MECHANISMS OF WORD-LEARNING IN TYPICAL AND ATYPICAL DEVELOPMENT

by

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ABSTRACT

The hippocampus plays a critical role in binding together information into an integrated memory, and memory for these arbitrary associations is important when learning new words. Recent studies have investigated a learning mechanism called fast mapping (FM), showing that rapid acquisition of novel arbitrary associations can be learned independent of the hippocampus. In the current study we examine word-learning across two conditions more and less likely to require information integration via the hippocampus in typically developing children and individuals with hippocampal dysfunction (e.g., Down syndrome). Individuals with Down syndrome (DS) manifest hippocampal dysfunction and display memory and learning difficulties, hence could potentially benefit from alternative learning strategies. The current study found no benefit of the FM condition in either group. Both groups performed similarly and above chance level across the two conditions and over a week's delay, but a delay by group interaction suggested that the typically developing children showed improvement across all conditions after 1 week whereas performance in DS stayed consistent. Given the evidence for sleep deficits in DS, we examined how sleep disturbance related to delayed word retention. Sleep efficiency did not appear to be driving maintenance in either group. Future studies investigating when an individual with DS sleeps after learning could provide a better understanding of how sleep can influence the word learning process. Additionally, future studies in an older group of children can also provide information on when the hippocampus and sleep dependent learning may develop in childhood.

Chapter 1. INTRODUCTION

Memory is essential to our everyday lives. Without it we would lose a sense of our life history, our ability to efficiently acquire new knowledge, and even our ability to predict and plan for the future. The hippocampus plays a critical role in explicit memory by binding or linking together acquired information into an integrated memory (i.e., facts and events) (Yonelinas et. al., 2001; Davachi & Wagner, 2002; Giovanello, 2008). Memory for arbitrary associations is also important when learning new words. Investigating various learning mechanisms and the neural processes they evoke when binding a new label to a referent can provide a better understanding of the word learning process in children and individuals with developmental disorders.

One model that has been important for understanding the processes involved when acquiring arbitrary associations is the complementary learning system model of memory. This model proposes that sparse representations (little or no overlap in neural representations) are rapidly formed by the hippocampus and medial temporal lobe systems. Under this model, distributed representations are more slowly formed by the neocortex (Davis & Gaskell, 2009; McClelland, McNaughton, & O'Reilly, 1995, but also see McClelland, 2013). The complementary learning system model also proposes that information initially supported by the hippocampus and neocortex is consolidated over time and becomes less dependent on the hippocampus. However, a few studies investigating a learning mechanism called fast mapping (FM), have provided evidence that rapid acquisition of novel arbitrary associations can be learned independent of the hippocampus (Sharon, Moscovitch, and Gilboa, 2011).

FM is an incidental, exclusion-based learning procedure commonly used to explain how young children are able to rapidly acquire language after being exposed to a word once or a few times. In a typical FM memory task, participants are presented with a familiar item, a novel item,

and the name of the novel item for each trial. Participants pair the novel item with the novel name. Participants are able to infer that the novel name is referencing the novel item and not the familiar item because they already know the name of the familiar item. Through this exclusion process, (e.g. disjunctive syllogism; Halberda, 2006) based on semantic knowledge, participants are able to form associations incidentally. FM has three key characteristics in which the novel word is: 1) encoded incidentally; 2) introduced in context with an already-known item; and 3) has a meaning that is apparent through inference (Coutanche & Thompson-Schill, 2014). In a matched condition using explicit encoding (EE), which is known to be hippocampal-dependent, participants are presented with just one novel item and its name and are instructed to remember the novel association.

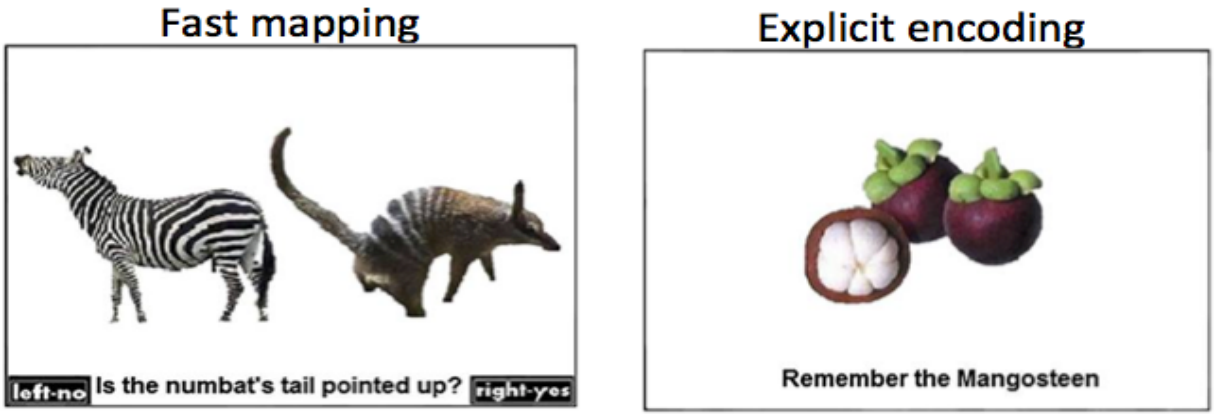

Figure 1. A: Fast mapping task (perceptual question). B: Explicit encoding task. (Sharon, Moscovitch, & Gilboa, 2011).

Contrary to the complementary learning system model, a study by Sharon, Moscovitch, and Gilboa (2011) found that patients with amnesia that had hippocampal damage were able to learn novel word-picture associations after two exposures and retained these associations after a week's delay. Six patients and 15 healthy controls learned two lists of novel words using the two different learning conditions for each list (FM and EE). The FM task used in this study utilized

perceptual questions to invoke incidental learning, “Is the numbat’s tail pointed up?” (Figure 1A). This study also paired the novel item with a familiar item that resembles the same category as the novel item. Participants were asked a perceptual question with the unknown label referencing the novel item. Half of the questions required the answer “no” and the other half required the answer “yes.” After the FM encoding phase participants were tested using a three-alternative forced choice recognition test after a 10-minute and 1-week delay. Next, participants learned a new set of novel items and their associated names through the EE condition. In this condition participants were presented with a novel item and were instructed to remember the novel item “Remember the Mangosteen.” (Figure 1B). This study found that four of the six patients were able to form novel arbitrary associations better through FM compared to the EE task. The four patients that presented with amnesia had lesions either to the hippocampi bilaterally or severance of the fornices bilaterally. The other two patients had additional damage to the anterior temporal lobe (ATL), a site known to support semantic associations. The controls had better 10-minute and long-term retention in the EE condition compared to the FM condition. In the EE condition, amnesic patients performed significantly below controls. However, in the FM condition, amnesic patients performed significantly above chance and not significantly different from the controls both immediately and after 1-week**.** The two patients with ATL lesions recognized 36% of the novel items in association with their name, after the 10-minute delay. This was significantly worse than controls. After the one-week delay, both were still not significantly above chance. Findings from this study suggest that amnesic patients are able to rapidly acquire arbitrary novel associations using FM, independent of the hippocampus, and that a potential area responsible for this is the ATL.

