Exploring Connections between Maternal Speech and Infants' Use of Fine Motor Skills

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Abstract

During infancy, consistent exposure to frequent, responsive speech is fundamental for optimal language development to occur, but there is a great amount of variability in the language that infants hear across the first years of life. Because it is important to understand the ways that language may be influenced in the developing child's environment, the goal of the current study is to explore whether connections may exist between the fine motor skills (FMS) an infant is using and the maternal speech they hear simultaneously. To examine this question, naturalistic video recordings of snacks or meals from 29 infants' homes were coded to analyze the concurrent maternal speech and infant object manipulation. Our results revealed no linear relationship between FMS and maternal speech, but several characteristics of object manipulation suggest that mothers speak fewer words while their infants use complex FMS compared to when they engage in less complex hand movements. From this study, we aimed to learn more about the ways in which maternal speech varies within infants' everyday experiences, and these findings led us to a better understanding of how motor skills and language exposure may be related to each other over the course of early childhood development.

Introduction

Early experiences in the first few years of life have been shown to greatly impact many ongoing aspects of development throughout childhood, but researchers have been especially interested in how children's experiences influence the language they hear (Fox & Rutter, 2010). At birth, infants generally have all of the neural structures present that are required to learn language, and over the next several years of life will receive the language input that leads to the further development of a native language (Gervain & Mehler, 2010). There are many different factors that influence the rate at which babies learn to communicate, but in pathways of typical development, three of the most important are the quality, quantity, and responsiveness of language that they hear from their parents (Tamis-LeMonda et al., 2001; Tamis-LeMonda & Schatz, 2019; Newman et al., 2016). Because maternal speech is so vital to the process of language development in infants, it is important to examine the factors that are associated with increased amounts of high-quality language, which can even include the child's own behavior and interactions with the people and objects in their environment. For this reason, the goal of the current study is to explore whether a relationship may exist between the complexity and kinds of fine motor skill that an infant is using with the maternal speech that they are hearing simultaneously.

One way of conceptualizing how two sets of skills are related over development is a developmental cascade, formally defined as "the cumulative consequences for development of the many interactions and transactions occurring in [different] developmental systems" (Masten & Cicchetti, 2010). Developmental cascades may contribute to results that are directly related to the source of variability, such as infants learning to produce the names of objects more quickly when they touch the object, eliciting the label from their mothers (Suarez-Rivera et al., 2022b), but can also be much more indirectly related. For example, sitting independently allows infants to interact with objects and other people more freely, which increases their opportunity to engage in social interaction as well, strengthening the communicative input they receive (Iverson, 2021). Although the influence of any one experience that an infant has may be minimal, over time they may cumulatively have a major impact, altering the entire course of the individual's developmental trajectory. For these reasons, it is important to consider whether there are features of an infant's experience that lead to routine differences in maternal speech. Although the variation may seem inconsequential as it occurs on a micro-level, it could actually have significant consequences on infants' language exposure over the course of time, and as a result, have an effect on their language development as well.

On a much larger scale, cultural differences may lead to very different average developmental outcomes for infants in a population, such as the stages of motor development occurring at a much later age in cultures where infants' movements are restricted in comparison with cultures where infants are encouraged to move more often (Adolph et al., 2010). Cultural differences could mean that a very different relationship may exist between fine motor skills and language exposure among populations of children from other regions or cultures, or that there may even be no relationship at all. As a result, the findings of the present study can only be generalized to populations of infants within the northeastern region of the United States, since it uses data collected solely within this area.

Context and Language Exposure

One source of considerable influence on the language that a mother speaks to her child is the context, which involves location, movement, and activities that are occurring in the immediate environment of the child (Tamis-LeMonda et al., 2018). For example, during periods of time where the infant is playing, mothers tend to respond with language that includes more object names, features, actions, and questions, usually related to the objects or sets of items the infants are using at the time (Bornstein et al., 2008). Different types of play can even elicit distinctive types of language in response (Tamis-LeMonda & Schatz, 2019). Each of these correlations points to the existence of a relationship between the activity that infants are engaged in and the maternal language input that they hear at the same time.

In a similar manner, the child's manual exploration of objects can often be a source of variation in the speech that their mothers produce. When mothers verbally provide an infant with a label for an object within their home, visual or tactile cues are involved 95% of the time, meaning that either the infant or mother is almost always looking at or touching an object that is being given a name (Custode & Tamis-LeMonda, 2020). This further supports the idea that the speech infants hear from their mothers in their everyday routine is affected by what the infant is doing. Also, mothers tend to speak fewer words to their infants when they are holding objects, which could result from mothers realizing that infants are devoting less attention to language input when focused on object manipulation (West & Iverson, 2017). However, the concentration of object labels within this speech is significantly higher than it is during other periods of time. For vocabulary acquisition to occur, it is most effective for mothers to provide labels for objects while infants manipulate them, especially since these activities are likely to promote shared attention between the mother, infant, and object (Yu & Smith, 2016). Therefore, the phenomenon that mothers respond with more labels while their infant is holding an object is likely instrumental for successful word learning. Existing research indicates that there is a clear relationship between the way that infants manipulate objects and the speech they hear from their mothers, but there has been no research as to whether the skill level of infants' manual object exploration might be related to the complexity of mothers' speech.

Motor Skills and Language Development

Similarly, there is a connection that exists between motor skills and the child's gradual development of language over time. Part of the association between these two developmental processes is motivated by the way that motor milestones change the manner in which infants can interact with objects and other people. For example, the onset of walking leads to the rapid growth of infants' use of gestures and vocalizations, and mothers tend to respond more frequently to their children when they have the ability to walk than when they have only mastered crawling (West & Iverson, 2021). These changes in the infant's language environment can lead to interesting developments in their speech production. Additionally, as infants develop the physical ability to engage in rhythmic arm movements such as banging objects with their hands, they usually also reach a similar stage of language development, involving highly repetitive syllables which have similar acoustics, indicating that motor skills in infancy are tied to speech skills (Iverson, 2010).

