxygenation of the aging brain, supporting neurotransmitter metabolism and minimizing the neural effects of increased cardiovascular and cerebrovascular risk and pro-inflammatory processes. The specific PF effects on object naming may reflect its distinct oxygenation demands, as compared to other language tasks, arguably attributable to the extent to which it implicates cognitive processes. To shed light on this hypothesis, future studies should carefully examine the putative relationship between language and cognition and the degree to which each interacts with pulmonary function and other cerebrovascular risk factors that affect cognitive aging. Nonetheless, the current findings serve as a small additional step in demonstrating the importance of examining cerebrovascular health status when assessing language in the aging brain.

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Table 1Descriptive statistics for the analytic sample ($n=180$).

	<i>N</i>	<i>M</i> / (%)	<i>SD</i>	Range
<u>Pulmonary function:</u>				
FEV1 (liter per second)	180	2.11	0.6	0.93 – 4.00
FVC (liter)	180	2.81	0.82	1.56 – 5.05
Height (cm)	180	163.77	9.23	141 – 184
<u>Language performance:</u>				
S: % accurate	170	89.99	7.10	68.1 – 100
N: % accurate	172	93.13	5.84	54.0 – 100
ANT: % accurate	180	87.74	6.41	70.2 – 98.3
BNT: % accurate	180	83.53	9.84	45.0 – 98.3
<u>Covariates:</u>				
Age	180	71.18	8.09	55 – 84
Sex (1=female, 0=male)	180	66.1%	--	--
Education (years)	180	15.25	1.90	9 – 17
Smoking (1=current/former, 0=never)	180	47.8%	--	--
Respiratory disease (1=yes, 0=never)	180	19.6%	--	--
Physical activity z-score	180	0.05	0.81	–1.20 – 2.36

Note: Raw values (i.e., not height-adjusted) for FEV1 and FVC are shown. Descriptive statistics for covariates are based on maximum likelihood estimates.

Table 2

Skewness and correlations among all analytic variables ($n=180$).

	Skewness	FEV1_h	FVC_h	FFR	Female	Age	Education	Respiratory disease	Physical activity z-score	Smoking	S [†]	N [†]	ANT
FEV1_h	0.58	--											
FVC_h	0.85	0.91											
FFR	-1.17	0.38	-0.04										
Female	-0.69	-0.33	-0.42	0.15									
Age	-0.35	-0.24	-0.19	-0.16	-0.12								
Education	-0.85	0.19	0.19	0.04	-0.04	-0.20							
Respiratory disease	1.55	-0.09	-0.02	-0.16	0.06	-0.15	0.09						
Physical activity z-score	0.64	0.12	0.13	-0.01	-0.06	-0.17	0.20	-0.11					
Smoking	0.09	-0.26	-0.19	-0.20	-0.07	0.06	-0.10	0.14	0.002				
S [†]	-0.52	-0.10	-0.14	0.05	-0.15	0.32	-0.22	-0.12	-0.15	0.05			
N [†]	-0.72	0.01	0.03	-0.05	-0.24	0.14	-0.13	-0.07	0.12	0.06	0.25		
ANT	-0.63	0.13	0.16	-0.08	0.03	-0.22	0.22	0.05	0.09	-0.06	-0.42	-0.22	
BNT	-0.85	0.19	0.25	-0.09	-0.11	-0.24	0.30	0.09	0.10	0.031	-0.44	-0.22	0.52

Notes: Correlations were estimated with full-information maximum likelihood robust method. Bold indicates $p < .05$.

[†] S and N percent accuracy were subtracted from 101 and then log-transformed due to skewness; higher scores indicate lower accuracy.

Table 3

Unadjusted and Fully Adjusted Regression Model on the Association between Height-Adjusted FEV1 and Language Performance ($n=180$).

	Sentence Comprehension						Naming					
	S			N			ANT			BNT		
	<i>b</i>	<i>SE</i>	<i>p</i>	β	<i>b</i>	<i>SE</i>	<i>p</i>	β	<i>b</i>	<i>SE</i>	<i>p</i>	β
Unadjusted model:												
FEV1	-0.40	0.33	0.22	-0.10	0.03	0.36	0.93	0.01	4.29	2.72	0.11	0.13
Adjusted model:												
FEV1	-0.26	0.34	0.44	-0.07	-0.16	0.34	0.65	-0.04	2.19	3.08	0.48	0.06
Female (1=F, 0=M)	-0.23	0.11	0.03	-0.32	-0.41	0.12	0.001	-0.50	0.52	1.03	0.61	0.08
Age	0.02	0.01	0.003	0.22	0.01	0.01	0.17	0.10	-0.12	0.06	0.05	-0.16
Education	-0.05	0.03	0.08	-0.14	-0.06	0.03	0.06	-0.14	0.57	0.24	0.02	0.17
Ever smoked (1=Y, 0=N)	0.01	0.11	0.91	0.02	0.02	0.13	0.09	0.03	-0.18	0.95	0.85	-0.03
Respiratory disease (1=Y, 0=N)	-0.15	0.14	0.28	-0.21	-0.03	0.16	0.09	-0.03	0.37	1.20	0.76	0.06
Physical activity z-score	-0.08	0.07	0.23	-0.10	0.16	0.06	0.01	0.15	0.20	0.63	0.76	0.03
									0.04	0.82	0.96	0.004

Note: Bold indicates $p < .05$. *b* = unstandardized regression coefficient; SE = standard error; β = standardized regression coefficient. S and N percent accuracy were subtracted from 101 and then log-transformed; therefore, higher values represent worse accuracy, and positive coefficients correspond to predictors of worse accuracy. Physical activity was the average of z-scores based on two variables: *Number of city blocks walked daily* (0–50), and *frequency of engaging in sports or vigorous exercise* (from 1=never to 5=five or more times per week). For binary predictors, β was standardized with regard to the outcome variable only. For continuous predictors, β was standardized with regard to both the predictor and outcome. Fit indices for the unadjusted model were: AIC = 6189.4, BIC = 6435.3; and for the fully adjusted model: AIC = 3196.6, BIC = 3330.7.