Merhav, Karni, and Gilboa (2015) further investigated whether semantic associations acquired through FM can be integrated directly into cortical regions. A possible brain region that is responsible for forming semantic associations is the ATL (Bonner & Price, 2013; Patterson, Nestor, & Rogers, 2007; Rogers et al., 2004). This would explain how amnesic patients are able to learn novel associations through FM, independent of the hippocampus. In this study, participants with no history of neurological disorders, psychiatric disorders, or learning disabilities, underwent a FM and EE encoding phase. The FM and EE encoding conditions used the same tasks as the Sharon et al. (2011) study (Figure 1). Participants' fMRI BOLD responses were measured during the four-alternative forced choice recognition test of the semantic associations they acquired. Compared to the EE group, the FM group had significantly increased activity in the ATL. This finding suggests that an ATL-related network is responsible for associations learned through FM.

Another study by Atir-Sharon, Gilboa, Hazan, Koilis, and Manevitz (2015) using fMRI and Multivoxel pattern analysis also investigated the neural correlates for the two different encoding conditions. Atir-Sharon et al. (2015) found that ATL voxels were more predictive of memory performance, after the FM condition, than hippocampal voxels. In conjunction, hippocampal activity was the best predictor of memory performance after EE. Searchlight algorithms also revealed that successful FM encoding was related to lateral occipitotemporal, parietotemporal neocortex, and ventrolateral prefrontal cortex activity; EE successful encoding was related to activity in medial and dorsolateral prefrontal and parahippocampal cortices. These studies provide a potential alternative learning strategy for novel arbitrary associations that is mediated by the ATL (i.e. independent of the hippocampus). Therefore, the current study seeks to examine word-learning based on hippocampal and hippocampal-independent ways of

encoding and retaining words in individuals with Down syndrome (DS) and in mental age (MA) matched typically developing (TD) children.

1.1 Down syndrome: Word-learning mechanisms in atypical populations

DS is a chromosomal condition that occurs when an individual has an extra copy of chromosome 21 (Lejeune, Gautier, and Turpin, 1959). It is the most common genetic form of intellectual disability, with an estimate of about 6,000 diagnoses of DS made each year in the United States (Parker et al., 2010). Specifically, individuals with this chromosomal defect display memory and learning difficulties (Nadel, 2003; Edgin, 2013). One study examining brain development in 101 individuals with DS found delays in myelination and proposed that these delays could alter the function of the hippocampal circuitry (Wisniewski, 1990). The trisynaptic circuit of the hippocampus (DG/CA3/CA1) is proposed to play a role in episodic memory (Jabès, Lavenex, Amaral, & Lavenex, 2011). A study by Ábrahám et al., (2012) found decreased density of myelinated axons of the dentate gyrus (DG) from the start of myelination until adulthood in individual with DS. Individuals with DS also showed reduced volume of the hippocampus (Menghini, Costanzo, & Vicari, 2011). Genetic mouse models of DS and human testing using neuropsychological tasks that are mediated by the hippocampus have revealed deficits in hippocampus-dependent tasks, such as pattern separation and spatial navigation (Pennington et. al., 2003; Lavenex, et al. 2015). Individuals with DS that were assessed on an allocentric spatial memory task showed deficits compared to MA matched TD children (Lavenex, et al. 2015). Given the availability of data highlighting alterations in hippocampal structure and function in the DS mouse model and in humans studied across the lifespan in DS, DS is one of the most convincing models of hippocampal dysfunction in patients without focal lesions.

In addition to memory deficits, individuals with DS also show language delays. A study

by Mervis and Robinson (2000) found that 92% of toddlers with DS had expressive vocabularies below the 5th percentile for their chronological age. This is consistent with findings of higher comprehension language skills compared to productive language skills in DS (Chapman, 1995). Other studies that have highlighted deficits in language skills found poor vocabulary growth, grammar deficits, and deficits in speech sound production in individuals with DS (Yoder, Woynaroski, Fey, and Warren, 2014; Singer Harris, Bellugi, Bates, Jones, and Rossen, 1997; Fidler, 2005). Therefore, it is critical to understand the mechanisms underlying these impairments.

It is important to further investigate whether the FM learning mechanism (i.e., hippocampal-independent) can be beneficial for individuals with disordered development of memory systems, like DS. Findings from the proposed study may influence learning strategies and therapy development that can help individuals with DS to overcome their cognitive deficits due to dysfunction in these neural systems. Evidence that these learning strategies do apply to patients with "indirect" lesions to these regions is an important extension of past work. The studies mentioned above suggest that FM allows for rapid acquisition of arbitrary associations that are integrated cortically instead of depending on the hippocampus (Coutanche & Thompson-Schill, 2014; Merhav, Karni, & Gilboa, 2014; Sharon et al., 2011, but see Greve, Cooper, & Henson, 2014; Smith, Urgolites, Hopkins, & Squire, 2014; Warren & Duff, 2014; Warren, Tranel, & Duff, 2016). This raises the question: if there is an alternative, rapid learning mechanism that is independent of the hippocampus, can this mechanism be utilized in young typically developing children and children with developmental disorders? The proposed study will investigate the FM mechanism and what additional variables may be impacting encoding and retrieval.

There are also other factors that can influence memory recognition performance for DS. Individuals with DS have sleep disruptions impacting their quality of sleep. One main influence is the prevalence of obstructive sleep apnea in individuals with DS (Dyken et al., 2003; Goffinski et al 2015; Shott et al., 2006). Sleep plays an important role in memory consolidation (Diekelmann & Born, 2010). Poor sleep and cognitive deficits have been strongly correlated with one another (Breslin et al., 2014; Gomez & Edgin, 2015). Measures of sleep will be collected, using actigraphy, to determine the relationship between sleep and long-term retention of the novel arbitrary associations.

Aims

1. Determine whether fast mapping can support forming novel arbitrary associations, independent of the hippocampus, in individuals with DS. **The central hypothesis** is that individuals with DS will learn novel arbitrary associations better through FM than EE and their EE performance will be impaired in relation to controls. Therefore, individuals with DS should learn more associations from the FM condition than from the EE condition (i.e., hippocampal-dependent).
2. Examine the word learning process in the two different learning conditions while testing the influence of sleep efficiency. **The hypothesis** is that the overall amount of novel arbitrary associations retained over the delay will be moderated by an individuals' quality of sleep. Those with lower sleep efficiency scores will have retained few novel arbitrary associations than those with higher sleep efficiency scores.