Each of the previous examples involves only gross motor skills, but there are also connections between an infant's development of language and fine motor skills. For instance, the fine motor skills present in early childhood are associated with the development of both receptive and expressive language in the following years, meaning both the words that a child can understand and produce, but there is limited research in this field (Gonzalez et al., 2019). Specifically, fine motor skills in infants at one year of age are correlated with the communication skills present at twenty-four months (Valla et al., 2020). While there is an apparent connection that exists between language and motor development, knowledge of the mechanisms linking them is minimal, especially in the area of fine motor development, and researchers generally agree that more investigation is needed to better understand this relationship. This evidence again indicates that the achievement of important motor skill milestones can have a substantial impact on the way infants view and interact with their environment, along with the ways that mothers respond to their children with language.

Language Exposure and Language Development

It is valuable to understand the ways that maternal language input may vary in infants' everyday activities because there is a strong correlation between the speech that infants hear and the language that they eventually produce (Ramírez-Esparza et al., 2014; Newman et al., 2016). Although there are many characteristics of maternal speech that are associated with future language outcomes, there are three prominent, easily-measurable features that are often linked to their child's optimal language development: the quantity, quality, and responsiveness of maternal language (Huttenlocher et al.,1991; Tamis-LeMonda & Schatz, 2019; Tamis-LeMonda & Bornstein, 2002).

The importance of the quantity of maternal language is evident through the association that exists between the amount of language that infants hear from their mothers and their vocabulary growth (Huttenlocher et al., 1991; Tamis-LeMonda & Schatz, 2019), as well as the language input they receive from other caregivers (McCartney, 1984). If mothers provide a spoken label for the objects used in playtime around the home, the odds that the word will appear in the infant's vocabulary are 3.26 times higher than if she had not named it (Suarez-Rivera et al., 2022a). This evidence points to an important association between the amount of speech that mothers produce with infants' early language learning.

While some experts have argued for an effect of the number of words on linguistic outcomes, others have demonstrated an equally important pattern based on the *quality* of language, which can be measured as the lexical diversity of speech exposure (Huttenlocher et al., 1991; Rowe, 2012). The number of unique words an infant hears is correlated with their ability to communicate with words and gestures at a later age (Tamis-LeMonda & Schatz, 2019). Other characteristics that represent the quality of language input from adults and have been linked to more advanced language development are simplified grammar, high pitch, slower speed, exaggerated pronunciation, and one-on-one interactions (Ramírez-Esparza et al., 2014). Infants who follow pathways of typical language development are reliant on caregivers to provide a variety of high-quality language input to them.

Finally, a third factor that has an effect on infants' ability to learn language is the responsiveness of their caregivers. The rate at which mothers reply to infants' speech productions, gestures, and attempts to gain attention is crucial for effective language development (Tamis-LeMonda et al., 2002). Maternal scores on responsiveness ratings, which measure speech in terms of descriptiveness, involved play, and imitations, can predict their infants' future achievement of language milestones (Tamis-LeMonda et al., 2001), and when mothers respond more quickly to their infants with meaningful contributions of language, it typically leads to better word learning (Tamis-LeMonda et al., 2014; Masek et al., 2021). Based on this evidence, it is apparent that there is a need for high-quality, responsive language input from parent to child in order for optimal language development to occur. Consequently, it is important to examine the variation that can occur in children's language environments, especially when that variation could be connected to their own behavior, and this is why the present study seeks to explore the differences that could be associated with motor skills.

Research Question

Despite the significance of language input in relation with language development, and the evidence that fine motor skills are also associated with this process, there is no existing research on the relationship between the amount and quality of language being spoken and the level of complexity of fine motor skill the infant is engaging in simultaneously. Because of this gap in the literature, the present study explores whether there is a connection between the level of fine motor skill an infant is using and the language input they are receiving from their mother. Since this study investigates the concurrent relationship between fine motor skills and maternal speech, responsiveness is an inherent part of the analysis.

There are two possible underlying mechanisms that could explain a connection between fine motor skills and speech from mothers if a relationship does exist. The previously mentioned association between fine motor skills and vocabulary acquisition (Gonzalez et al., 2019) may be a result of higher-level maternal language spoken to children who use advanced fine motor skills frequently. Additionally, this might be accounted for by the contingency of maternal responses: when an infant is manipulating an object in an interesting or complicated way, perhaps the mother is likely to respond more thoroughly or quickly, as she has increased opportunities to describe the objects and expand on their properties and uses (West & Iverson, 2021). Similarly, West & Iverson (2017) pose the possibility that “as infants’ actions become more elaborate, so does the verbal input they receive.” This relationship could have a deeper basis in joint attention, which involves both a parent and child attending to each other and another object simultaneously, considering the mother may be likely to take notice of the object a child is holding when they are using more advanced fine motor skills and thus offer a comment corresponding with the infant’s action (Tomasello & Farrar, 1986).

Alternatively, it is possible that there could be an inverse relationship between maternal speech complexity and object manipulation complexity. There are limits to the amount of information an infant can attend to and process at one time, so as infants hear more speech from their mothers, this could restrict their ability to process sensory modalities. As a result, complex maternal speech could be a distraction from higher-level object manipulation (Wetzel et al., 2018). It could also be possible that as mothers focus on their infants' advanced fine motor skills, they are less likely to provide large quantities of language input. A final possibility is that there is no existing relationship between infants' usage of fine motor skills and maternal language input at the same time. However, based on the quantity of research supporting the connection between context, fine motor skill, and language development, it seems likely that the first hypothesis could be true — as infants are engaging in complex activities using fine motor skills, mothers are more likely to respond with elevated quantities of high-quality, responsive language.

Method

Participants

The present study was conducted using video data from Databrary.org, a secure data-sharing platform for researchers, in which experimenters recorded naturalistic sessions of the infant-mother dyads who participated (Tamis-LeMonda & Adolph, 2017). 64 children at the age of either 13, 18, or 23 months were included in this data set (*M*=17.5 months), which is titled "The Science of Everyday Play" and consists of a total of 93 shared videos. The participants were recruited from a large urban city, and families were compensated for their time with a $75 gift card (Suarez-Rivera et al., 2022a). From this collection of videos, only 29 are utilized in the present study (*M*=17.6 months, *SD*=126.8 days), which includes twelve 13-month olds (*M*=13.2 months, *SD* = 6.9 days), eight 18-month olds (*M*=18.2 months, *SD* = 6.3 days), and nine

23-month olds (*M*=23.1 months, *SD*=4.6 days). The rest of the participants from the data set were not analyzed because their recorded sessions did not include any meal or snack times, which are the specific periods of time being coding within this study. Two other participant videos were excluded because the footage of the infant's hands was obstructed for a majority of the time (*N*=1) or the audio was distorted (*N*=1). The sample was predominantly White (White: 69%, More than one: 29%, Black: 3%), and few infants were identified as having Hispanic or Latino ethnicity (17%). It included 16 males (55%) and 13 females (45%).

