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EXPLORATORY REPORT

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Associations between risk factors, developmental outcomes, and executive function in neonatal intensive care unit graduates at 2 years: A retrospective study

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Abstract

This study explores the extent to which medical and sociodemographic variables and cognitive and language skills are associated with executive function (EF) skills in neonatal intensive care unit (NICU) graduates at 24 months of adjusted age. We explored cognitive, language, and EF skills in 42 NICU graduates who participated in a NICU follow-up programme clinic. The association between risk factors and EF and the completion of the EF assessment were explored. Correlational analyses revealed that child gender was associated with EF scores. Analyses revealed cognitive skills, language skills, and multiple gestational births were associated with EF assessment completion. Our findings are among the first to examine EF skills in NICU graduates as young as 24 months of age using a multidimensional, child completed measure. Implications for NICU follow up programmes, the consideration of early interventions aimed to positively affect EF skills, and considerations for future studies are discussed.

KEYWORDS
at-risk infants, cognitive and language development, executive function, NICU follow up, prematurity

1 | INTRODUCTION

Neonatal intensive care unit (NICU) admissions continue to rise (Harrison & Goodman, 2015), and these admissions are associated with a higher risk for developmental impacts in these children compared to their healthy peers (Smith et al., 2011). A NICU admission is associated with risk for neurodevelopmental delays in the early childhood years and decreased school readiness (Pritchard et al., 2014). One critical component of school readiness is the development of executive function (EF) skills (Shaul & Schwartz, 2014). These skills have been shown to be a stronger predictor of a child's school readiness than intelligence quotients (Blair & Peters-Razza, 2007). EF is a set of cognitive processes that encompass attentional and inhibitory control, self-regulation, working memory, cognitive flexibility, reasoning, problem solving, and planning that develop over time as the brain matures (Bolton & Hattie, 2017; Diamond & Lee, 2011). EF is a relatively undifferentiated construct in young children, becoming differentiated with varied experiences and maturation. (Diamond, 2006; Wiebe et al., 2011; Zelazo et al., 2016)

EF plays a key role in the regulation of behaviour and learning, thus growing literature links these functions to academic success (Barkley, 2001; Nayfeld et al., 2013). For example, Fuhs and colleagues (Fuhs et al., 2014) found children's EF abilities at age four were associated with math and oral language. Controlling for this effect, EF was a strong predictor of math abilities and a moderate predictor of language abilities at age five. EF skills have also been associated with reading skills, social competence, and self-regulation in pre-kindergarteners (Sasser & Bierman, 2015). Further, there is a significant association between EF skills and adaptiveness, social emotional competence, and academic performance for adolescents, suggesting these effects persist throughout development (Best et al., 2011; Sasser & Bierman, 2015).

Given that EF is associated with language and cognitive development (Gooch et al., 2016; Müller et al., 2009), identifying interventions targeting deficits is critical. Specifically, early childhood is thought to be a prime opportunity to influence EF skills through focused interventions (Zelazo et al., 2016), and these interventions can improve EF skills in children through enrichment programmes and activities (Bierman et al., 2008; Lillard & Else-Quest, 2006).

There are multiple influences on the development of children's EF that should be considered in NICU graduates. Infants born prematurely, with low birthweight, multiple gestational pregnancy, and those with neonatal complications, have been found to have poor EF skills in their preschool and school age years (Vohr, 2014). These deficits have long-term impacts with subsequent influence on academic success (Aarnoudse-Moens et al., 2009). In addition to medical risk factors, sociodemographic risk factors, such as socioeconomic status and gender are also associated with EF (Hackman et al., 2015; Matthews et al., 2009).

Considering many NICU graduates appear to be at high-risk for EF difficulties, it is critical that we establish relevant factors influencing these skills to identify children most at-risk for delays as early as possible to ensure the implementation of focused interventions targeted at cultivating EF skills and subsequently improving academic outcomes. While associations between EF and academic abilities have been implicated, most investigations have been completed with school-aged children and adolescents. Few studies to date focused on NICU graduates have examined these associations in early childhood, and explorations of these relationships utilizing a multidimensional assessment in this population as early as the toddler years have not been conducted. To address this gap, this study explores (Harrison & Goodman, 2015) the extent to which medical and sociodemographic variables and (Smith et al., 2011) cognitive and language skills are associated with EF skills in NICU graduates at 24 months of adjusted age.