Chapter 2. METHODS

2.1 Participants

Twenty-six 11-28 years old individuals with DS (*M* = 18.70 years, *SD* = 4.80, 15 male)

participated in the current study. DS was verified by karyotype report or medical records. Group ethnicity breakdown for the DS group was 50.0% White Non-Hispanic, 30.8% White Hispanic, 3.8% African American Hispanic, 3.8% Native American, and 11.5% biracial. The majority household income for the DS group was between $25,000 and $50,000 and majority maternal education completed was 1-3 years of college. Twenty-six 3-5 years old TD controls (M = 4.52 years, SD = .71, 13 male) participated in the current study. Group ethnicity breakdown for the TD group was 73.1% White Non-Hispanic, 23.1% White Hispanic, and 3.8% biracial. The majority household income for the TD group was more than $100,000 and majority maternal education completed was a master's degree. 84.6% of the TD group's household income was above $50,000 while 50.0% of the DS group's household income was above $50,000 [$c^2$ (1, N = 52) = 7.08, p = .008]. The DS and TD group achieved similar verbal [$t(50) = .099$, $p = .922$] and nonverbal [$t(50) = -.818$, $p = .417$] scores on the Kaufman Brief Intelligence Test – second edition (K-BIT II). The DS group had a mean verbal raw score of 26.73 [range = 1-54] and a mean nonverbal raw score of 14.27 [range = 0-22], while the TD group had a mean verbal raw score of 26.42 [range = 11-47] and a mean nonverbal raw score of 15.69 [range = 1-34].

All groups were recruited through local and parent organizations and advertisement in Tucson, AZ and Phoenix, AZ. Parents signed informed consent, and families received a $20 gift card for each of the first 3 sessions, and a $60 gift card at the end of their 4th session. The exclusion criteria for this study included: past head injury or brain trauma, incident of loss of consciousness (i.e., greater than 5 minutes in length), accidental poisoning, chemotherapy or radiation therapy, enrollment in a randomized clinical trial 8 weeks prior to the study, uncorrected vision impairments, and uncorrected hearing impairments. An additional exclusion criterion for the DS group was a dual diagnosis of DS and autism spectrum disorder. The whole

experiment took approximately 4.5 hours over a span of 4 weeks. All experimental procedures were approved by the University of Arizona Institutional Review Board.

2.2 Equipment and Stimuli

2.2.1 Actigraphy

The Actiwatch-2 (Actiwatch 2, Phillips Respironics Mini-Mitter, Bend, OR) was used to obtain sleep data. The Actiwatch-2 has been validated against polysomnographic recordings (Weiss, Johnson, Berger, & Redline, 2010). Participants were asked to wear the watch for one week. Data for 4 participants, from each group, were not collected due to technical errors or because participants refused to wear the watch. Parents also completed a sleep log as supplemental data. Data were collected in 30-s epochs and analyzed using commercially available software (Respironics Actiware 5.71.0, Bend, OR). Actigraphy data were scored at the medium sensitivity threshold (activity counts = 40/min), with sleep onset and sleep end marked by a period of 3 and 5 min of immobility or more, respectively (Meltzer, Montgomery-Downs, Insana, & Walsh, 2012). Each epoch of data from the Actiwatch was assessed as sleep or wake, based on whether the activity score exceeded the medium threshold. The actigraphy variables of interest are: Average sleep efficiency (percent of time spent asleep from sleep onset to offset), Average sleep time (time spent asleep minus any periods of wake), Average wake after sleep onset (time spent awake), Average wake percentage (percent of time spent wake from sleep onset to offset), and Average sleep fragmentation (an index of restlessness based on the sum of mobile time and immobile time that last less than a minute during the night). Averages were taken across all nights of sleep collected.

2.2.2 Stimuli

Participants learned 2 different lists of 4 novel items and 2 familiar items in each list (A and B).

All items can be categorized into 2 categories (animal or fruit). List A and B have 2 novel animal items and 2 novel fruit items in each list (8 novel items total). Most stimuli were provided by Asaf Gilboa, Rotman Research Institute at Baycrest and Center for Stroke Recovery; Department of Psychology, University of Toronto, Toronto. Additional familiar items were taken from the World Wide Web.

2.3 Design and Procedure

Pilot work showed that perceptual based questions, like the ones used in the Sharon et al. (2011) study, were too language demanding for individuals with DS. Results from pilot 1 showed individuals with DS were only able to correctly answer the perceptual based question during the encoding phase, 61.36% of the time, marginally above chance (p = 0.048). A design similar to the Spiegel & Halberda (2011) study was used in pilot 2. Participants were asked to touch the target item instead of answering a perceptual based question. Participants performed significantly better on the FM encoding task for pilot 2 than pilot 1 ($t(17)$ = -3.205, p = 0.005). Participants correctly touched the target item 82.52%, significantly above chance (p = 0.002). Therefore, the current study used a similar paradigm as pilot 2.

All participants learned two lists of associations, one using the FM learning mechanism and the other using the EE learning mechanism. Each list consisted of 4 novel and 2 familiar target items, for a total of 6 items. The two lists were counterbalanced between the two learning conditions. To ensure that participants encoded the items incidentally in the FM condition, every participant underwent the FM condition before the EE condition (Figure 2). Each session was separated by about a week.

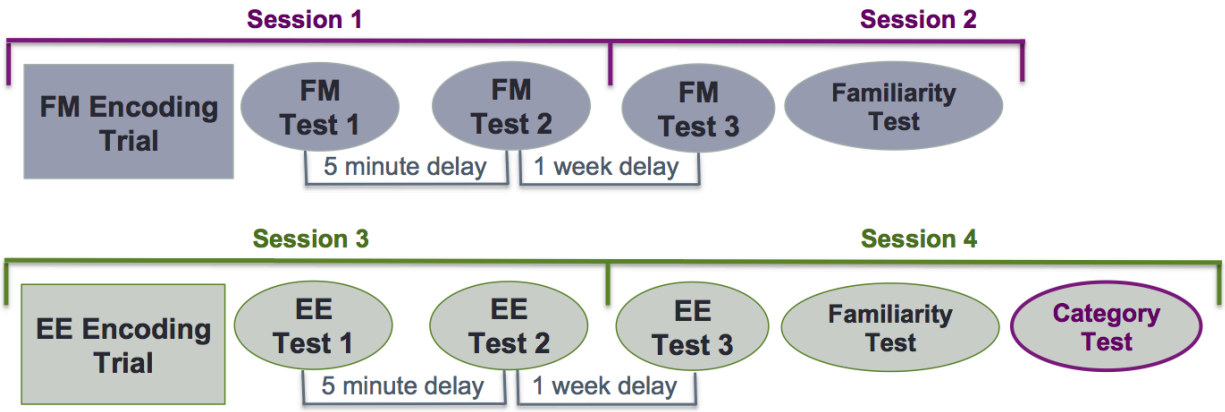

Figure 2. Study design. Fast mapping condition: sessions one and two. Explicit encoding condition: sessions three and four. The category test consisted both lists from the FM and EE condition.

