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Women who breastfeed exhibit cognitive benefits after age 50

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ABSTRACT

Background and objectives: Women who breastfeed may experience long-term benefits for their health in addition to the more widely appreciated effects on the breastfed child. Breastfeeding may induce long-term effects on biopsychosocial systems implicated in brain health. Also, due to diminished breastfeeding in the postindustrial era, it is important to understand the lifespan implications of breastfeeding for surmising maternal phenotypes in our species' collective past. Here, we assess how women's breastfeeding history relates to postmenopausal cognitive performance.

Methodology: A convenience sample of Southern California women age 50+ was recruited via two clinical trials, completed a comprehensive neuropsychological test battery and answered a questionnaire about reproductive life history. General linear models examined whether cognitive domain scores were associated with breastfeeding in depressed and non-depressed women, controlling for age, education and ethnicity.

Results: Women who breastfed exhibited superior performance in the domains of Learning, Delayed Recall, Executive Functioning and Processing Speed compared to women who did not breastfeed (*P*-values 0.0003–0.015). These four domains remained significant in analyses limited to non-depressed and parous subsets of the cohort. Among those depressed, only Executive Functioning and Processing Speed were positively associated with breastfeeding.

Conclusions and implications: We add to the growing list of lifespan health correlates of breastfeeding for women's health, such as the lower risk of type-2 diabetes, cardiovascular disease and breast cancer. We surmise that women's postmenopausal cognitive competence may have been greater in past environments in which breastfeeding was more prevalent, bolstering the possibility that postmenopausal longevity may have been adaptive across human evolutionary history.

Lay Summary: Breastfeeding may affect women's cognitive performance. Breastfeeding's biological effects and psychosocial effects, such as improved stress regulation, could exert long-term benefits for the mother's brain. We found that women who breastfed performed better on a series of cognitive tests in later life compared to women who did not breastfeed.

KEYWORDS: breastfeeding; lactation; reproductive life-history; cognitive health; dementia; Alzheimer's risk factors

1. INTRODUCTION

The long-term health effects of breastfeeding for the mother have received far less attention than its effects on child development. Yet, breastfeeding represents a physiologically, psychologically and behaviorally transformative experience for the mother in underappreciated ways. Breastfeeding is practiced by the majority of women on earth [1] and ~72% of women in the U.S [2, 3]. Furthermore, breastfeeding norms have recently changed dramatically compared to the vast majority of human history [4, 5], potentially with concomitant changes in breastfeeding's health consequences for women. Women today breastfeed less frequently and, on average, for a shorter duration than we surmise would have been the norm in the past [6], thus women today may benefit less from any maternal health benefits that breastfeeding confers.

Here, we focus on the relationship between maternal breastfeeding history and cognitive performance in women over age 50. Cognitive health is a crucial outcome because it is critical to well-being in aging adults. Cognitive impairment is the primary symptom of Alzheimer's Disease (AD), the leading form of dementia and one of the leading causes of disability among the elderly worldwide [7]. Cognitive impairment after age 50 is a strong predictor of AD risk [8]. Currently, there is no consensus on whether breastfeeding is beneficial for cognition later in life. A very small number of previous studies exhibit conflicting evidence for breastfeeding's association with cognitive performance or AD risk among postmenopausal women. Hence, the aim of the current study is to address the issue of the effects of breastfeeding on cognition in later life by administering a more comprehensive neuropsychological test battery than has been used in prior studies.

1.1. Women's reproductive life-history and health across the lifespan

Reproductive life-history describes the timing and implementation of reproductive events and stages across the lifespan and includes birth, menarche, pregnancy, breastfeeding and menopause. Aspects of a woman's reproductive life-history exert acute and long-term effects across many domains of her health. For example, there are well-established relationships between pregnancy and increased risk of depression onset [9], i.e., immediate postpartum effects. There are also well-established patterns reflecting long-term effects, such as the relationship of greater parity with reduced breast cancer risk and the relationship of earlier first pregnancy with reduced breast cancer risk [10].