Design

The naturalistic, observational study design is useful to examine the relationship between the use of fine motor skills and maternal speech in infants' everyday life. Given that there may be differences in the observable behaviors of children and mothers in the lab setting in comparison with naturalistic environments, it is valuable to use video data from homes to represent the diversity and quantity of language being spoken to infants on a regular basis as accurately as possible (Tamis-LeMonda et al., 2017). We looked for connections between the level of fine motor skill complexity an infant is using and the language that is being spoken by their mother within the same time window. Additionally, the data was analyzed in order to determine whether there is a relationship between maternal speech and other characteristics of fine motor skills, such as independent finger movement, bimanual object manipulation, and the use of multiple objects at once.

Materials

In each video, participating infants and their mothers were video- and audio-recorded in their homes for two hours. There were two study visits conducted for each participant, but due to time constraints on the present study, only the second visit was coded and used in the data set.

The second visit was chosen for analysis because this allowed infants and their mothers to become accustomed to the experimenter's presence during the first visit, so that their behaviors might more accurately reflect what was typical for them during the second. The mothers were instructed to follow their usual routine for the duration of the visit and ignore the presence of the experimenter, who used a hand-held video camera to follow the child around their home environment. As a result, these videos include a very broad variety of activities, including play, feeding, grooming, media usage, parent-child conversation, book-sharing, and many other experiences. The researchers attempted to maintain a clear view of both the infant's and mother's activities within the video frame, but would focus on the infant if it was not possible to capture both participants simultaneously. In addition, the experimenter holding the video camera tried to be as unobtrusive as possible by filming from the corners of the room and avoiding contact and conversation with the participants.

Data Coding

There is a large amount of variability within infants' everyday experiences and activities, so in order to maintain some control in the current study, only time periods of meals or snacks have been used in this analysis so that each participant is engaging in a similar activity level. These periods of time were purposefully selected because mothers and infants are often within close range of each other during these moments, and the mother is typically attending to the infant's actions. Videos were analyzed using online software called Datavyu that allows behavioral data to be coded with precise time stamps (Datavyu Team, 2014). First, coders marked the onset and offset of each meal or snack, which are collectively referred to as snacktimes, that occurred during these videos (*Figure 2)*. Onsets were set as the first frame where infants have lifted an object when these conditions are met, and the offset took place when either the infant ceases sitting or being held, or after the final piece of food has been released or touches the infant's mouth. Next, the segments of video that include snacktimes were coded for fine motor skills (FMS). Each occurrence of a snack was divided into 5-second intervals, and within each interval, the highest level of FMS that the infant exhibits was recorded according to *Figure 1* below, which was adapted from a study on object manipulation in primates (Heldstab et al., 2020). If the view of the object manipulation is obscured, coders also made note of this.

Motor Skill Level	Is there more than one object?	Is there more than one hand?	Independent finger movement?	Are hands doing different things?
FMS-8	Yes	Yes	Yes	
FMS-7	Yes	Yes	No	
FMS-6	No	Yes	Yes	Yes
FMS-5	No	Yes	Yes	No
FMS-4	No	No	Yes	
FMS-3	No	Yes	No	Yes
FMS-2	No	Yes	No	No
FMS-1	No	No	No	

Figure 1: Motor Skill Level Coding Scheme (Heldstab et al., 2020)

Note: This figure does not include FMS Level 0, which represents no objects being held within an interval in our coding scheme.

Finally, every utterance spoken by the mother during these segments was coded according to the guidelines outlined in the PLAY Project Transcription Guide, which has been used to transcribe maternal speech on videos following a similar protocol of home video recordings, and follows conventions set forth by the Codes for the Human Analysis of Transcripts (https://www.play-project.org/coding.html#Transcription; Sfuarez-Rivera et al., 2022a). Coders wrote down every word that they heard mothers speak during snacktimes, with the onset being marked immediately after coders discerned the beginning of an utterance.

Key Terms	
snacktimes	- period of time where infant consumes multiple bites of food and is a) in seated, stationary position or b) being held by mother - does not include solely drinking or breastfeeding
object	- anything that an infant lifts completely off the ground or surface using their own hands - examples: food, toy, spoon, etc. - does not include objects being manipulated while resting on a table, being worn by the mother or baby, or lifted without using hands
object manipulation	- starts when the infant removes the object from the ground/surface/etc. - continues to count if the object is placed in the infants' lap and touch continues - ceases when the object is returned to resting state, the infant releases the object, or if an item of food, when the last piece touches the infant's mouth to be consumed
view obstructed	- coder is unable to see any instances of FMS within the interval - hands may be completely out of view, or view of fingers may be obstructed by object
independent finger movement	- fingers on one hand are moving separately from one another, i.e. not all at the same time, in different directions, etc.
synchronous hands	- hands doing the same type of action - can differentiate actions by asking what verb is used to describe what the hand is doing
utterance	- unit of speech separated by grammatical closure, intonation contour, or prolonged pausing, which can function as a natural break during speech - all speech sounds transcribed

Figure 2. Definitions of Key Terms and Measures

Reliability statistics

A 25% segment of each of the participant videos was selected randomly for secondary coding of both FMS and transcription, and Cohen's kappa was calculated to ensure an adequate level of inter-rater reliability. For each video, inter-rater reliability on the assignment of fine motor skill levels was calculated using Cohen's kappa statistic, and across all participants, the average score was 0.77, indicating that there was substantial agreement between coders, with a range from 0.57 to 1. Additionally, we assessed the reliability of maternal speech transcription using ICCs for number of words spoken per participant and percent agreement of words in each utterance. Between primary and secondary coders, there was a high level of reliability on the number of overall words spoken per participant, with an ICC of 0.998 ($p < 0.001$). The average word agreement between coders ranged from 73% to 100%, with a total average of 87.61% across all coded sessions, which demonstrated good reliability on the language being spoken by mothers. Most differences between coders involved small discrepancies such as disagreements on single-word content (such as “a” vs. “the”, “are” vs. “were), singular words vs plurals, and the spelling of words.