2 | METHODS

2.1 | Participants

The Institutional Review Board granted approval for this retrospective study. Data were obtained from the database of one midwestern state's NICU follow up programme and the data are not publicly available. The participants were 42 NICU graduates enrolled in the Midwestern statewide NICU follow up programme. The children were graduates

of four tertiary care NICUs located in a metropolitan area of the state, with unit admissions covering a larger geographical area. During an 18-month period, comprehensive developmental assessment data (cognitive, language, and EF) were collected during a follow up clinic visit when the children were approximately 24 months adjusted age ($M = 24.28$ months, $SD = 0.58$ months).

A selected set of sociodemographic and medical risk factor variables were obtained from each child's medical records. The sociodemographic risk variables included ethnicity, child gender, payment type (as a proxy for socioeconomic status), and maternal age at the time of birth. The medical risk variables considered were the child's birthweight, gestational age, length of NICU stay, and multiple gestation birth. The selected set of variables were included in the analyses based on previous research suggesting the influence of these variables on child outcomes, including academic achievement, attention problems, and internalizing behaviour problems, visuomotor and visuospatial function, and EF (Baron et al., 2012; Bierman et al., 2008). Variables that were dichotomously coded for analyses are: ethnicity (Caucasian or minority); gender (male or female); payment type (private insurance or Medicaid); and multiple gestation birth (single or multiple).

2.2 | Procedure

Parents were invited to enrol their infant in the programme if their infant had a NICU stay of at least 72 h. The statewide follow up programme is a 3-tiered model of follow-up (Jackson & Needelman, 2007), with each child assigned a level of follow-up based on their level of risk. Children considered to be at high-risk for impacts on their development due to risk criteria related to their NICU stay, such as a birthweight less than 1500 grams, a hypoxic ischemic event, or congenital anomalies, are seen by an interdisciplinary team at one of five statewide clinics for developmental assessment. Children are seen for a clinic visit at 6, 16, and 24 months of age when adjusted for prematurity (how old the infant is based on their expected date of delivery). During clinic visits, a comprehensive developmental assessment, and neurodevelopmental screening are completed.

The children's caregiver(s) were present for the assessment administration. All efforts were made to ensure the child was in the best possible health at the time of the assessment. The assessments were completed in person during a single visit. The examiner established rapport with the child through play and social engagement prior to beginning the assessments. Neutral praise and encouragement were used to encourage the completion of the assessment tasks. All measures for this study were administered by one examiner who maintains certification in both child assessment measures. The examiner was trained for reliability by testing consultants highly trained and experienced in the administration of each assessment used for this study.

2.3 | Measures

The Bayley III (Bayley, 2005) was administered at the 24-month adjusted age follow-up visit as a measure of the children's cognitive and language abilities. The Bayley III is a widely used standardized measure of children's cognitive and language development, with well-established reliability and validity. In the current analyses, the composite standard score for each area (cognitive and receptive/expressive language) was used. Bayley III data were available for the 42 participants. The Bayley III was completed prior to the introduction of the EF assessment.

The Minnesota Executive Function Scale (MEFS) (Carlson & Zelazo, 2014) was administered at the 24-month adjusted age follow up visit to measure children's EF skills. On the MEFS, children are provided instructions and modelling for two types of card sorts, and then children practice the card sort during two pre-assessment trial sets. Children who pass both trial sets move onto the assessment administration. Children who are unable to pass both trial sets do not move onto the assessment administration, and these children are considered non-completers of the MEFS assessment. The MEFS reliably measures early learning and school readiness skills related to EF and is the only

early learning readiness, child-completed assessment that can be used with children as young as 24 months of age. The MEFS is normed on a representative sample of children from 2 to 13 years, with a mean age of 60.2 months. Data from approximately 400 24-to-25-month-olds were used in the normative sample. MEFS has demonstrated

TABLE 1 Descriptive statistics for all study variables.