Breastfeeding, by comparison, has received less attention for its effects on maternal health. Nonetheless, there is ample reason to suspect breastfeeding profoundly influences maternal health, with not only acute but also long-term effects, described below.

1.2. Hypothesis

In the current study, our aim is to clarify whether breastfeeding has long-term benefits on cognition. We hypothesize that breastfeeding should be associated with improved cognitive performance. Our reasons for this prediction are four-fold: (i) the biological effects of breastfeeding would plausibly be neuroprotective [11–17]; (ii) previous studies demonstrate positive correlations between breastfeeding and lower risk of other diseases that have been strongly connected to cognitive health [18–26]; (iii) evidence that breastfeeding is associated with a lower AD risk; (iv) the psychosocial effects of breastfeeding being associated with better mental health [27].

Lactation has persistent, reorganizing effects on maternal physiology, including postweaning increased insulin sensitivity and improved glucose homeostasis, more efficient β-cell function [11], increased adipose tissue mobilization [12] and favorable lipid metabolism [13]. Little is known about the precise roles of lactation-related hormones (e.g. prolactin and oxytocin) in these processes, or whether these effects can be partially attributed to fewer menstrual cycles, so future research is needed to elucidate the biomechanisms. Nonetheless, each of these pathways has been implicated as AD risk factors and/or in AD pathogenesis [14–17], justifying our hypothesis that breastfeeding should be neuroprotective in later life.

Women's history of breastfeeding has been associated with lower risk of type-2 diabetes [18], hypertension, hyperlipidemia, cardiovascular disease [19], metabolic syndrome [20], myocardial infarction [21] and breast cancer [22], as well as AD [23]. Type-2 diabetes [24], hypertension [25], hyperlipidemia and cardiovascular disease [26] have each been associated with enhanced risk of AD in multiple studies with a few exceptions [28], with these epidemiological patterns likely due to compromise of brain metabolism and cerebrovascular function [29]. The negative association between breastfeeding and these AD-associated conditions justifies our hypothesis that breastfeeding should be associated with long-term superior cognitive performance.

1.3. Previous studies

Two previous studies have demonstrated correlations between women's breastfeeding history and cognitive impairment. Heys et al. found that the average duration of breastfeeding per child was negatively associated with both immediate and delayed 10-word recall, as well as Mini-Mental State Exam (MMSE), in a cohort of 11 094 women from the Guangzhou Biobank Cohort Study in southern China [30]. A smaller study by Hesson *et al.* [31] found that longer breastfeeding duration was associated with lower performance on a prospective memory assessment in a cohort of 50 women in British Columbia, Canada. In contrast, one study found that breastfeeding was associated with lower AD risk. Fox *et al.* [23] found, in a cohort of 81 British women, longer cumulative duration of breastfeeding per cumulative duration of pregnancies across the lifespan was associated with lower AD risk.

1.4. Psychosocial effects

Previous studies of the links between women's reproductive life-history and long-term health have overlooked psychosocial mechanisms. While reproductive life-history events have transformative effects on biological systems, they also transform social roles and networks. We further justify our hypothesis that breastfeeding should be associated with long-term improved cognitive performance with evidence that breastfeeding promotes improved maternal stress regulation, lower risk of postpartum depression and bonding with the infant [27]. Chronic stress [32, 33], mid-life depression [34, 35] and lack of social support (specifically from children [36, 37]) are each positively associated with cognitive decline, dementia and specifically AD risk.