Results

Descriptive statistics

Across all participants included in the dataset, 394.33 minutes were spent in snacktimes and subsequently coded for the presence of FMS and maternal speech. This time was divided into five-second intervals, and after partial intervals were excluded (any with a duration of less than 5 seconds that occurred at the end of a snack segment,) there were 4,696 intervals available for analysis. Some of the participants from our dataset only engaged in snacktimes for a very brief period, while others lasted for long spans of time (M = 13.53 minutes, range = 0.72 – 36.27

minutes). For the final analysis, 97 intervals were filtered out because the coder's view of the hands or objects were obstructed, leading to 4,599 intervals being analyzed in the model.

Across all participants, infants manipulated objects by holding them during 3391 of the 4599 intervals (73.73%). It is likely that these findings would not replicate across all types of activities or segments of the day, since objects are frequently being lifted to the infant's mouth during snacktimes. When infants were interacting with an object, the average fine motor skill level was 4.32 (*SD* = 2.45). This average did vary slightly between age groups, with a surprising trend of decreasing motor skill complexity as the infants' age increased. 13-month-olds had an average of 4.73 (*SD* = 1.32), 18-month-olds averaged 4.48 (*SD* = 1.11), and 23-month-olds had an average of 3.9 (*SD* = 0.93). This could be attributed to babies developing more efficient fine motor skills between the first and second year of life: as infants grow, their hands become larger in size, which may allow them more proficiency at lifting objects using only one hand, which in the past required two hands. Additionally, it is worth noting that out of all 4,599 intervals, FMS Level 3 only appeared 8 times, representing less than 1% of intervals, meaning that any results pertaining to it should not be interpreted meaningfully.

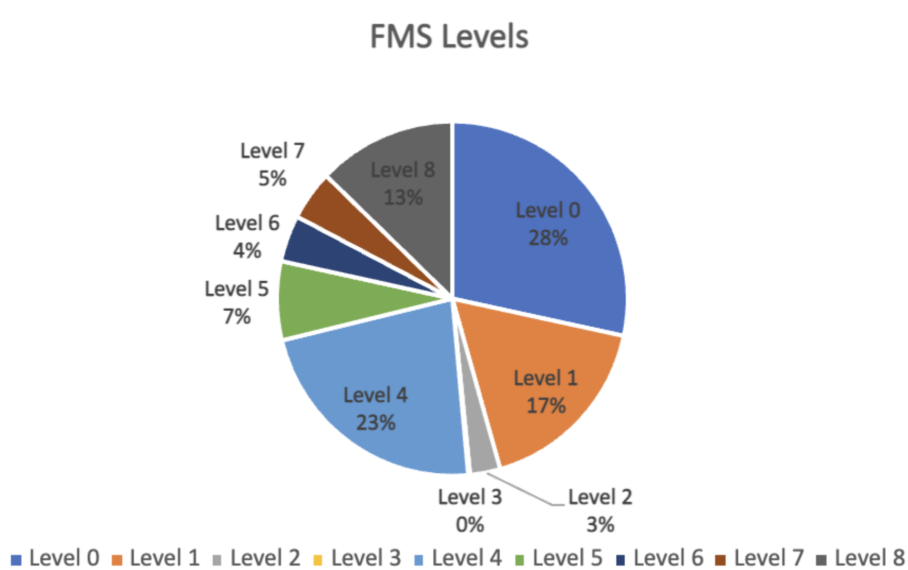

Figure 3: *Percentage of FMS Skills Coded Across Intervals*

Our analysis included a total of 4,340 utterances from mothers, with the number of utterances in a single session ranging from 5 to 664. As expected, there was wide variation in the rate of maternal speech, with some mothers speaking either very rarely or very frequently, ranging from 1.21 utterances per minute to 25.39 utterances per minute (*M* = 11.88 utterances per minute). This also varied somewhat with age, as mothers spoke an average of 9.59 utterances per minute in the 13-month-old age group (*SD* = 5.74), 13.17 utterances per minute in the 18-month-olds (*SD* = 6.55), and 13.41 utterances per minute in the 23-month-olds (*SD* = 8.32). Word counts within a single utterance ranged from 1-27 words (*M* = 3.29, *SD* = 4.57).

Are Infant Fine Motor Skills Correlated with the Quantity of Maternal Speech?

A generalized linear mixed model used to measure the relationship between word count and fine motor skill level showed that the number of words being spoken during intervals when FMS were occurring was lower than the intervals where no FMS were occurring, which is consistent with previous findings that caregiver speech is less frequent when infants are holding objects (West & Iverson, 2017). Each average word count associated with an FMS level is significantly lower than the intercept, which represents intervals where there was no fine motor skill taking place (*Table 1*). *Figure 4* represents the means of the word counts spoken by mothers during each interval according to FMS level categorization.

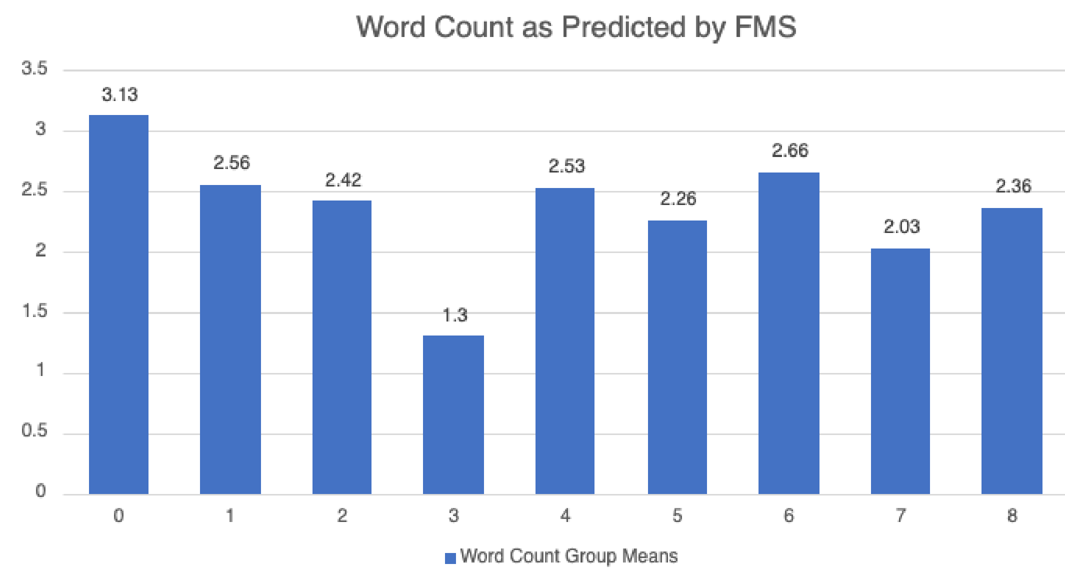

Figure 4. Measuring Quantity of Speech: Average Word Count as Mean of Groups (Accounting for Individual Clustering)