Sociodemographic risk factors	
White	$N = 36$ (85.7%)
Other	$N = 6$ (14.3%)
Female	$N = 25$ (59.5%)
Male	$N = 17$ (40.5%)
Private insurance	$N = 34$ (81.0%)
Medicaid	$N = 8$ (19.0%)
Maternal age (in years)	$M = 29.6$ (SD = 4.5)
Medical risk factors	
Birthweight (in kg)	$M = 1.4$ (SD = 0.58)
Gestational age (in weeks)	$M = 30.1$ (SD = 3.7)
Length of NICU stay (in days)	$M = 60.1$ (SD = 32.1)
Multiple birth	$N = 15$ (35.7%)
Singleton	$N = 27$ (64.3%)
Outcome variables	
24-month cognition	$M = 93.3$ (SD = 12.4)
24-month language	$M = 94.4$ (SD = 14.3)
24-month MEFS	$M = 91.5$ (SD = 7.2)
Completed MEFS	$N = 31$ (73.8%)

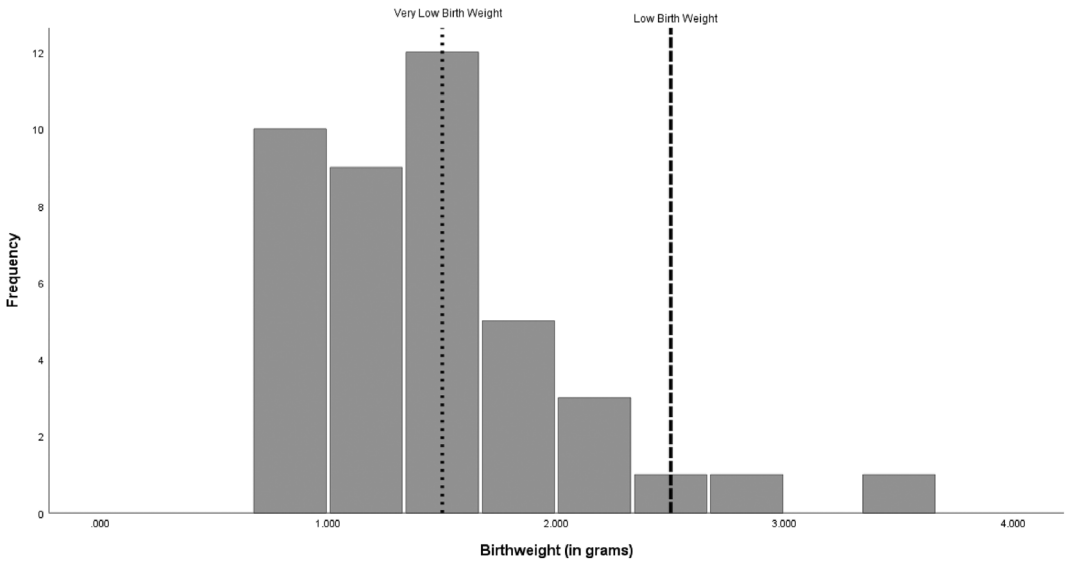

FIGURE 1 Histogram showing participant birthweights in grams. The average birthweight was 1450 grams and 64.3% of the sample had a birthweight less than 1500 g.