2. METHODS

This is a cross-sectional, secondary analysis completed on baseline data collected from two randomized controlled trials, the 'Brain Connectivity and Response to Tai Chi in Geriatric Depression' study (NCT02460666; referred to as DEP) that included depressed participants, and the 'Reducing Risk for Alzheimer's Disease in High Risk Women through Yoga or Memory Training' study (NCT03503669; referred to as MEM) that included non-depressed participants with current subjective memory complaints and cardiovascular risk based on the 2013 ACC/AHA Guideline on the Assessment of Cardiovascular Risk. DEP participants were randomized to either a 12-week Tai Chi or a Health and Wellness Education intervention. MEM participants were randomized to either a 12-week Memory Enhancement Training or a yogic meditation intervention. Both studies were conducted at the University of California, Los Angeles (UCLA), and all study procedures were approved by the UCLA Institutional Review Board and comply with the Declaration of Helsinki. For DEP, the presence of depression was assessed by a Hamilton Rating Scale for Depression score of >14 at baseline consistent with moderate depression. Participants were stable on antidepressant treatments for at least four months. For MEM, participants were excluded if clinically significant depressive symptoms were present as indicated by a Beck Depression Inventory score >17. Other exclusion criteria for both trials included a diagnosis of dementia or mild cognitive impairment, other psychiatric diagnoses including bipolar disorder, psychosis (except for comorbid anxiety or insomnia for DEP), alcohol/drug dependence, unstable medical or neurological disorders, disabilities preventing their participation in Tai Chi exercise, yoga or Memory Training, currently taking psychoactive medications, or participating in psychotherapy that involves cognitive training. Inclusion criteria for both trials included MMSE score >24, sufficient English proficiency, and capacity to provide informed consent. Both trials had identical neuropsychological testing protocols. Neuropsychological assessments were administered by trained raters at baseline and week 12, but the present study analyzed only the baseline measures.

2.1. Cognitive measures

Participants completed a comprehensive neuropsychological test battery that evaluated the following cognitive domains: Learning (California Verbal Learning Test-II (CVLT-II) [Trial 1 through 5 Total] or Hopkins Verbal Learning Test (HVLT) [Total Recall], Rey–Osterrieth Complex Figure Test (ROCF) [3-minute recall]); Delayed Recall (CVLT-II [long delayed free recall] or HVLT [Delayed Recall], ROCF [30-minute delayed recall]); Executive Functioning (Trail Making Test B (TMT), Controlled Oral Word Association test (FAS)); and Processing Speed (TMT A, Stroop Color Naming [Kaplan version]). CVLT-II involves the immediate and delayed memory trials assessing memory of two 16 word lists from four semantic categories [38]. HVLT involves immediate and delayed recall of 12 words from three semantic categories [39]. ROCF evaluates visuospatial constructional ability and visual memory using copy, immediate recall and delayed recall tasks [40]. TMT-A involves connecting randomly arranged circles containing numbers following the numerical sequence as fast as possible [41]. TMT-B is similar but alternates between numbers and letters. FAS involves naming as many words as you can beginning with a single letter in one minute [42]. The Stroop Color Naming task, where participants are required to name the color of the ink instead of reading the word, is a test that assesses the ability to inhibit cognitive interference and processing speed. Raw scores were transformed to *z*-scores for each test score for each participant, reversing *z*-scores as necessary so that high *z*-scores represented good performance for all