Word Count as Predicted by FMS

	word_count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
(Intercept)	3.13	2.26 – 4.34	**<0.001**
fms [1]	0.82	0.78 – 0.86	**<0.001**
fms [2]	0.77	0.70 – 0.85	**<0.001**
fms [3]	0.41	0.21 – 0.83	**0.013**
fms [4]	0.81	0.77 – 0.85	**<0.001**
fms [5]	0.72	0.67 – 0.78	**<0.001**
fms [6]	0.85	0.78 – 0.93	**<0.001**
fms [7]	0.65	0.59 – 0.71	**<0.001**
fms [8]	0.75	0.71 – 0.80	**<0.001**
Random Effects			
σ^2	0.33		
$\tau_{00\ id}$	0.79		
ICC	0.71		
N_{id}	29		
Observations	4599		
Marginal R^2 / Conditional R^2	0.014 / 0.711		

Table 1

Because the *ICC* = 0.71, this is evidence that there is high internal consistency within the subjects, which is why the use of the multilevel model was necessary in order to account for variation across participants. The marginal R^2 for the overall proportion of variance in word count explained by FMS level was very small ($R^2 = 0.014$, $p < 0.001$) while the conditional R^2 was high ($R^2 = 0.711$), meaning that the fine motor skill level that infants are using explains a very small proportion of the variance in word count. However, across thousands of observations, we find that even though FMS is only associated with a small amount of variance, the difference is very consistent, as evidenced by the low P-values across comparisons. We ran post-hoc pairwise comparisons using Tukey's adjustment in order to contrast distinct levels with each other, and found several pairings (19 out of 36) that differed significantly from each other (*Appendix T1*). After evaluating the relationship between maternal speech and each level of FMS separately, we created models grouping levels together based on a few different characteristics of object manipulation.

Comparing Low-Level and High-Level Skills

First, we compared the differences between intervals after categorizing them as low-level (1-4) or high-level (5-8). There were significant differences between the low levels and high levels, with high-level manipulation being associated with 7% fewer words than were linked to low-level manipulation ($p = 0.001$).

Word Count as Predicted by Low vs High Level FMS

	Word Count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
Low Skill Level (Intercept)	2.55	1.85 – 3.51	**<0.001**
High Skill Level	0.93	0.89 – 0.97	**0.001**
Random Effects			
σ^2	0.34		
$\tau_{00\ id}$	0.76		
ICC	0.69		
N_{id}	29		
Observations	3294		
Marginal R^2 / Conditional R^2	0.001 / 0.692		

Table 2

Comparing the Number of Objects Being Manipulated

Next, we compared the intervals based on the number of objects involved in the highest level of FMS. The intervals were grouped depending on whether they had one (levels 1-6) or multiple objects (levels 7-8) being held during object manipulation. When infants manipulated multiple objects during a period of time, the word count was on average 9% lower than when only one object was being manipulated (p <0.001).

Word Count as Predicted by Number of Objects

	Word Count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
One Object (Intercept)	2.54	1.84 – 3.50	**<0.001**
Multiple Objects	0.91	0.87 – 0.96	**<0.001**
Random Effects			
σ^2	0.34		
$\tau_{00\ id}$	0.77		
ICC	0.69		
N_{id}	29		
Observations	3294		
Marginal R^2 / Conditional R^2	0.001 / 0.693		

Table 3

Comparing Independent Finger Movement

We also analyzed the intervals based on whether or not there was independent finger movement present in the highest level of FMS that was observed. When object manipulations without independent finger movement (levels 1-3 and 7) were compared with those that did have independent finger movement (levels 4-6 and 8), there was no significant difference in the number of words present ($p = 0.504$).

Word Count as Predicted by Independent Finger Movement

	Word Count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
No Independent Finger Movement (Intercept)	2.45	1.78 – 3.38	**<0.001**
Independent Finger Movement	1.02	0.97 – 1.06	0.504
Random Effects			
σ^2	0.34		
$\tau_{00\ id}$	0.76		
ICC	0.69		
N_{id}	29		
Observations	3294		
Marginal R^2 / Conditional R^2	0.000 / 0.691		

Table 4

Comparing Number of Hands Involved

When intervals were grouped into categories of unimanual (one-hand) or bimanual (two-hand) object manipulation for analysis, we found that there was a statistically significant difference in word count per interval. The number of words during segments with bimanual object manipulation were 7% fewer than the amount of words in intervals where the highest level of FMS used was unimanual ($p < 0.001$).

Word Count as Predicted by Number of Hands

	Word Count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
Unimanual (Intercept)	2.56	1.86 – 3.53	**<0.001**
Bimanual	0.93	0.89 – 0.97	**<0.001**
Random Effects			
σ^2	0.34		
$\tau_{00\ id}$	0.76		
ICC	0.69		
N $_{id}$	29		
Observations	3294		
Marginal R^2 / Conditional R^2	0.001 / 0.693		

Table 5

Comparing Actions of Hands

Finally, we isolated only the intervals where there was more than one hand involved in the manipulation, and then grouped them based on whether the hands were doing the same (levels 2 and 5) or different things (levels 3 and 6) during the recorded FMS level. The multilevel model did not find any significant difference between the word count of the groups ($p = 0.069$).

Word Count During Asynchronous vs. Synchronous Movement of Hands

	Word Count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
Synchronous Hands (Intercept)	2.26	1.48 – 3.43	**<0.001**
Asynchronous Hands	1.10	0.99 – 1.22	0.069
Random Effects			
σ^2	0.36		
$\tau_{00\ id}$	1.11		
ICC	0.76		
N $_{id}$	26		
Observations	663		
Marginal R^2 / Conditional R^2	0.001 / 0.757		

Table 6

Are Infant Fine Motor Skills Correlated with the Quality of Maternal Speech?