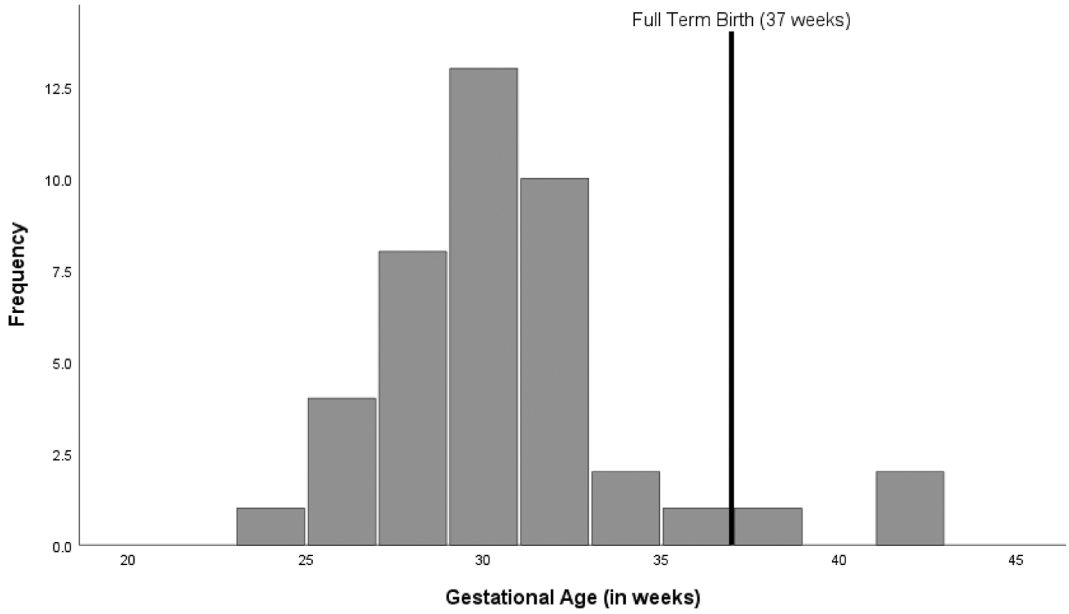

FIGURE 2 Histogram showing participant gestational age in weeks. The average gestational age was 30.1 weeks and 92.9% of participants were born prematurely (<37 weeks).

significant correlations with other measures related to EF (e.g., dimensional change card sort, EF Touch) and has excellent test and retest reliability. Such results of adequate concurrent validity with other measures of EF add support to its ability to measure EF (Carlson, 2020). The MEFS assessment is administered via an electronic application on an iPAD. Of the 42 participants, 31 completed (73.8%) the MEFS, and 11 children (26.2%) were unable to engage in the assessment to complete the adequate number of items on the MEFS to obtain a score.

2.4 | Data analyses

Due to the exploratory nature of the present study and the lack of precedent established in the literature base, descriptive analyses and bivariate correlations were conducted to determine whether associations existed between the sociodemographic and medical risk factors, cognitive and language scores from the Bayley III, and MEFS scores in a sample of 24-month-old children. Based on preliminary findings from the bivariate correlation analysis, one-way ANOVAs were used to compare cognitive and language skills between those who completed the MEFS versus those who did not.

3 | RESULTS

Descriptive statistics for all study variables can be found in Table 1. Participants were mostly White (85.7%), female (59.5%), and had private insurance (81.0%). The average birthweight was 1450 grams, with 95.2% of the sample being characterized as low birth weight (less than 2500 grams) and 64.3% of the sample being characterized as very low birth weight (less than 1500 grams; Figure 1). The average gestational age was 30.1 weeks, with 92.9% of the sample being born prematurely (prior to 37 weeks; Figure 2). The average length of stay in the NICU was 60.1 days. Standardized scores on the Bayley III and MEFS for the overall sample were in the average range (85–115).

TABLE 2 Correlations between all study variables.

	1	2	3	4	5	6	7	8	9	10	11	12
1. Ethnicity	1.00											
2. Gender	0.06	1.00										
3. Payment type	−0.03	0.03	1.00									
4. Maternal age	−0.03	−0.34*	−0.37*	1.00								
5. Birthweight	−0.10	−0.02	0.06	−0.15	1.00							
6. Gestational age	−0.10	0.03	−0.03	−0.16	0.88**	1.00						
7. Length of stay	0.12	0.03	−0.04	0.01	−0.71**	−0.81**	1.00					
8. Multiple births	−0.30	−0.50**	−0.11	0.44**	−0.14	−0.22	0.11	1.00				
9. 24 month cognition	−0.22	0.05	−0.31	−0.03	0.04	−0.02	−0.05	0.17	1.00			
10. 24 month language	−0.18	0.19	−0.23	−0.23	−0.08	−0.04	−0.03	−0.11	0.67**	1.00		
11. Completed MEFS	−0.22	−0.05	0.01	−0.21	−0.24	−0.29	−0.01	0.33*	0.48**	0.55**	1.00	
12. 24 months MEFS	0.05	0.49**	−0.03	−0.08	−0.11	−0.18	0.22	−0.28	0.12	0.33	--	1.00

Note: Ethnicity coded as 1 = Other; Gender coded as 1 = female; Payment type coded as 1 = Medicaid; Multiple births coded as 1 = multiple births; completed MEFS coded as 1 = completed.

*$p < 0.05$; **$p < 0.01$.

Bivariate correlations were run between all study variables to ascertain whether sociodemographic or medical risk factors were associated with cognitive skills, language skills, or EF at 24 months (Table 2). Due to the small sample size and exploratory nature of the present study, no correction for multiple correlations was used. Gender and multiple births were the only sociodemographic or medical risk factors significantly correlated with the outcome measures. On average, females scored 7 points higher on the MEFS assessment than males (94.42 vs. 87.42), and children who were multiple births were more likely to complete the MEFS versus singletons.

