Exploring How Temporal Memory Develops and the Underlying Neural Processes that Support It Using ERP

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MDLaB
Memory Development Learning and Brain

Introduction

Episodic memory is memory for events that occur in a specific time and place. Memory for temporal information (i.e., temporal memory) is a critical feature of episodic memory (Tulving, 1985). However, relatively little is known about how temporal memory develops.

Temporal order: Events in relation to each other (e.g., X happened before Y)
- Memory for temporal order emerges in infancy (see Bauer, 2007), but shows protracted development. Age-related improvements are observed from early to late childhood (e.g., Friedman, 1991, 1992; Pathman & Ghetti, 2014).

Temporal context: Placing events in time (e.g., X happened in March)
- Less is known about the development of memory for temporal context, especially in middle and late childhood.

Conventional Time: systems and representations of temporal patterns that a culture uses (e.g., days of the week, months of the year)
- There is evidence for improvements in understanding of conventional time patterns (i.e., ordering months of the year) from middle to late childhood (Friedman, 1978).
- Researchers have found a relation between CTK and memory for temporal order of events in middle to late childhood (e.g., Friedman et al., 2011; Pathman & Ghetti, 2014).

Event-Related Potentials (ERPs) & Recognition Memory:
- ERPs provide unique way to investigate memory processes.
- Children and adults show differences in ERPs between old and new stimuli, but often children show these differences later than adults (Czernochowski et al., 2009; Haese & Czernochowski, 2016).
- From studies with source memory, researchers speculate these effects could reflect recollection-based processes (Cycowicz et al., 2003; Sprondel et al., 2011).

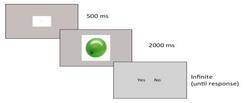
Goals of current study:
- Track the development of memory for *temporal context* from middle to late childhood and into adulthood
- Examine the neural signatures associated with temporal context memory across age
- Investigate how temporal memory in a lab-based paradigm relates to knowledge of conventional times scales across development

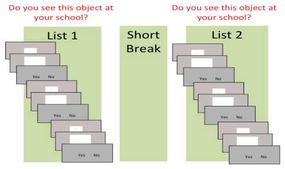
Method

Participants & Procedure:
- 7- to 9-year olds (n = 29; M_{age} = 7.89, SD = 0.84), 10- to 12-year-olds (n = 29; M_{age} = 11.00 , SD = 0.83), and young adults (n = 31; M_{age}= 21.29, SD = 3.24)
- 2 hour session – various tasks assessing memory, language, reasoning (including Wechsler Abbreviated Scale of Intelligence; Wechsler, 1999)

Temporal memory task: *Encoding* phase:
- Participants studied two sets of objects (50 per set) and indicated if they saw each object at school

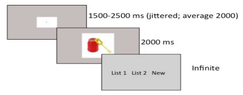
Sample Encoding Trial

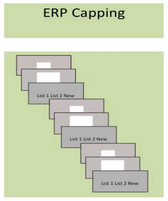




Temporal memory task: *Retrieval* phase:
- ERPs recorded as participants viewed and identified objects as being List 1, List 2, or Novel

Sample Retrieval Trial





Conventional Time Knowledge (CTK) Task:
- Measures children and adults' ability to mentally and flexibly move through conventional time scales (Friedman, 1989; Pathman & Ghetti, 2014)
- Example question: "If you're going backward and you start in May, which would you come to first, September or January?"

Behavioral Results

Trial

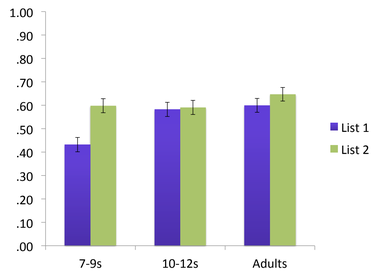
Participant Response	List 1	List 2	New
List 1 (old)	Source Hit	Source Error	False Alarm
List 2 (old)	Source Error	Source Hit	False Alarm
New	Miss	Miss	Correct Rejection

Temporal Context Memory

Source Hits (List 1 Hits v. List 2 Hits) x Age group ANOVA:

1. Main effect of Age group, $F(2, 86) = 20.151$, $p < .001$
- Significant differences between all age groups: 7-9 year olds < 10-12 year olds < Adults

2. Main effect of List, $F(1, 86) = 5.551$, $p = .021$
- Overall significantly more List 2 hits (M = .612, SE = .017) than List 1 hits (M = .538, SE = .017)
- However, t-tests revealed this was driven by 7-9 year-olds.



Relations with Conventional Time Knowledge Task (CTK)

Partial Correlations Controlling for Age & WASI

	All Old	Source Hits	Source Errors
CTK (Months)	**.291****	**.243***	-.101

* = $p < .05$; ** = $p < .01$; *** = $p < .001$

Overall, better performance on the CTK task was related to better memory in the temporal memory task.