In order to analyze whether fine motor skills have an impact on the quality of speech being spoken to infants, we created a model that excluded the intervals with no speech. While this is a surface-level measure of the quality of speech, examining only the intervals where the mother was talking allows us to evaluate the concentration of speech, with higher word counts likely indicating a higher level of complexity and elaboration in the mother's language occurring during the time frame. During intervals with speech in them, the highest observed level of FMS explains a very small proportion of variance overall ($R^2 = 0.016$, $p < 0.001$), and although most of the FMS levels are significantly different from 0, there are far fewer pairs that differ from each other (9 out of 36) than there were in the first model comparing overall word count with FMS level (*Appendix T2*). As a result, fine motor skill level is likely a better predictor of the quantity of speech than it is of the quality, and in order to draw conclusions about the relationship with quality of speech, further investigation would be needed using more precise measurements, such as length of utterances, diversity of language, and interactivity of speech (Rowe, 2012).

Word Count (Excluding Intervals with No Speech) as Predicted by FMS

	word_count		
Predictors	*Incidence Rate Ratios*	*CI*	*p*
(Intercept)	6.31	5.59 – 7.13	**<0.001**
fms [1]	0.92	0.87 – 0.97	**0.001**
fms [2]	0.87	0.79 – 0.95	**0.003**
fms [3]	0.67	0.33 – 1.36	0.270
fms [4]	0.87	0.83 – 0.91	**<0.001**
fms [5]	0.85	0.79 – 0.92	**<0.001**
fms [6]	0.96	0.88 – 1.04	0.295
fms [7]	0.81	0.74 – 0.89	**<0.001**
fms [8]	0.93	0.88 – 0.98	**0.009**
Random Effects			
σ^2	0.16		
$\tau_{00\ id}$	0.10		
ICC	0.38		
N_{id}	29		
Observations	2340		
Marginal R^2 / Conditional R^2	0.016 / 0.394		

Table 7

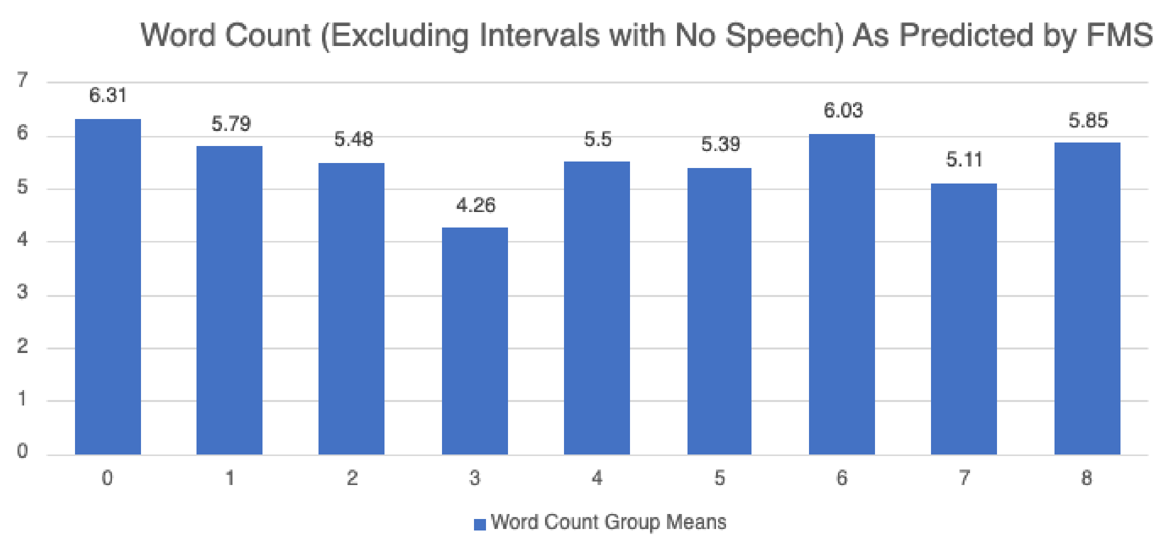

Figure 5. Measuring Quality of Speech: Average Word Count as Mean of Groups when Mother is Speaking (Accounting for Individual Clustering)

Discussion

The main question we asked in this study was whether there was a relationship between the level of complexity of infants' fine motor skills and some aspect of their mother's speech occurring concurrently. We now have a clear answer to this question: our results reveal that when an infant uses complex fine motor skills to manipulate an object, there are fewer words being spoken by their mother as compared to bouts of simple object manipulation. These results suggest that there is a relationship between the infant's use of fine motor skills and the maternal speech that they hear simultaneously during snacktimes. Although the differences associated with the various characteristics of fine motor skills that we have observed are modest, they tend to have strong statistical significance, meaning that they appeared consistently across our many observations. We classified intervals based on the highest level of fine motor skill that was displayed during each interval, and found increased word counts during those that had only one object being manipulated, used only one hand, or were among the lower levels. There was no significant difference between the comparisons based on whether hands were doing the same thing or different things, or whether or not they involved independent finger movement. Still, the evidence generally supports the argument that concurrent infant FMS and maternal speech are connected.

Of all the different ways we grouped fine motor skills, level 6 was associated with the highest number of words per interval, at a group rate of 2.66 words per every 5 seconds. At first, this finding was surprising because two of the statistically-significant characteristics of level 6 (using two hands and being high-level) are associated with lower word count. However, it involves only one object, which is linked to higher word counts. This highlights how influential the number of objects is on the relationship between FMS and word count, with two-object manipulation associated with 9% fewer words than intervals with only one object. Furthermore, it is interesting that level 7, which involves two objects, has the lowest group mean (2.03) and differs significantly from all other groups (except for 5, marginally) in the pairwise comparisons. One possible explanation for this difference could be that as infants pick up a second object, mothers tend to pause and devote more attention to their child's actions instead of continuing to speak. In the future, it could be worthwhile to examine the timing of speech more precisely, specifically by comparing periods of object manipulation with the window immediately following the addition of an object.

Although the differences between the word count based on group means of FMS levels may be small (2.66 during the highest level and 2.03 during the lowest), it is important to remember that these are only measuring the number of words occurring within a small 5 second-window. The 0.63 differential in word count between the highest and lowest levels would equate to 7.56 words per minute and 453.6 words per hour. Although we found that children generally engage in many different levels of FMS throughout bouts of object manipulation, these numbers demonstrate that there could cumulatively be a large influence over an extended period of time in the infant's daily routine.