Table 1. Demographic and other characteristics of participants

Variable	Non-depressed ($n = 51$)	Depressed ($n = 64$)	Statistics
Demographics			
Age[a]	66.5 (8.5), 55–86	69.1 (6.4), 60–86	$t(113) = 1.9$, $P = 0.06$
Education	15.7 (1.9)	15.9 (1.8)	$t(113) = 0.6$, $P = 0.5$
Race			Fisher's exact $P = 0.3$
Caucasian	34 (66.7%)	53 (82.8%)	
African American	8 (15.7%)	4 (6.3%)	
Asian	3 (5.9%)	4 (6.3%)	
Other	5 (1.0%)	2 (3.1%)	
Hispanic	1 (2.0%)	1 (1.6%)	
Cognitive measures			
MMSE	28.3 (1.5)	28.8 (1.2)	$t(113) = 1.9$, $P = 0.06$
Learning	−0.15 (1.0)	0.12 (1.0)	$t(108) = 1.4$, $P = 0.2$
Delayed recall	−0.08 (0.9)	0.06 (1.0)	$t(108) = 0.7$, $P = 0.5$
Executive functioning	0.01 (1.2)	−0.01 (0.8)	$t(108) = 0.1$, $P = 0.9$
Processing speed	−0.12 (0.9)	0.09 (1.0)	$t(108) = 1.1$, $P = 0.3$
Reproductive history			
Parity[a]	2.3 (1.6), 1–8	1.2 (1.4), 0–7	$t(108) = 4.0$, $P = 0.001$
Gravidity[a]	3.6 (2.8), 1–8	2.3 (1.9), 0–8	$t(108) = 2.9$, $P = 0.004$
Age at menopause (years)	49.68 (5.46)	49.06 (6.71)	$t(113) = 0.5$, $P = 0.59$
Duration of breastfeeding (months)[a]	11.5 (13.0), 0–48	6.6 (10.7), 0–54	$t(113) = 2.2$, $P = 0.03$
Ever breastfed	33 (64.7%)	28 (43.8%)	$\chi^2(1) = 5.0$, $P = 0.03$

Mean (SD) for continuous variables and number (%) for categorical variables.
MMSE, Mini Mental State Exam.
[a]Mean (SD) is followed by range.
Depressed participants derive from the DEP sub-cohort and non-depressed participants derive from the MEM sub-cohort.

measures. These *z*-scores were averaged within each neuropsychological domain to produce composite domain scores.

2.2. Reproductive history variables

All participants were administered a questionnaire via phone or email regarding their reproductive history. This questionnaire was designed and implemented for the present study and not part of the clinical trials' original study designs. Women were asked about age at menarche, number of complete pregnancies, number of incomplete pregnancies (spontaneous and elective abortions), duration of breastfeeding for each child (regardless of exclusivity) and age at menopause, if applicable. Gravidity was operationalized by summing all reported complete and incomplete pregnancies. Approximately half (47%) of the participants included in the study reported that they had not breastfed, i.e., duration of breastfeeding was zero for all children, so we categorized the breastfeeding variable as Ever Breastfed/Never Breastfed for analyses. We took steps to account for the possibility that 0 breastfeeding duration could statistically behave as a proxy for 0 parity. Hence, another set of models repeated the first set of analyses in the subset of cohort with parity greater than 0. Additionally, supplementary analyses were performed in order to investigate potential dose-dependent effects of breastfeeding. For this purpose, we partitioned the breastfeeding variable into three groups based on duration: 0 months, 1–12 months and more than 12 months of cumulative breastfeeding. No participants in this cohort exhibited cumulative breastfeeding duration between 0 and 1 month.

2.3. Statistical analysis

Prior to analyses, data were inspected for outliers, skewness and homogeneity of variance to ensure the appropriateness of parametric statistical tests. T-tests and chi-square tests were used to examine demographic as well as cognitive differences between depressed and nondepressed participants. General linear models (GLM) were used to examine whether cognitive

domain scores were associated with cumulative duration breastfeeding operationalized dichotomously (Ever/Never), with supplementary models repeating this analysis within the parous cohort subset as well as models utilizing a three-tier operationalization of breastfeeding duration (Table S2).

All models controlled for age, educational level and ethnicity. Since depression has been associated with both lower breastfeeding rates [43] and worse geriatric cognitive performance [44], depression status is a possible confounder and we addressed this concern in two ways. Firstly, we included depression status as an additional control variable. Secondly, in separate sets of models, we investigated the two groups separately: depressed and non-depressed. We considered whether to include parity and gravidity as additional covariates; however, both of these were highly significantly associated with breastfeeding ($P < 0.0001$) and this may lead to multi-collinearity in the models. Hence, we did not include these in the model. Controlling for age at assessment allowed us to adjust for age-typical trends in cognitive performance as well as the changing breastfeeding norms across history because all women were assessed within 3.5 years of each other. While data were not available on household income either during women's reproductive years or postmenopause, we were able to control for some potential socio-economic confounders by including educational level and ethnicity as covariates. Ethnicity was operationalized dichotomously as Caucasian/non-Caucasian due to the variable's distribution in our cohort. Educational level was operationalized as a continuous variable reflecting years of schooling.