2.3.1 Fast Mapping Condition

Practice encoding trials: For session one, all participants began with the same five non-randomized practice trials (3 familiar and 2 novel targets). Participants were told that they would be playing a pointing game (Figure 3). Participants used a pointing stick to make their selection. For each trial, participants heard the target name and were shown the target item and a familiar (i.e., blueberries) comparison item from the same category, for 5000 milliseconds. After the 5000 millisecond exposure, participants were instructed to point to the target item ("Now point to the *target*"). They were allowed 5000 milliseconds to make their selection. A researcher selected the corresponding key on a keyboard as the participants made their response. The amount of time allowed for selection (5000 ms.) was estimated based on one standard deviation from the mean time it took participants in pilot 2 to make their selections. The selection-screen timed out after 5000 milliseconds to ensure that every participant was exposed to the stimuli for the same amount of time. A feedback screen was provided after their selection for 2000 milliseconds (Figure 3).

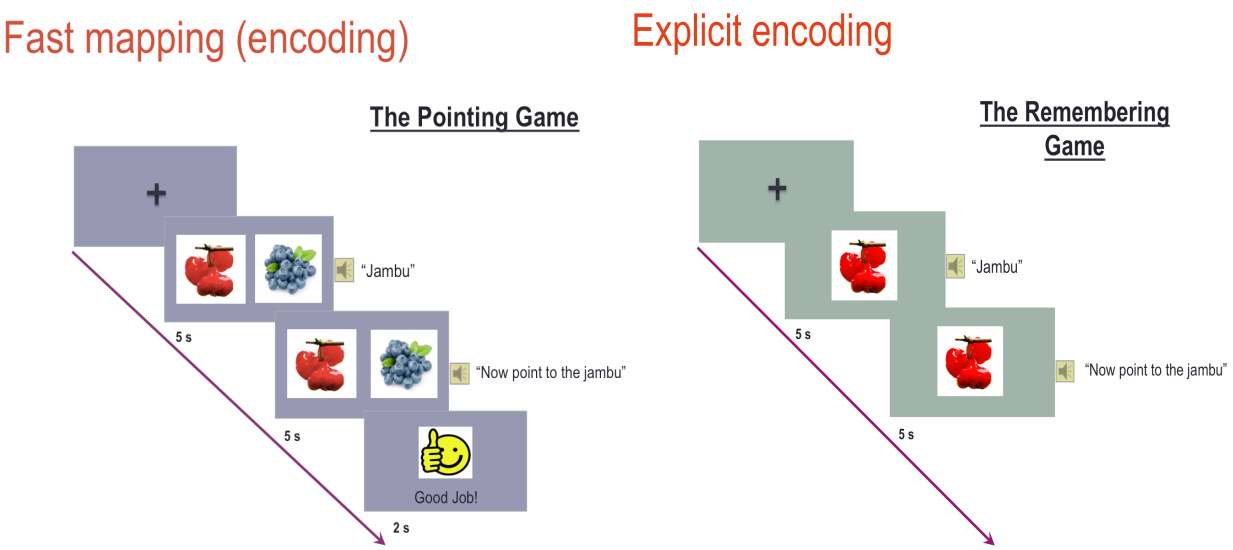

Figure 3. Encoding task trials.

Encoding: After the practice encoding trials, participants were presented with the encoding phase for the FM condition (4 novel and 2 familiar targets). The FM task followed the same presentation as described for the practice trials. They received two randomized blocks of 6 trials, for a total of 12 trials. Between the two blocks, target items were counterbalanced for where they were displayed (left, right). Comparison items were also different between the two blocks to prevent context effects.

Recognition test: Immediately after the FM task, participants were tested for their recognition memory for the four novel target items. They were presented with three choices (3 of the 4 novel items) for at least 5000 milliseconds and were asked, "Now point to the *target*." They had unlimited time to make their selection (Figure 4). Each target item was tested three times (3 blocks of 4 trials), also counterbalanced between the three locations, for a total of 12 test trials. Participants were tested two more times: 1) after a 5-minute delay 2) after a 1-week delay. Participants watched a short video during the 5-minute delay. There were three different randomized versions of the recognition test. Participants received the same version at the same delays.

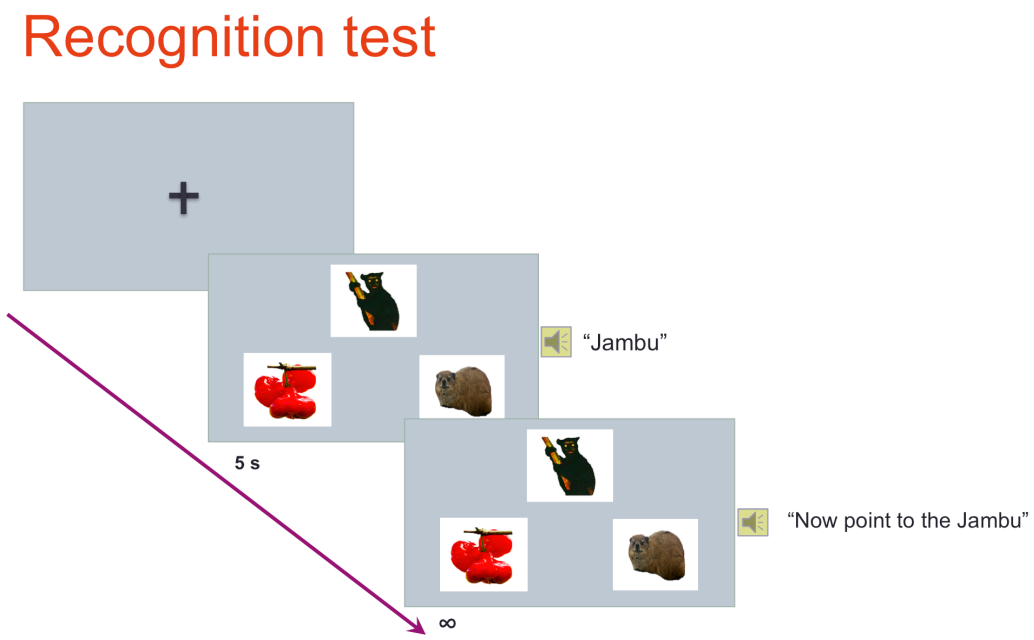

Figure 4. Recognition test trials.

Familiarity test: After one-week participants returned for session two and performed a familiarity test for the FM items they learned after their one-week delay recognition test. During this test, participants are asked "Did you see this in the game we just played with the pointing stick?" for an array of items from the FM task, novel items they have never seen before, and familiar items that were not seen in the game. This was to assess whether participants showed some memory of the novel target items from the FM task.

2.3.2 Explicit Encoding Condition

After one-week participants returned for session three. They participated in the EE condition that followed the same procedure as the FM condition, however they did not have practice trials. The only difference was that participants were told that they would play a remembering game, where they would have to remember the names of the items. They were also only presented with a single item each trial (Figure 3). Participants were still asked to point to the target item. This was to equate the two learning conditions as much as possible, aside from

having a familiar item presented or not and whether the task was incidental or not. Since there was only one picture, participants did not need to receive feedback.

After one-week participants returned for session four and performed a familiarity test for the EE items they learned after their one-week delay recognition test.