These findings generally opposed our hypothesis that more difficult or complex fine motor skills would be associated with more language input. We found no linear relationship between the levels and word count, but when grouped together, the lower levels were associated with fewer words, and when categorizing the levels based on various characteristics, all significant findings revealed that features of more complex object manipulation were associated with fewer words during the interval. There are several potential explanations for this relationship. First, it is possible that mothers may subconsciously alter their speech depending on the type of manual exploration the infant is engaged in. As their infant completes more challenging tasks or motor skills, the mother may stop to watch, or if the infant is not using any complex skills, the mother may see that as an opportunity to engage her baby in social interaction by speaking more. This theory is supported by prior evidence that mothers' speech is responsive to their infants' object manipulation and activity (West & Iverson, 2021; Tamis-LeMonda et al., 2018). Previous research reveals that children are distracted from tasks with the presentation of auditory stimuli (Wetzel et al., 2018; Hoyer et al., 2021), suggesting that they cannot simultaneously focus on fine motor manipulation and maternal speech. As a result, mothers may learn from prior experiences that delivering complex language to their infant who is engaged in complex fine motor behavior is an unsuccessful endeavor, as the infant is not dedicating attention to what the mother is saying.

Alternatively, infants could be the driving force behind the persistent variation. Babies have a limited ability to attend to multiple different sources of input simultaneously. A "trade-off" may occur when the infant prioritizes one domain over another, such as infants vocalizing less when they first begin to crawl or having difficulty with motor tasks while simultaneously processing cognitive tasks (Berger et al., 2017). Competition between domains for an infant's attentional resources can cause them to focus on one for a period of time. Infants also learn that their actions can alter the language they receive from their environment at a very early age. For example, newborns who are not even three days old have the ability to distinguish their mother's voice from someone else, and will alter their rate of sucking on a pacifier in order to hear it (DeCasper & Fifer, 1980). This evidence shows that babies may alter their actions to influence the type of speech that they hear from their mothers. Within the home, mothers do tend to talk about the objects that infants are manipulating, but at lower rates as the object bout extends into longer periods of time (Suarez-Rivera et al., 2022). Babies may recognize this pattern, which could lead to them engaging in shorter and less complicated bouts of FMS in order to encourage stimuli from their mother. Additionally, in the context of this study, if the cognitive load of focusing on maternal speech and complex fine motor skills at the same time is too difficult, an infant may choose to focus on the language input from their mother, leading to the usage of less complex fine motor skills. Support for this theory is reflected in the trend of fine motor skills during snacktimes decreasing with age, as the number of words and utterances per interval increased across the three age groups observed.

Another surprising conclusion that can be drawn from these data is that the LEGO coding levels do not necessarily indicate the difficulty of a fine motor skill. There is no pattern to the frequency of the levels that would suggest that the groups we classified as higher levels are actually more challenging for infants. In fact, the average FMS level showed a trend of decreasing as the infants' age increased. If the previously-mentioned theory that infants may alter their utilization of FMS based on their mother's speech holds true, this could mean that with age, they become more attuned to maternal language input during snacktime, which would lead to less complex object manipulation. As a result, rather than consider the levels hierarchically as we did in this study, in the future they might more accurately be used as an unranked system of categorizing the fine motor activities that children are engaging in, as determined based on characteristics such as number of objects, independent finger movement, and synchronization of hands.

Limitations and Future Directions

A primary limitation of the present study is that our findings can only be generalized to the context of snacktimes, and not the rest of the infants' everyday experiences. Because we narrowed our focus to meals and snacks so that we could observe periods of times that mothers and their children were directly interacting, it is logical to conclude that there would be substantial differences in the language that infants hear during the rest of their day (Zimmerman et al., 2019; Hoff-Ginsberg, 1991). It is also probable that if the connection between FMS and maternal speech is based on mothers' and infant' ability to see and hear each other, there may be less proximity throughout the rest of the day, which could greatly alter the relationship between these two measures. For example, it is likely that mothers dedicate more visual attention to their children during meals for safety reasons, which would allow her to see the fine motor skills the child is using, but during periods of play or free exploration, the mother is less likely to be closely monitoring the child's hands and activity. Furthermore, mothers speak different kinds and quantities of words depending on the context, activity, and location of the infant, all of which can vary greatly across different times of the day (Custode & Tamis-LeMonda, 2020; Tamis-LeMonda et al., 2018; Malachowski et al., 2023). As a result, our findings only apply to a very limited segment of infants' experiences. In the future, it would be interesting to explore whether the relationship we have discovered is specific to snacktimes, or if it would generalize across all of the infant's experiences.

Another limitation of this study was a result of the nature of the observational data we were coding and analyzing. The video was recorded without specialized equipment to capture speech and was sometimes filmed from a distance. In some instances, it could be difficult to hear what the mother was saying and rarely, whether or not she was even speaking. Additionally, the video was almost always focused primarily on the infant, which allowed an adequate view of the fine motor skills being used, but at times, the precise movements could be obstructed by food, the mother, other objects, or even the infant's own body. While we took this into consideration and implemented inter-rater reliability coding, there were several intervals that had to be excluded from analyses due to the view being obstructed, which could have possibly influenced the final outcomes.

Finally, we originally intended to measure the quantity, quality, and responsiveness of maternal speech in a variety of ways, but time constraints prevented us from doing so. It would be interesting to explore these factors more precisely, especially with a more detailed look at speech on an utterance level and responsiveness as an exact, time-linked response. More measures of maternal speech should be taken into consideration in order to provide a fuller picture of the way that it varies across different fine motor skill actions, such as utterance length, word diversity, and expressiveness. Furthermore, it could be worthwhile to explore whether a causal relationship might exist between the two factors by measuring whether there is an increased likelihood that the infant's use of FMS changes immediately following the mother's speech, or alternatively, whether the mother's speech changes right after the onset of a new FMS level. Overall, future research could provide a much clearer understanding of the directionality of this relationship.