All analyses were performed using SAS version 9.4 (SAS System for Windows, Cary, NC, USA). We present test statistics as well as effect sizes (Cohen's d) for group differences.

3. RESULTS

A total of 115 (64 depressed and 51 non-depressed) participants aged 50 years and older were included in the analysis. Table 1 compares the groups in terms of baseline characteristics. There were no significant differences between depressed and non-depressed participants in age, race, education, MMSE scores or other cognitive measures. Depressed participants tended to be older (mean age 69.1 (SD 6.4) years) than the non-depressed participants (mean age 66.5 (SD 8.5) years), although the difference was not statistically significant. All of the non-depressed participants reported at least one completed pregnancy compared to 57.8% of the depressed participants (27 women were nulliparous). In addition, non-depressed women reported a significantly greater number of completed pregnancies (parity) and number of initiated pregnancies (gravidity) and more non-depressed women reported breastfeeding compared to depressed (64.7% non-depressed vs. 43.8% depressed). Twenty-two women (13 non-depressed and 9 depressed) had parity ≥ 1 but did not breastfeed.

All four cognitive domain scores (i.e. Learning, Delayed Recall, Executive Functioning and Processing Speed) were associated with breastfeeding in the full cohort, controlling for age, education, ethnicity and depression status. Those who breastfed had higher scores in all the four cognitive domains than those who did not breastfeed, with medium to large effect sizes (*P*-values ranging from 0.0003 to 0.015; effect sizes ranging from 0.46 to 0.71; Fig. 1, Table 2; Table S1). To account for the possibility that zero breastfeeding could inadvertently serve as a proxy for nulliparity, we examined results just for the parous cohort subset. We found, similarly, among parous women, those who breastfed had higher scores in all the four cognitive domains than those who did not breastfeed, with notably greater significance and effect sizes than in the full cohort (*P*-values ranging from <0.0001 to 0.002, all large effect sizes ranging from 0.80 to 0.97, Table 2 and Table S5).

Examining the depressed and non-depressed groups separately, in the non-depressed participants, all four cognitive domain scores were significantly associated with breastfeeding. In the depressed group, only the Executive Functioning and Processing Speed domains were significantly associated with breastfeeding (Table 2 and Table S1), with the same patterns when considering only the parous subset of depressed participants, with notably greater significance and effect sizes (Table S5). In the depressed group compared to the non-depressed group, Executive Functioning had a smaller effect size (as did Learning and Delayed Recall although those effects were not significant) and Processing Speed had a greater effect size.

The relationship between breastfeeding operationalized as three groups and cognitive performance was also significant for all four cognitive domains (Table S3). We conducted t-tests post-hoc to the GLM—thus accounting for the covariates—comparing mean cognitive scores for each dyadic combination of breastfeeding groups (Table S4). The 0 breastfeeding group exhibited cognitive scores significantly lower than the >12 months group for all cognitive domains, and significantly lower than the 1–12 months group for 3 of the 4 domains. Although the longest breastfeeding group had the highest cognitive performance scores, none of the comparisons between the middle and longest breastfeeding groups were significant (Table S4).