Category test: At the end of the EE condition, participants received a category test where they were asked to sort pictures of the novel target items learned in both conditions into three baskets (animal, fruit, and other). This was to assess whether participants categorized each item as the intended category.

Chapter 3. RESUTS

During the fast mapping encoding task both the TD and DS groups performed significantly above chance ($p = 0.000$) and not significantly different from each other [$t(43) = -.835$, $p = 0.408$] (Figure 5). The DS group correctly chose the target item 86.788% of the time while the TD group correctly chose the target item 91.35% of the time. The groups did not perform significantly different from each other on the familiarity test [$t(49) = -1.36$, $p = 0.181$] or the category test [$t(50) = .948$, $p = 0.348$].

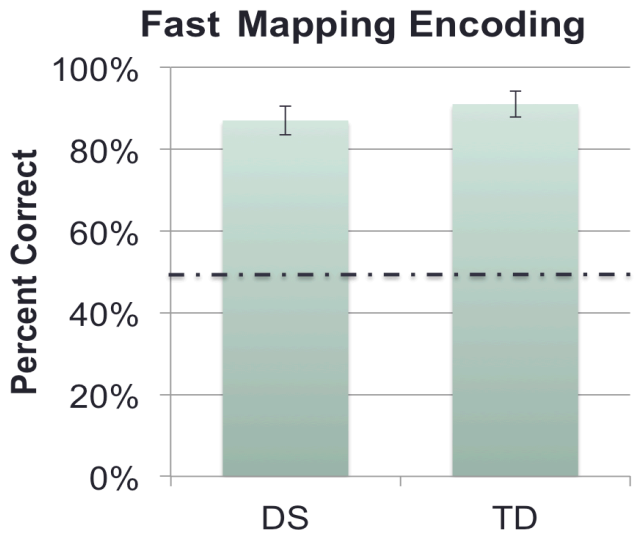

Figure 5. Fast mapping encoding performance.

Performance for all delays and conditions for the two groups were also significantly above chance ($p < 0.001$). Contrary to our hypothesis that individuals with DS would learn novel arbitrary associations better through FM than EE, we found no significant differences at immediate test [$t(25) = -1.443$, $p = 0.162$], 5-minute delay [$t(25) = -0.815$, $p = 0.423$], or at 1 week-delay [$t(25) = -0.551$, $p = 0.587$] (Figure 6). Similarly, we did not find significant differences in the TD group between the two conditions at immediate test [$t(25) = -0.842$, $p = 0.408$], 5-minute delay [$t(25) = 0.535$, $p = 0.597$], or at 1 week-delay [$t(25) = -0.360$, $p = 0.722$].

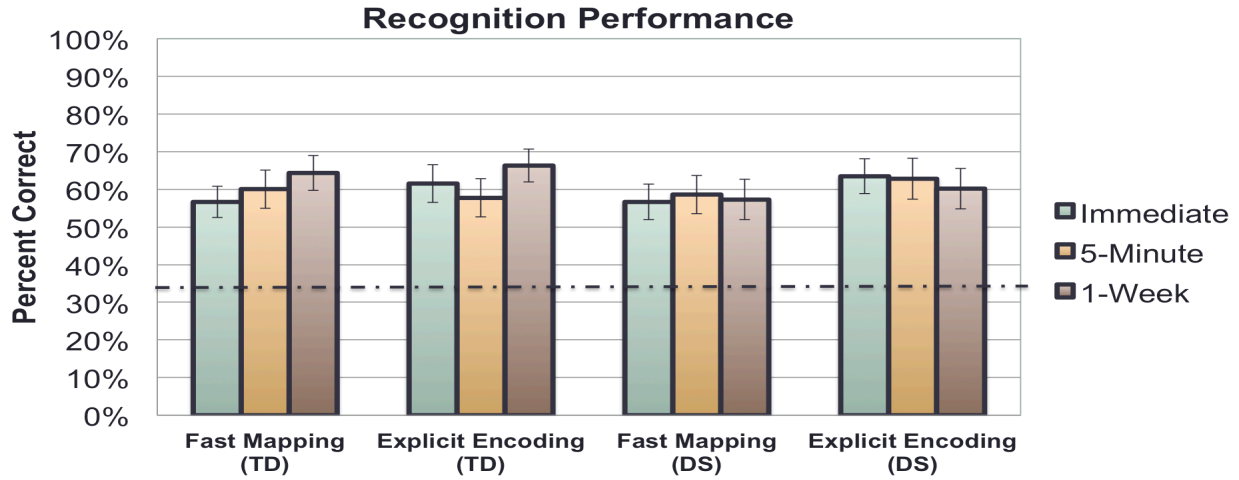

Figure 6. Recognition performance.

A 2 x 2 x 3 repeated measures analysis of variance (group x condition x delay) was conducted to compare the effect of delays on the number of words learned in each condition within the two groups. There was no main group [$F(1,50) = 0.063$, $p = 0.804$], delay [$F(2,49) = 1.321$, $p = 0.276$], or condition [$F(1,50) = 0.841$, $p = 0.363$] effect. There were no condition x delay x group [$F(2,49) = 0.483$, $p = 0.620$] or condition x delay [$F(2,49) = 1.289$, $p = 0.285$] interactions. However there was a significant group x delay interaction [$F(2,49) = 4.385$, $p = 0.018$]. This interaction was more evident between the 5-minute and 1-week delay and reflected a tendency for the controls to improve from 5-minutes to 1-week while the DS group showed

less improvement. Therefore, we computed gain/loss scores between the last two delays for each group by condition. In the EE condition, the DS group had a mean loss of 2.63%, while the TD group had a mean gain of 8.58%. These gains and losses for the DS and TD group were significantly different [$t(50) = -2.793$, $p = 0.007$]. In the FM condition, the DS group had a mean loss of 1.35%, while the TD group had a mean gain of 3.65%. These gains and losses were not significantly different from each other [$t(50) = -1.035$, $p = .306$] (Figure 7). There was a similar pattern for the two groups in both of the conditions but there wasn't a significant interaction for condition x group [$F(1,50) = 0.819$, $p = 0.370$].