Brain-Behavior Relations

CTK and ERP Relations
- We calculated ERP difference scores in the 'early' and 'late' time windows for hits and errors [Hits – Errors] by averaging mean amplitude across coronal electrode regions for each response type.
- The difference scores capture the temporal nature of the task, and reflect responses relying on more recollection-based processes.

Partial Correlations Controlling for Age & WASI

	Early Central	Early Parietal	Late Parietal
CTK (Months)	**.248***	**.274***	**.311****

* = $p < .05$; ** = $p < .01$; *** = $p < .001$

Overall, better performance on the CTK task was positively related to increased ERP differences in amplitude between hits and errors.

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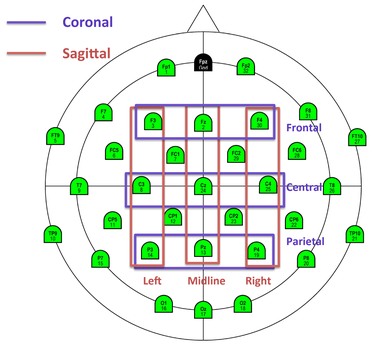
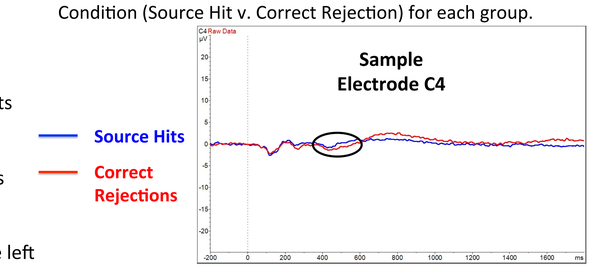
ERP Results



ERP Analyses:
- Typical examination of ERPs of recognition memory includes correct responses ('hits' and 'correct rejections') only (Rugg & Curran, 2007).
- We analyzed 9 electrodes based on previous studies with children and adults (Czernochowski et al., 2005; Riggins et al., 2013; Sprondel et al., 2011).
- Two analysis time windows were selected based on visual inspection of grand averages and previous research (de Chastelaine et al., 2007; Haese & Czernochowski, 2016): 300-600ms for adults and 1200-1600ms for children.
- For all age groups, mean amplitude was the dependent measure, consistent with prior work (Riggins & Rollins, 2015; Sprondel et al., 2011).
- We conducted 4-way ANOVAs: Coronal Plane (Frontal v. Central v. Parietal electrodes) x Sagittal Plane (Left v. Midline v. Right) x Condition (Source Hit v. Correct Rejection) for each group.

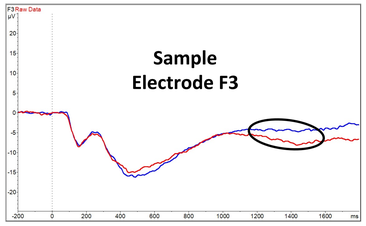
ADULTS

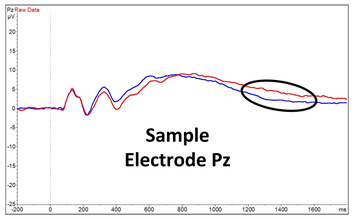
We found a **Sagittal x Condition** interaction, $F(2, 58) = 3.959$, $p = .027$.
- Follow up: In the right hemisphere mean amplitude was more positive for source hits (M = 1.326, SE = .393) than CRs (M = .652, SE = .359).
- In the midline region, mean amplitude was more positive for source hits (M = 1.017, SE = .342) than CRs (M = .387, SE = .304).
- There were no condition differences in the left hemisphere.



CHILDREN

We found a **Coronal x Sagittal x Condition** interaction, $F(4, 244) = 3.847$, $p = .008$.
- Follow up: At **F3**, mean amplitude for source hits (M = -4.677, SE = 1.116) was more positive than for CRs (M = -7.080, SE = 1.211).
- At **Pz**, mean amplitude for source hits (M = 2.483, SE = .799) was more negative than for CRs (M = 4.588, SE = .948).
- There were no condition differences at any central sites.





Summary & Conclusions

- Extending previous work, we see continued development of temporal context memory throughout mid-late childhood and into adulthood through the patterns of source hits and source errors across age groups.
- Memory for temporal context was found to be related to children's conventional time knowledge from middle-late childhood.
- The ERP results revealed two patterns of condition differences between old and new stimuli across child and adult groups, which is intriguing since most old/new effects are characterized by old items resulting in more positive amplitude. However, other researchers have found a similar flipped pattern with children and adults (Czernochowski et al., 2009; Riggins & Rollins, 2015).
- Children and adults differed in the *timing* of ERP differences between conditions, with adults showing these effects much earlier. This is consistent with prior work (de Chastelaine et al., 2007; Haese & Czernochowski, 2016; Sprondel et al., 2011), and could reflect differences in processing speed.
- ERP difference scores and CTK task correlations suggests that neural activity that may reflect recollection-based temporal memory processes are related to the processes involved in ordering conventional time.
- This study adds to the literature on the development of temporal memory and the underlying processes that support it. This work has implications for our understanding of episodic memory development.