Regarding associations between the outcome measures (cognitive skills, language skills, and EF), cognitive and language skills were significantly and strongly correlated ($r = 0.67$). In addition, while cognitive skills and language skills were not associated with EF scores on the MEFS, they were significantly associated with whether children completed the MEFS or not.

Given that one-quarter of the sample did not complete the MEFS assessment and significant positive correlations were found between 24-month cognitive skills and language skills and MEFS completion, one-way ANOVAs were conducted to examine group differences in cognitive and language skills for MEFS completers and non-completers. There were significant differences in both cognitive skills ($F = 11.43$, $df = 1$, $p = 0.002$) and language skills ($F = 16.88$, $df = 1$, $p < 0.001$) between completers and non-completers (Table 3). Children who completed the MEFS

TABLE 3 One-way ANOVA results comparing MEFS completers to MEFS non-completers.

	MEFS completers		MEFS non-completers					
	N	*M* (SD)	*N*	*M* (SD)	*df*	*F*	η^2	*p*
24-month cognition	31	96.6 (11.1)	10	83.0 (11.1)	1	11.43	0.23	0.002
24-month language	31	98.8 (12.8)	10	80.8 (9.3)	1	16.88	0.30	<0.001
	N (%)		*N* (%)		*df*	*F*	η^2	*p*
Gender					1	0.10	0.00	0.75
Female	18 (58.1%)		7 (63.6%)					
Male	13 (41.9%)		4 (36.4%)					
Multiple birth					1	4.92	0.11	0.03
Multiple	14 (45.2%)		1 (9.1%)					
Singleton	17 (54.8%)		10 (90.9%)					

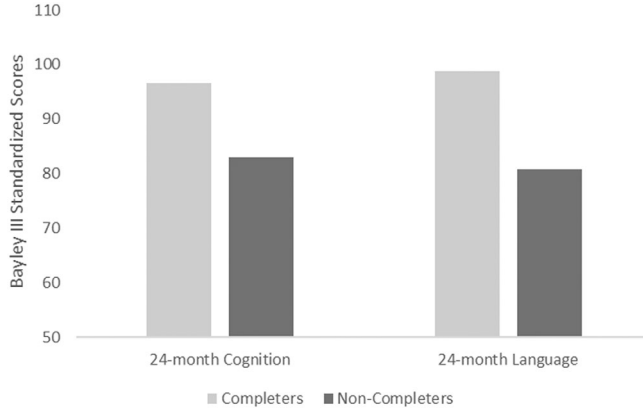

FIGURE 3 Comparison of Bayley Scales of Infant and Toddler Development- 3rd edition cognition and language scores at 24 months adjusted age between MEFS completers and MEFS non-completers.

had significantly higher cognitive and language scores than children who did not complete the MEFS (Figure 3). Effect sizes were large: $\eta^2 = 0.23$ for cognitive skills and $\eta^2 = 0.30$ for language.

ANOVAs examining gender and multiple birth differences between completers and non-completers were also run. Significant differences were found between completers and non-completers in the proportion of those who were multiple births versus singletons ($F = 4.92$, $df = 1$, $p = 0.03$) with a moderate effect size ($\eta^2 = 0.11$) (93.3% of multiples completed the MEFS assessment, while 63% of singletons completed the MEFS assessment). No significant differences were found in gender between completers and non-completers.

4 | DISCUSSION

We know that admission to the NICU is associated with increased risk for neurodevelopmental delays, decreased school readiness skills, and a higher incidence of attention problems (Aarnoudse-Moens et al., 2009; Vohr, 2014). Further, EF has been implicated in academic performance and social competence in school-aged children (Sasser & Bierman, 2015). The findings of this study are among the first to examine EF skills in NICU graduates as young as 24 months of age using a multidimensional, child completed measure, and the results suggest several directions for future research.

Results from the correlational analyses point to the importance of investigating those factors that are related to EF assessment completion. While further understanding of what accounts for non-completers proves relevant to understanding child outcomes, rates of noncompletion in the current study were comparable to rates in prior research evaluating EF skills in typically developing children at 2.5 years, 3.5 years, and 4.5 years of age (Beck et al., 2011), where approximately 25% of the 2.5-year-old participants did not complete the EF task.