4. DISCUSSION

The long-term effects of breastfeeding on women's cognitive health is an important and understudied topic with implications for biopsychosocial and evolutionary sciences. In a cohort of women over age 50, those who had breastfed exhibited better performance in all four cognitive domains we measured, compared to women who had not breastfed. Effect sizes were

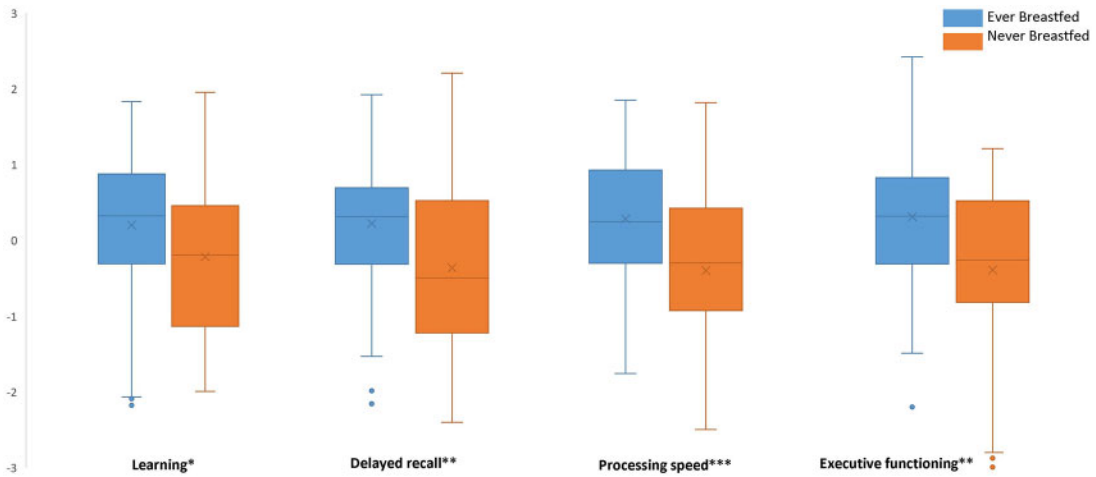

Figure 1. Box-and-whiskers plot of cognitive domain z-scores by breastfeeding groups, showing the mean, median, quartiles, range, and outliers: X in the box represents the mean, the line represents the median and the box represents 50% of the data, distributed between the 1st and 3rd quartiles. The whiskers extend up to the largest data element that is less than or equal to 1.5 times the interquartile range (IQR) and down to the smallest data element that is larger than 1.5 times the IQR. Values outside this range are represented by dots. *$P < 0.05$ ** $P < 0.01$ *** $P < 0.001$.

medium to large—contextually, most clinical trials target a medium effect size [45]. The non-depressed subset of women showed a relationship between breastfeeding and cognitive performance in all four domains, while the depressed subset of women showed a relationship only for two domains. Cognitive scores were significantly higher for women who breastfed, compared to those who did not, regardless of whether the cumulative breastfeeding duration was 1–12 or >12 months. The excess improvement for the longer duration group was not statistically significantly different from the middle duration group. The results held—and were stronger—among the parous subset of cohort, suggesting that breastfeeding history was not serving merely as a proxy for parity.

4.1. Biopsychosocial context

Breastfeeding involves a suite of interacting processes across biological, psychological, and social systems. The various elements of the biopsychosocial triad might contribute to relationships between maternal breastfeeding history and late-life cognitive health. Breastfeeding may exert long-term, neuroprotective effects for the lactating woman via improvement in metabolic and psychosocial conditions. In our study, we found that breastfeeding ever was more frequent and breastfeeding duration was longer among the non-depressed cohort compared to depressed, consistent with the possibility that breastfeeding could be associated with lower late-life depression risk. Depression is a widely recognized risk factor for dementia [46] and AD [47]. Breastfeeding is associated with mother–infant bonding and attachment [27], and strained relationships with adult children have been associated with higher levels of depression [48] and cognitive limitations [49] among older adults. Although beyond the scope of this study, it is worth noting that although breastfeeding has not (known to the authors) been directly linked with adult relationship quality, this may be deserving of future study given that the positive association with mother-infant relationship may have long-term implications for adult relationship quality. If this speculation were endorsed by future studies, it would support the possibility that breastfeeding could be protective against depression and/or cognitive decline in older age via improvement in relationship quality with adult children.

Together, the ways in which breastfeeding promotes neurobiological benefits as well as psychological and social benefits each indicate the likelihood of lower risk of dementia and AD in later life, as well as the intervening risk factor of depression.