Table 4

Unadjusted and Fully Adjusted Regression Model on the Association between Height-Adjusted FVC and Language Performance ($n=180$).

	Sentence Comprehension						Naming					
	S			N			ANT			BNT		
	<i>b</i>	<i>SE</i>	<i>p</i>	β	<i>b</i>	<i>SE</i>	<i>p</i>	β	<i>p</i>	<i>b</i>	<i>SE</i>	β
Unadjusted model:												
FVC	-0.43	0.26	0.10	-0.14	0.11	0.28	0.69	0.03	0.04	10.95	3.58	0.002
Adjusted model:												
FVC	-0.45	0.28	0.11	-0.14	-0.15	0.28	0.59	-0.04	0.15	7.85	4.06	0.05
Female (1=F, 0=M)	-0.29	0.11	0.01	-0.40	-0.42	0.12	<0.001	-0.51	0.33	-0.74	1.85	0.69
Age	0.02	0.01	0.01	0.21	0.01	0.01	0.16	0.10	0.06	-0.14	0.10	0.05
Education	-0.05	0.03	0.10	-0.13	-0.06	0.03	0.06	-0.14	0.03	1.25	0.37	0.00
Ever smoked (1=Y, 0=N)	-0.00	0.11	0.97	-0.01	0.03	0.12	0.84	0.03	0.93	1.81	1.40	0.19
Respiratory disease (1=Y, 0=N)	-0.14	0.14	0.33	-0.20	-0.02	0.16	0.90	-0.03	0.81	0.75	1.74	0.67
Physical activity z-score	-0.08	0.07	0.26	-0.09	0.16	0.06	0.01	0.15	0.80	-0.03	0.80	0.97

Note: Bold indicates $p < .05$. *B* = unstandardized regression coefficient; *SE* = standard error; β = standardized regression coefficient. S and N percent accuracy were subtracted from 101 and then log-transformed; therefore, higher values represent worse accuracy, and positive coefficients correspond to predictors of worse accuracy. Physical activity was coded such that 1 = never, 2 = less than once per week, 3 = one or two times per week, 4 = three to four times per week, and 5 = five or more times per week. For binary predictors, β was standardized with regard to the outcome variable only. For continuous predictors, β was standardized with regard to both the predictor and outcome. Fit indices for the unadjusted model were: AIC = 6254.6, BIC = 6500.5; and for the adjusted model: AIC = 3192.3, BIC = 3326.4.

Unadjusted and Fully Adjusted Regression Model on the Association between FFR (ratio of height-adjusted FEV1 to height-adjusted FVC) and Language Performance ($n=204$).

Table 5

	Sentence Comprehension						Naming					
	S			N			ANT			BNT		
	<i>B</i>	<i>SE</i>	<i>p</i>	β	<i>b</i>	<i>SE</i>	<i>p</i>	β	<i>b</i>	<i>SE</i>	<i>p</i>	β
Unadjusted model:												
FFR	0.46	0.63	0.46	0.05	-0.54	0.72	0.45	-0.05	-6.48	6.78	0.34	-0.08
Adjusted model:												
FFR	1.06	0.59	0.07	0.12	0.09	0.72	0.91	0.01	-10.69	6.81	0.12	-0.13
Female (1=F, 0=M)	-0.21	0.11	0.05	-0.304	-0.39	0.12	0.001	-0.47	0.43	0.93	0.64	0.07
Age	0.02	0.01	<0.001	0.26	0.01	0.01	0.13	0.11	-0.15	0.06	0.01	-0.19
Education	-0.06	0.03	0.06	-0.15	-0.06	0.03	0.05	-0.14	0.60	0.24	0.01	0.18
Ever smoked (1=Y, 0=N)	0.06	0.11	0.55	0.09	0.04	0.13	0.76	0.05	-0.64	0.92	0.49	-0.10
Respiratory disease (1=Y, 0=N)	-0.10	0.14	0.44	-0.15	-0.02	0.16	0.92	-0.02	-0.10	1.18	0.94	-0.02
Physical activity z-score	-0.08	0.07	0.23	-0.09	0.16	0.06	0.01	0.15	0.15	0.62	0.81	0.02
									0.004	0.80	1.00	0.00

Note: Bold indicates $p < .05$. *B* = unstandardized regression coefficient; *SE* = standard error; β = standardized regression coefficient. S and N percent accuracy were subtracted from 101 and then log-transformed; therefore, higher values represent worse accuracy, and positive coefficients correspond to predictors of worse accuracy. Physical activity was coded such that 1 = never, 2 = less than once per week, 3 = one or two times per week, 4 = three to four times per week, and 5 = five or more times per week. For binary predictors, β was standardized with regard to the outcome variable only. For continuous predictors, β was standardized with regard to both the predictor and outcome. Fit indices for the unadjusted model were: AIC = 5918.3, BIC = 6164.2; and for the fully adjusted model: AIC = 3193.7, BIC = 3327.8.