The extant literature related to the association between gender and EF is inconsistent, and the correlational results from this study add to these inconsistencies. To date, much of the EF research suggests that EF skills develop at a similar rate across genders (Pauls & Archibald, 2016); however, some findings suggest gender differences in the development of EF in NICU graduates (Hackman et al., 2015; Matthews et al., 2009). Based on the current participants' ages and that stratification of EF typically begins around mid-childhood (Anderson, 2002), EF was measured as a unitary construct in the current study. Given the higher association of MEFS completion with cognitive and language skills, it is possible that items load heavier on verbal processing, information processing, and memory. Future studies should investigate if item loading on EF measures might inadvertently lead to a gender effect.

Results from the one-way ANOVAs support previous findings that language and EF skills have a reciprocal relationship, with language thought to be a fundamental precursor to the development of EF skills (Pauls & Archibald, 2016) and cognitive constructs known to be key components for EF development (Langkamp & Brazy, 1999). As such, language and cognitive impairments may be a cue to providers to attend closely to concerns related to EF and assess these abilities if concerns arise. If EF concerns are present in addition to language and/or cognitive impairments, all deficit areas would need targeted interventions for continued support for the child. The results of this exploratory study cannot discern if language and cognitive skills are necessary precursors to the development of EF skills in 24-month-olds or if these skills must be congruent with the lower end of the testing age range (24 months age) to complete the MEFS assessment.

While previous research has shown that sociodemographic risk factors (e.g., low income, minority status) and medical risk factors (e.g., birthweight) can be associated with lower EF skills, the only factor associated with EF skills in this sample was that children from multiple gestational births were more likely to complete the MEFS. This finding was unexpected given previous findings demonstrating that children born from multiple gestation pregnancies are at higher risk for developmental delays (Aarnoudse-Moens et al., 2009; Vohr, 2014). Similarly, SES was not associated with EF despite previous findings linking EF with SES. It may be that despite previous research finding significant associations between insurance type (i.e., Medicaid) and traditional measures of SES (e.g., income, education), predicting health outcomes may be dependent upon the measure of SES (Casey et al., 2018). Therefore, using

insurance type as a proxy for SES may not be an accurate method. In addition, this midwestern state's NICU follow up programme has identified disparities in who completes follow up services. Results found that those with Medicaid and minority status were less likely to complete follow up services through the first 2 years of life (Roberts et al., 2016). These known disparities may further contribute to the findings of this study. The unequal sample size between groups may reflect that those children at highest social risk may not have completed follow up services; therefore, they may not have attended their 24-month clinic visit to participate in the assessments and be included in this study. Future research with a larger, more representational sample size is needed to further examine the association between sociodemographic risk factors and medical risk factors known to be associated with EF skills in this population.

Findings of this study that are not congruent with the literature base may be due to the limitations of a small sample size and unequal sample sizes between the MEFS completers and non-completers. These limitations may account for the lack of associations between included variables known to influence EF and the findings conflicting with the current literature base related to multiple gestation pregnancy. Future studies should consider including a control group of non-NICU graduates to compare outcomes and the applicability of the results to the population.

Despite its limitations, the current study provides preliminary evidence into the development of EF skills in toddler-aged children with a NICU history, supports the need to monitor this population for delays, and provides direction for future studies. With a recent push to refine EF assessment methods and monitor children to identify the need for interventions in the early childhood years (EF, n.d.), future studies must consider the child's language and cognitive abilities prior to evaluating their EF skills and before designing interventions aimed to promote the development of these critical processes (Ansell et al., 2017). Early identification of deficits is key to intervening. Discussions about promoting child development skills with caregivers during NICU follow up contacts may be beneficial in supporting EF skill growth and development for NICU graduates. Longitudinal studies are needed to examine such interventions and their influence on EF in the NICU graduate population.

AUTHOR CONTRIBUTIONS

Kerry Miller: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; supervision; writing – original draft; writing – review and editing. **Amanda Prokasky:** Formal analysis; methodology; writing – review and editing. **Holly Roberts:** Formal analysis; methodology; writing – review and editing. **Carol McMorris:** Data curation. **Howard Needelman:** Writing – review and editing.

CONFLICT OF INTEREST STATEMENT

The authors have no financial or conflicts of interest to disclose.

PEER REVIEW

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DATA AVAILABILITY STATEMENT

The data are not publicly available and research data are not shared.

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