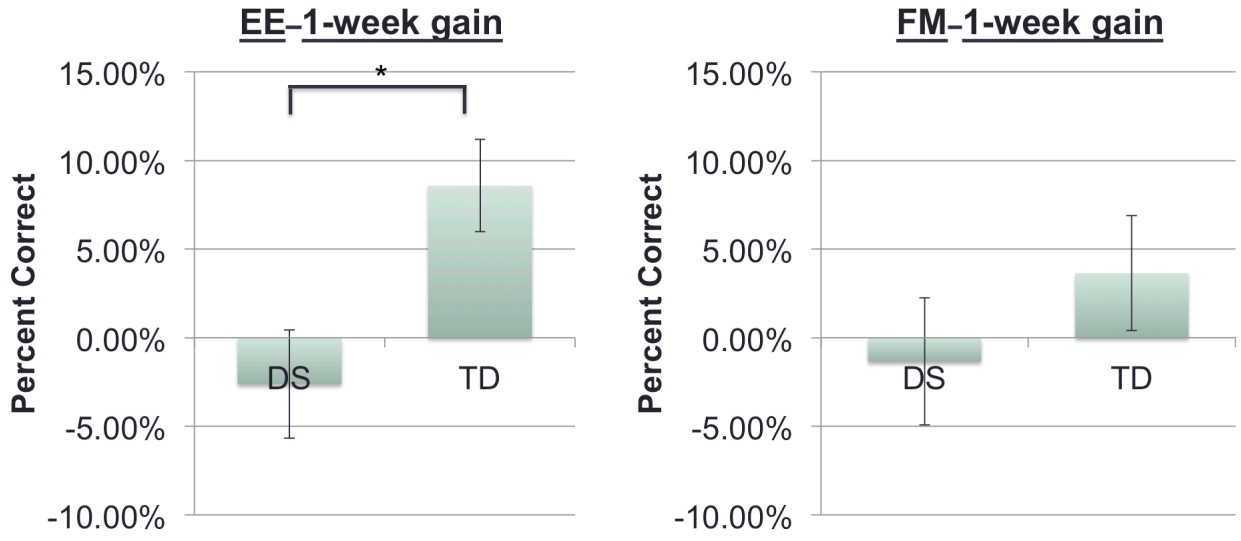

Figure 7. Explicit and Fast mapping encoding gains/loss between 5-minute test and 1-week test.

We then examined the role of sleep. We hypothesized that the overall number of novel arbitrary associations retained over the delays would be moderated by an individuals' quality of sleep. Individuals with DS showed a significant difference in sleep efficiency scores [$t(42) = -2.024$, $p = 0.049$] and average sleep time [$t(42) = -2.662$, $p = 0.011$] compared to TD children. However, there were no significant differences in average after sleep onset [$t(42) = 0.809$, $p = 0.423$], average wake percentage[$t(42) = 1.872$, $p = 0.068$], or sleep fragmentation [$t(42) =$

1.370, p = 0.178] (Table 1). Sleep efficiency for the DS group was not correlated with gain scores in either the FM [$r(22)$ = .006, p = .980] or EE [$r(22)$ = -.183, p = .416] condition. This was also the case for the TD group in both the FM [$r(22)$ = .180, p = .423] and EE [$r(22)$ = .235, p = .292] condition.

	DS group			TD group		
	n	*M*	*SD*	*n*	*M*	*SD*
Average Sleep Efficiency	22	82.82	10.16	22	87.51	3.85
Average Sleep Time	22	422.96	95.41	22	482.04	41.58
Average Wake After Sleep Onset	22	67.08	35.62	22	60.26	17.26
Average Wake Percentage	22	13.93	6.86	22	10.98	2.73
Average Sleep Fragmentation	22	28.14	9.03	22	25.04	5.57

Table 1. Sleep measures for the DS and TD groups. Average sleep efficiency (percent of time spent asleep from sleep onset to offset), Average sleep time (time spent asleep minus any periods of wake), Average wake after sleep onset (time spent awake), Average wake percentage (percent of time spent wake from sleep onset to offset), and Average sleep fragmentation (an index of restlessness based on the sum of mobile time and immobile time that last less than a minute during the night). Averages were taken across all nights of sleep collected.

Chapter 4. DISCUSSION

A study by Sharon et al., 2011 found that patients with amnesia who had damage to the hippocampus were able to learn novel word-picture associations after two exposures and retained these associations after a week's delay. We investigated whether the FM paradigm used in the Sharon et al., 2011 study would benefit individuals with DS who also have hippocampal dysfunction. The central hypothesis of this study was that individuals with DS would learn novel arbitrary associations better through FM and their EE performance would be impaired compared to controls. We expected that individuals with DS would learn more associations from the FM condition than from the EE condition. Inconsistent with findings from Coutanche & Thompson-

Schill (2014), Merhav, Karni, and Gilboa (2014), and Sharon et al., (2011) and contrary to our hypothesis, the results from the current study showed no significant benefit in the FM condition for the DS group. This result is consistent with other work that also found no FM benefit in healthy older adults, memory-impaired patients (damage to the hippocampus), patients with amnesia (damage to the hippocampus), and patients with left temporal lobectomies (Greve et al., 2014; Smith et al., 2014; Warren & Duff, 2014; Warren et al., 2016). The study by Greve et al., (2014) with healthy older adults investigated whether FM could alleviate memory deficits associated with normal aging compared to a younger group of individuals. The younger group performed significantly better than the older group across both conditions after 10 minutes and a 1-week delay. The healthy older adults did not show any benefit in the FM condition compared to the EE condition. It appears that evidence is mixed regarding the benefit of FM for the retention of arbitrary labels in individuals that do not have amnesia. Patients with amnesia that have more severe damage to their hippocampus may have developed alternative methods (i.e., fast mapping) to form associations as a way to compensate for poor hippocampal function. Alternatively, individuals without amnesia may have some residual hippocampal function they can rely on, and therefore the FM mechanism might not be operating in the same way for them when compared to patients with amnesia who have more severe damage to their hippocampus.

Results from the current study did show a group x delay interaction that was more prominent between the 5-minute and 1-week test delay across both conditions. The gains/loss scores, surprisingly, showed that the DS group maintained what they had learned over a long-term delay. FM literature with young typically developing children show mixed results as to whether young children can retain FM words over a long-term delay. Some studies have shown rapid forgetting for fast-mapped words (Horst & Samuelson, 2008; Vlach & Sandhofer, 2012),

while others have supported long-term retention (Carey & Bartlett, 1978; Markson & Bloom 1997; Waxman & Booth, 2000; Brady & Goodman, 2014). One argument raised by Vlach and Sandhofer (2012) is that previous studies have incorporated various memory supports (i.e., saliency, repetition, and generation) in the FM paradigms they used. Vlach and Sandhofer (2012) examined word learning and retention in children without providing any memory support over a 1-week and 1-month delay and failed to find retention across the delays. However, a study by Waxman and Booth (2000) showed 1-week retention for fast-mapped words. This was consistent with findings from the current study, as the TD group maintained and showed some gain over a week's delay.

A common finding for the control groups of studies that used a similar paradigm as the current study is an EE benefit (Atir-Sharon, Gilboa, Hazan, Koilis, & Manevitz, 2015; Coutanche & Thompson-Schill, 2014; Greve, Cooper, & Henson, 2014; Merhav et al., 2015; Sharon et al., 2011; Smith, Urgolites, Hopkins, & Squire, 2014; but see Warren & Duff, 2014; Warren et al., 2016). Although this finding was not consistent with the finding in the current study, this might suggest that the EE benefit emerges with hippocampal development and sleep dependent learning since the EE condition is proposed to be dependent on the hippocampus. Future studies may investigate whether this EE benefit emerges in an older group of children.