Conclusion

As a result of these findings, we have reached a better understanding of the ways that fine motor skills and maternal speech are connected to each other during the context of snacktimes during an infant's everyday routine. Infants hear fewer words from their mothers during intervals where they are engaging in object manipulation using two hands, multiple objects, or high-level FMS levels, according to our system of categorization. The aim of this study is not to suggest any changes or implications for the way that infants and mothers should behave, but rather to provide insight into the characteristics that link the domains of motor and language development together. Mother-child interactions within the home provide one of the strongest sources of language input to infants, and responsive speech from mothers scaffolds language learning during early development (Masek et al., 2021). Interactions between caregivers and infants often involve both language and object manipulation simultaneously, and examining everyday activities and routines is crucial to understanding how babies develop both of these skills. Our findings provide evidence that there is a relationship between infant fine motor skill use and the concurrent maternal speech they hear, and further our understanding of how the domains of motor skills and language development overlap in the first two years of life.

Appendix

Post-Hoc Pairwise Comparisons of FMS Levels

Comparison		*Ratio*	*SE*	*df*	*z-ratio*	$P_{Tukey's}$
0	*1*	1.224	0.0326	Inf	7.598	<.0001***
0	*2*	1.294	0.0612	Inf	5.447	<.0001***
0	*3*	2.412	0.8562	Inf	2.479	0.0263*
0	*4*	1.235	0.0294	Inf	8.894	<.0001***
0	*5*	1.384	0.0524	Inf	8.596	<.0001***
0	*6*	1.178	0.0517	Inf	3.726	0.0007***
0	*7*	1.545	0.0729	Inf	9.225	<.0001***
0	*8*	1.327	0.0387	Inf	9.714	<.0001***
1	*2*	1.057	0.0522	Inf	1.124	0.3134
1	*3*	1.970	0.6999	Inf	1.909	0.0921
1	*4*	1.009	0.0297	Inf	0.314	0.7538
1	*5*	1.131	0.0456	Inf	3.050	0.0063*
1	*6*	0.962	0.0439	Inf	-0.849	0.4193
1	*7*	1.262	0.0602	Inf	4.879	<.0001***
1	*8*	1.084	0.0340	Inf	2.578	0.0211*
2	*3*	1.864	0.6659	Inf	1.743	0.1221
2	*4*	0.955	0.0462	Inf	-0.955	0.3706
2	*5*	1.070	0.0580	Inf	1.244	0.2651
2	*6*	0.910	0.0535	Inf	-1.602	0.1512
2	*7*	1.194	0.0739	Inf	2.867	0.0100*
2	*8*	1.026	0.0513	Inf	0.508	0.6289
3	*4*	0.512	0.1820	Inf	-1.883	0.0935
3	*5*	0.574	0.2045	Inf	-1.558	0.1590
3	*6*	0.488	0.1742	Inf	-2.009	0.0798
3	*7*	0.641	0.2288	Inf	-1.247	0.2651
3	*8*	0.550	0.1955	Inf	-1.681	0.1336
4	*5*	1.120	0.0439	Inf	2.901	0.0096*
4	*6*	0.953	0.0429	Inf	-1.065	0.3330
4	*7*	1.251	0.0604	Inf	4.626	<.0001***
4	*8*	1.074	0.0332	Inf	2.318	0.00387**
5	*6*	0.851	0.0440	Inf	-3.129	0.0053*
5	*7*	1.116	0.0616	Inf	1.990	0.0798
5	*8*	0.959	0.0396	Inf	-1.019	0.3465
6	*7*	1.312	0.0768	Inf	4.639	<.0001***
6	*8*	1.127	0.0520	Inf	2.592	0.0211*
7	*8*	0.859	0.0411	Inf	-3.180	0.0048**

*: less than 0.05
**: less than 0.005
***: less than 0.0005

P-value adjustment: fdr method for 36 tests

Appendix Table 1

Post-Hoc Pairwise Comparisons of FMS Levels in Intervals where Mother is Speaking

Comparison		*Ratio*	*SE*	*df*	*z-ratio*	$P_{Tukey's}$
0	1	1.091	0.0292	Inf	3.233	0.0110*
0	2	1.153	0.0545	Inf	3.006	0.0190*
0	3	1.484	0.5311	Inf	1.102	0.4635
0	4	1.149	0.0274	Inf	5.812	<.0001***
0	5	1.172	0.0443	Inf	4.194	0.0003***
0	6	1.047	0.0456	Inf	1.048	0.4820
0	7	1.236	0.0578	Inf	4.522	0.0001***
0	8	1.079	0.0313	Inf	2.619	0.0352*
1	2	1.057	0.0521	Inf	1.124	0.4635
1	3	1.361	0.4875	Inf	0.859	0.5203
1	4	1.053	0.0312	Inf	1.751	0.1920
1	5	1.075	0.0434	Inf	1.782	0.1920
1	6	0.960	0.0437	Inf	-0.900	0.5179
1	7	1.133	0.0538	Inf	2.627	0.0352*
1	8	0.989	0.0309	Inf	-0.341	0.7759
2	3	1.287	0.4635	Inf	0.701	0.5940
2	4	0.996	0.0483	Inf	-0.074	0.9411
2	5	1.017	0.0552	Inf	0.306	0.7817
2	6	0.908	0.0535	Inf	-1.637	0.2289
2	7	1.072	0.0661	Inf	1.126	0.4635
2	8	0.936	0.0467	Inf	-1.325	0.3701
3	4	0.774	0.2773	Inf	-0.715	0.5940
3	5	0.790	0.2838	Inf	-0.656	0.5940
3	6	0.706	0.2540	Inf	-0.969	0.5027
3	7	0.833	0.3001	Inf	-0.508	0.6671
3	8	0.727	0.2606	Inf	-0.889	0.5179
4	5	1.020	0.0400	Inf	0.514	0.6671
4	6	0.911	0.0408	Inf	-2.071	0.1227
4	7	1.076	0.0515	Inf	1.524	0.2698
4	8	0.939	0.0291	Inf	-2.017	0.1227
5	6	0.893	0.0462	Inf	-2.185	0.1039
5	7	1.054	0.0578	Inf	0.964	0.5027
5	8	0.921	0.0378	Inf	-2.011	0.1227
6	7	1.180	0.0687	Inf	2.847	0.0229*
6	8	1.031	0.0472	Inf	0.661	0.5940
7	8	0.873	0.0416	Inf	-2.844	0.0229*

*: less than 0.05
**: less than 0.005
***: less than 0.0005
P-value adjustment: fdr method for 36 tests

Appendix Table 2

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