4.2. Evolution, cognition and human longevity

This study is partly motivated by an interest in the evolutionary dynamics of postmenopausal longevity in humans. Living beyond age 50 is estimated to have emerged between 1.6 million and 150 000 years ago [50], and the modal adult age at death among contemporary hunter-gatherers is 72 years [51]. It remains controversial whether longevity itself began as a byproduct of another adaptation, emerged due to positive selection from grandmother allomothering, or another reason [52, 53]. However, its initial emergence is not relevant to this study. Regardless of the reason for its initial emergence, it is widely suggested that postmenopausal longevity affects inclusive fitness [54]. Widely accepted is the notion that, across human history, women who lived for several years beyond menopause enhanced their inclusive fitness by engaging in activities that benefited kin [55]. The activities that have received the most attention in the anthropological literature include childcare of weanlings and food production, but it should

Table 2. Association of cognitive scores with breastfeeding

Measure	Full cohort[a]		Parous subset		Depressed subset		Non-depressed subset	
	Statistics	Effect size[b]	Statistics	Effect size[b]	Statistics	Effect size[b]	Statistics	Effect size[b]
Learning	$F(1,109) = 6.10$; $P = 0.015^{*}$	0.46	$F(1,77) = 9.91$; $P = 0.002^{*}$	0.81	$F(1,57) = 1.16$; $P = 0.30$	0.25	$F(1,47) = 9.51$; $P = 0.004^{**}$	0.94
Delayed recall	$F(1,109) = 9.09$; $P = 0.003^{**}$	0.57	$F(1,77) = 13.85$; $P = 0.0004^{***}$	0.97	$F(1,57) = 2.14$; $P = 0.15$	0.38	$F(1,47) = 11.36$; $P = 0.002^{**}$	0.97
Executive functioning	$F(1,109) = 8.77$; $P = 0.004^{**}$	0.58	$F(1,77) = 12.40$; $P = 0.0007^{***}$	0.80	$F(1,57) = 4.63$; $P = 0.04^{*}$	0.43	$F(1,47) = 4.72$; $P = 0.04^{*}$	0.63
Processing speed	$F(1,109) = 13.97$; $P = 0.0003^{***}$	0.71	$F(1,77) = 17.58$; $P < 0.0001^{***}$	0.94	$F(1,57) = 10.59$; $P = 0.02^{*}$	0.83	$F(1,47) = 6.13$; $P = 0.02^{*}$	0.74

Marginal effects reflecting the associations between breastfeeding and cognitive scores, controlling for covariates. These results are derived from general linear models reflecting the dependence of each domain of cognitive performance on breastfeeding history and control variables. Breastfeeding variable was categorized as Ever Breastfed/Never Breastfed. Depressed participants derive from the DEP sub-cohort and non-depressed participants derive from the MEM sub-cohort. All models controlled for age, educational level and ethnicity and in addition, the models for the full cohort and parous subset controlled for depression status.

[a]Box-and-whiskers plot in Fig. 1.

[b]Cohen's d.

$^{*}P < 0.05$.

$^{**}P < 0.01$.

$^{***}P < 0.001$.

be noted that other important activities may have included domestic labor, skills training and teaching grandchildren how to engage and succeed in the complex social world [56]. Importantly, these activities all require intact cognitive ability. Therefore, it is necessary to discern what cognitive health might have been across human evolutionary history in order to assess the fitness landscape of postmenopausal longevity.

One of the most profound ways in which female human physiology has changed in the modern era is the shift in female reproductive life history. Earlier age at menarche and fewer pregnancies typify contemporary industrialized populations, compared to human historical and pre-historical norms [57]. Breastfeeding norms have also shifted dramatically, with women in many industrialized societies today practicing less breastfeeding than would have been typical in the pre-modern past [6]. Virtually, all surviving infants would have been breastfed before the advent of infant formula. We can estimate breastfeeding duration across human history by looking to contemporary non-industrialized populations as well as archaeological evidence from skeletal remains, although both methods are flawed and limited. Nonetheless, a meta-analysis of 113 contemporary non-industrialized populations demonstrated mean length of total breastfeeding per child of 29 ± 10 months [4], and skeletal isotope analyses of hunter-gatherer populations ranging from 12 000–2500 years ago demonstrated total breastfeeding per child of 22–68 months [5].