Sleep is known to play a role in memory consolidation (Diekelmann & Born, 2010). Additionally, poor sleep appears to be related to cognitive deficits (Breslin et al., 2014; Gomez & Edgin, 2015). Therefore, we were expecting differences among sleep efficiency between the DS and TD group and that this difference would be correlated with long-term retention of the novel arbitrary associations. The DS and TD group did show a significant difference in sleep efficiency scores, however this, and other sleep measures (i.e., average sleep time, average after sleep

onset, average wake percentage, and sleep fragmentation), were not related to retention across the delays or conditions for either of the groups. With significantly lower SE for the DS group than the TD group we would have expected loss over time. A study by Spanò et al., (in preparation) highlights the influence of sleep after learning for the DS group. This study found that the DS group that slept right after learning maintained much less at 4-hours and 24-hours, similarly to the DS group in the current study, than if they were awake. This finding was also apparent in an independent study conducted by Ashworth, Hill, Karmiloff-Smith, and Dimitriou (2015) where they found only a group with Down syndrome (compared to Williams syndrome and typically developing children) showed a loss when sleeping right after encoding. In the current study, the DS group slept 4 to 18 hours after the study sessions. Sleeping after learning for the DS group may influence retention levels, and future studies should investigate whether sleeping within 4-hours of learning like the Spanò et al., (in preparation) study could disrupt learning/ retention.

Individuals with DS also present deficits in some executive functions (Baddeley & Jarrold, 2007). In two studies, the DS group performed worse than the non-DS group at tasks that measure sustained attention, set shifting, and conceptual shifting (Lanfranchi, Jerman, Pont, Alberti, & Vianello, 2010; Rowe, Lavender, & Turk, 2006). The frontal lobe is known to be responsible for attentional processes (Baddeley & Jarrold, 2007), and there is evidence that individuals with DS could have abnormalities in the frontal lobes (Rowe et al., 2006). Attention control (i.e., frontal lobe functioning) may also moderate the effects of learning. To better understand the impact of attentional control on learning in the current study, eye-tracking measures that were recorded in the current study will also be examined in the future.

Chapter 5. CONCLUSION

Previous studies with patients with amnesia have shown evidence for hippocampal independent learning through the FM paradigm. Learning through the FM condition appeared to be more beneficial compared to the EE condition when patients learned novel arbitrary associations. Additional studies investigating the FM learning mechanism, along with the current study in individuals with DS, failed to find the same benefit. Although sleep efficiency was not correlated with retention for DS group, the time frame of sleep after learning may play a role. Further investigation of the time frame of sleep for individuals with DS can provide a better understanding of how the timing of sleep after learning can influence the word learning process. Future studies in an older group of children can also provide information on when the hippocampus and sleep dependent learning may develop in childhood.

REFERENCES

Ábrahám, H., Vincze, A., Veszprémi, B., Kravják, A., Gömöri, É., Kovács, G. G., & Seress, L. (2012). Impaired myelination of the human hippocampal formation in Down syndrome. *International Journal of Developmental Neuroscience, 30*(2), 147-158.

Ashworth, A., Hill, C. M., Karmiloff-Smith, A., & Dimitriou, D. (2015). A cross-syndrome study of the differential effects of sleep on declarative memory consolidation in children with neurodevelopmental disorders. *Developmental science*.

Atir-Sharon, T., Gilboa, A., Hazan, H., Koilis, E., & Manevitz, L. M. (2015). Decoding the formation of new semantics: MVPA investigation of rapid neocortical plasticity during associative encoding through Fast Mapping. *Neural plasticity*, *2015*.

Baddeley, A., & Jarrold, C. (2007). Working memory and Down syndrome. *Journal of Intellectual Disability Research, 51*(12), 925-931.

Bonner, M., & Price, A. (2013). Where Is the Anterior Temporal Lobe and What Does It Do? *Journal of Neuroscience, 33*(10): 4213-4215.

Brady, K. W., & Goodman, J. C. (2014). The Type, but Not the Amount, of Information Available Influences Toddlers' Fast Mapping and Retention of New Words. *American Journal of Speech-Language Pathology, 23*(2), 120-133.

Breslin, J., Spanò, G., Bootzin, R., Anand, P., Nadel, L., & Edgin, J. (2014). Obstructive sleep apnea syndrome and cognition in Down syndrome. *Developmental Medicine & Child Neurology, 56*(7), 657-664.

Bruce F. Pennington, Jennifer Moon, Jamie Edgin, Jennifer Stedron, and Lynn Nadel. The neuropsychology of Down syndrome: Evidence for hippocampal dysfunction. *Child Development 2003;74*: 75-93.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word.

Chapman, R. S. (1995). Language development in children and adolescents with Down syndrome. In P. Fletcher & B. MacWhinney (Eds.), *The handbook of child language* (pp. 641–663). Oxford, UK: Blackwell.

Cohen, J. (1992). A power primer. *Psychological bulletin, 112*(1), 155.

Coutanche, M. N., & Thompson-Schill, S. L. (2014). Fast mapping rapidly integrates information into existing memory networks. *Journal of Experimental Psychology: General, 143*(6), 2296.

Davachi, L., & Wagner, A. D. (2002). Hippocampal contributions to episodic encoding: insights from relational and item-based learning. *Journal of Neurophysiology*, *88*(2), 982-990.

Davis, M. H., & Gaskell, M. G. (2009). A complementary systems account of word learning: neural and behavioural evidence. Philosophical Transactions of the Royal Society B: *Biological Sciences, 364*(1536), 3773-3800.

Diekelmann, S., & Born, J. (2010). The memory function of sleep. *Nature Reviews Neuroscience, 11*(2), 114-126.

Dyken, M. E., Lin-Dyken, D. C., Poulton, S., Zimmerman, M. B., & Sedars, E. (2003). Prospective polysomnographic analysis of obstructive sleep apnea in down syndrome. *Archives of pediatrics & adolescent medicine, 157*(7), 655-660.

Edgin, J. O. (2013). Cognition in Down syndrome: a developmental cognitive neuroscience perspective. Wiley Interdisciplinary Reviews: *Cognitive Science,4*(3), 307-317.

Fidler, D. J. (2005). The emerging Down syndrome behavioral phenotype in early childhood: Implications for practice. *Infants & Young Children, 18*, 86–103.

Giovanello, K. S., Schnyer, D., & Verfaellie, M. (2009). Distinct hippocampal regions make unique contributions to relational memory. *Hippocampus, 19*(2), 111-117.

Goffinski, A., Stanley, M. A., Shepherd, N., Duvall, N., Jenkinson, S. B., Davis, C., ... & Roper, R. J. (2015). Obstructive sleep apnea in young infants with Down Syndrome evaluated in a Down Syndrome specialty clinic. *American Journal of Medical Genetics Part A, 167*(2), 324-330.

Gómez, R. L., & Edgin, J. O. (2015). Sleep as a Window Into Early Neural Development: Shifts in Sleep-Dependent Learning Effects Across Early Childhood. *Child development perspectives, 9*(3), 183-189.

Greve, A., Cooper, E., & Henson, R. N. (2014). No evidence that 'fast-mapping' benefits novel learning in healthy Older adults. *Neuropsychologia, 60*, 52-59.

Halberda, J. (2006). Is this a dax which I see before me? Use of the logical argument disjunctive syllogism supports word-learning in children and adults. *Cognitive psychology, 53*(4), 310-344.

Jabès, A., Lavenex, P. B., Amaral, D. G., & Lavenex, P. (2011). Postnatal development of the hippocampal formation: a stereological study in macaque monkeys. *Journal of Comparative Neurology, 519*(6), 1051-1070.

Lanfranchi, S., Jerman, O., Dal Pont, E., Alberti, A., & Vianello, R. (2010). Executive function in adolescents with Down syndrome. *Journal of Intellectual Disability Research, 54*(4), 308-319.

Lavenex, P. B., Bostelmann, M., Brandner, C., Costanzo, F., Fragnière, E., Klencklen, G., ... & Vicari, S. (2015). Allocentric spatial learning and memory deficits in Down syndrome. *Frontiers in psychology, 6*.

Lejeune, J., Gautier, M., & Turpin, R. (1959). Study of somatic chromosomes from 9 mongoloid children. *Comptes rendus hebdomadaires des seances de l'Academie des sciences, 248*(11), 1721.

Markson, L., Bloom, P., 1997. Evidence against a dedicated system for word learning in children. *Nature 385* (6619), 813–815.

McClelland, J. L. (2013). Incorporating rapid neocortical learning of new schema-consistent information into complementary learning systems theory. *Journal of Experimental Psychology: General, 142*(4), 1190.

McClelland, J. L., McNaughton, B. L., & O'Reilly, R. C. (1995). Why there are complementary learning systems in the hippocampus and neocortex: insights from the successes and failures of connectionist models of learning and memory. *Psychological review, 102*(3), 419.

Menghini, D., Costanzo, F., & Vicari, S. (2011). Relationship between brain and cognitive processes in Down syndrome. *Behavior Genetics, 41*(3), 381-393.

Merhav, M., Karni, A., & Gilboa, A. (2015). Not all declarative memories are created equal: Fast Mapping as a direct route to cortical declarative representations. *Neuroimage, 117*, 80-92.

Mervis, C. B., & Robinson, B. F. (2000). Expressive vocabulary ability of toddlers with Williams syndrome or Down syndrome: A comparison. *Developmental Neuropsychology, 17*, 111–126.

Nadel, L. (2003). Down's syndrome: a genetic disorder in biobehavioral perspective. *Genes, Brain and Behavior, 2*(3), 156-166.

Parker, S. E., Mai, C. T., Canfield, M. A., Rickard, R., Wang, Y., Meyer, R. E., ... & Correa, A. (2010). Updated national birth prevalence estimates for selected birth defects in the

United States, 2004–2006. *Birth Defects Research Part A: Clinical and Molecular Teratology, 88*(12), 1008-1016.

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience, 8*(12), 976-987.

Pennington, B. F., Moon, J., Edgin, J., Stedron, J. & Nadel, L. (2003). The neuropsychology of Down syndrome: evidence for hippocampal dysfunction. *Child Development, 74*, 75-93.

Rogers, T. T., Lambon-Ralph, M. A., Garrard, P., Bozeat, S., McClelland, J. L., Hodges, J. R., et al. (2004). Structure and deterioration of semantic memory: a neuropsy- chological and computational investigation. *Psychological Review, 111*, 205–235.

Rowe, J., Lavender, A., & Turk, V. (2006). Cognitive executive function in Down's syndrome. *British Journal of Clinical Psychology, 45*(1), 5-17.

Sharon, T., Moscovitch, M., & Gilboa, A. (2011). Rapid Neocortical Acquisition of Long-Term Arbitrary Associations Independent of the Hippocampus. *Proceedings of the National Academy of Sciences, 108*(3): 1146–1151.

Shott, S. R. (2006, August). Down syndrome: common otolaryngologic manifestations. In *American Journal of Medical Genetics Part C: Seminars in Medical Genetics* (Vol. 142, No. 3, pp. 131-140). Wiley Subscription Services, Inc., A Wiley Company.

Singer Harris, N. G., Bellugi, U., Bates, E., Jones, W., & Rossen, M. (1997). Contrasting profiles of language development in children with Williams and Down syndrome. *Developmental Neuropsychology, 13*, 345–370.

Smith, C. N., Urgolites, Z. J., Hopkins, R. O., & Squire, L. R. (2014). Comparison of explicit and incidental learning strategies in memory-impaired patients. *Proceedings of the National Academy of Sciences, 111*(1), 475-479.

Spanò Gómez Demara, Alt, Cowen, Edgin. (*in preparation*). To Nap or Not to Nap?: Sleep-dependent memory consolidation in typically and atypically developing preschoolers.

Spiegel, C., & Halberda, J. (2011). Rapid fast-mapping abilities in 2-year-olds. *Journal of experimental child psychology, 109*(1), 132-140.

Atir-Sharon, T., Gilboa, A., Hazan, H., Koilis, E., & Manevitz, L. M. (2015). Decoding the formation of new semantics: MVPA investigation of rapid neocortical plasticity during associative encoding through Fast Mapping. *Neural plasticity, 2015*.

Vlach, H.A., Sandhofer, C.M., 2012. Fast mapping across time: memory processes support children's retention of learned words. *Front. Psychol. 3,* 46.

Warren, D. E., & Duff, M. C. (2014). Not so fast: Hippocampal amnesia slows word learning despite successful fast mapping. *Hippocampus, 24*(8), 920-933.

Warren, D. E., Tranel, D., & Duff, M. C. (2016). Impaired acquisition of new words after left temporal lobectomy despite normal fast-mapping behavior. *Neuropsychologia, 80*, 165-175.

Waxman, S. R., & Booth, A. E. (2000). Principles that are invoked in the acquisition of words, but not facts. *Cognition, 77*(2), B33-B43.

Weiss, A. R., Johnson, N. L., Berger, N. A., & Redline, S. (2010). Validity of activity-based devices to estimate sleep. *Journal of Clinical Sleep Medicine, 6,* 336–342.

Wisniewski, K. E., Wisniewski, H. M., & Wen, G. Y. (1985). Occurrence of neuropathological changes and dementia of Alzheimer's disease in Down's syndrome. *Annals of Neurology, 17*(3), 278-282.

Yoder, P., Woynaroski, T., Fey, M., & Warren, S. (2014). Effects of dose frequency of early communication intervention in young children with and without Down syndrome. *American Journal on Intellectual and Developmental Disabilities, 119*, 17–32.

Yonelinas, A. P., Hopfinger, J. B., Buonocore, M. H., Kroll, N. E. A., & Baynes, K. (2001). Hippocampal, parahippocampal and occipital-temporal contributions to associative and item recognition memory: an fMRI study. *Neuroreport, 12*(2), 359-363.