We posit that there is an 'evolutionary mismatch' between the pre-modern norm of near-universal and long-duration breastfeeding and contemporary low breastfeeding rate and duration in many industrialized populations. The mismatch lies in the notion that selection on post-menopausal female physiological, cognitive and longevity traits would have occurred in the context of women who had the long-term effects of frequent and long-duration breastfeeding. The biopsychosocial effects of breastfeeding influence the health, minds and social lives of women. Our results suggest that women who breastfed may have had superior cognitive function in the post-menopausal stage of life compared to women who did not breastfeed. This would imply that as we evaluate the costs and benefits of post-menopausal longevity for inclusive fitness across human history, it may be necessary to consider the fitness landscape in the context of women who are more cognitively competent than typical, age-matched women in industrialized populations who breastfeed more seldom and for a shorter duration.

4.3. Limitations

Our results should be considered in light of several limitations. We relied on retrospective recall of reproductive life-history information, including breastfeeding data. A study of women 69–79 years of age with known breastfeeding history derived

from a contemporaneous diary study on reproductive patterns found that ever breastfeeding each child was recalled with 94% accuracy [58], suggesting reliability for the primary predictor variable here. Our study is limited by the fact that recruitment methods were designed for a different purpose related to the clinical trials described above. We used data collected at baseline so the interventions should not have an impact upon our results, but we were unable to target a cohort based on variability in reproductive life-history traits. Also, we were limited in how many questions we could ask to minimize participant fatigue, so we were not able to collect information on other relevant variables, such as age at first birth or postnatal age at the introduction of solid foods. Data were unavailable on the reasons to breastfeed or not, or reasons for breastfeeding cessation, which could be relevant for elucidating the relationship between breastfeeding and long-term health. It would be possible that an unmeasured confounder, such as stress or social support at the time of breastfeeding, could contribute to a statistical relationship between breastfeeding initiation or discontinuation and postmenopausal cognitive performance. Future studies are needed to examine how postmenopausal cognitive performance relates to women's circumstances and decisions to breastfeed during the reproductive years.

Because nearly half of the women in this study did not breastfeed at all, our data positioned us better to evaluate the difference between breastfeeding at all versus not at all, rather than measure the effects of breastfeeding duration. Our Southern California population appears to be typical of U.S. norms during the cohort's reproductive period, e.g., U.S. breastfeeding initiation rates were 25% in 1974, 47% in 1978 and 60% in 1984 [59]. We note that this population does not reflect human historical breastfeeding norms, and encourage future studies to measure the relationship between breastfeeding and cognitive function in populations with diverse life-histories.

5. CONCLUSION

Our cross-sectional data suggest that women who breastfed demonstrate superior cognitive performance after age 50 in certain domains compared to women who never breastfed. This effect was more consistent among the non-depressed cohort subset, who exhibited benefits in all four domains measured—Learning, Delayed Recall, Executive Functioning, Processing Speed—than those who were depressed, who only exhibited benefits in the latter two categories and diminished effect size in Executive Functioning. Future studies are needed to explore the relationship between women's breastfeeding history and cognitive performance in larger sample sizes, other comorbid contexts, as well as populations that reflect geographic, ethnic and cultural diversity. It would be useful to measure these relationships in non-contraceptive populations in order to more closely reflect the impact of reproductive life-history variance of ancestral populations. It would also be useful to measure these relationships in populations whose reproductive periods span different periods of history in order to elucidate contextual effect modifiers.

Supplementary data

Supplementary data is available at *EMPH* online.

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