The Effects of Acute Sleep Restriction on Inhibitory Control and Self-Regulation in 2-Year-Old Children

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The Effects of Acute Sleep Restriction on Inhibitory Control and Self-Regulation in 2-Year-Old Children

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Abstract

Introduction: Poor sleep health in early childhood is known to negatively affect behavioral self-regulation, which is linked to reduced school readiness and poor later life outcomes. The aim of this study was to understand the role of sleep loss in behavioral self-regulation strategies and inhibitory control using a standard task (Forbidden Toy) that measures a child’s capacity to delay gratification. Compared to a day when toddlers had a daytime nap, it was hypothesized that after acute nap deprivation they would have a shorter latency to touching the toy and would resort to more immature, maladaptive self-regulation strategies to delay gratification.

Methods: In this experimental, counterbalanced study, 25 healthy children (11 males, 34.1 ± 2.3 months-old) followed an sleep stabilization schedule for ≥5 days prior to a baseline (nap) and one day of acute nap deprivation condition (no-nap). Inhibitory control was assessed using an age-appropriate, attractive toy. Children were left alone with the toy for a 3-minute waiting period and videotaped. The videos were coded for latency to touch and 11 discrete self-regulation strategies. McNemar repeated measures Chi-Squared tests were used to compare between conditions: 1) the number of children who touched the toy and 2) the number of children who employed each of the strategies. Paired t-tests (one-tailed) were used to compared the latencies to touch and the percentage of time each strategy was employed between conditions.

Results: There was no difference between the baseline and sleep restriction conditions in the number of children who touched the toy (X-squared= 0, p = 0.50) and or their mean latency to touch (t = 0.27, p = 0.393). Of the 11 strategies coded, no significant differences were found in the number of children who used each of the strategies or the percent time the children spent using each strategy: visual inspection (t = 0.35, p = 0.37); self-soothing (t = 0.62, p = 0.27); talk about task rules (t = -1.32, p = 0.10); irrelevant speech (t = -0.04, p = 0.49); unintelligible speech (t = 0.16, p = 0.44); fidgeting (t = 0.38, p = 0.35); removing self (t = 1.03, p = 0.16); physical restraint (t = 1.64, p = 0.06); passive waiting (t = 0.80, p = 0.22); object distraction (t = -1.17, p = 0.13); and social bids (t = -0.03, p = 0.49).

Discussion: These findings indicate that acute nap deprivation in toddlerhood may not have an immediate impact on inhibitory control and self-regulation strategies. This is inconsistent with other findings reported in the field, and limitations in the task administration and contextual factors (e.g. socio-economic status) may contribute to the conflicting results. Through early childhood, there are striking developmental changes in behavior and control, and at 30-36 months of age, children may not have sufficient cognitive and emotional resources to exert inhibitory control and self-regulate. Future research should examine developmental changes in the effects of acute sleep restriction on inhibitory control and self-regulation strategies as children progress through the early childhood years.
**Introduction**

Sleep health has become increasingly important in understanding modifiable factors to improve inhibitory control and self-regulation (Miller et al., 2015, Hagger, 2010). Self-regulation, which changes rapidly throughout early childhood, represents a child’s ability to effectively manage their behavior, cognition, emotion, and attention (Heatherton and Wagner, 2011). As children develop, they transition from physical self-regulation strategies towards more effective verbal and cognitive strategies (Miller et al., 2015). This transition marks a shift from maladaptive towards more adaptive strategies, which reflect planful and more cognitively engaging behaviors (Miller et al., 2015, Supplee et al., 2011).

One key aspect of self-regulation is inhibitory control, or the ability to control one’s impulses in challenging contexts. The rate of development and deficits in these skills is associated with immediate and life outcomes (Mischel et al., 1989). Further, the transition from the toddler into the childhood years occurs simultaneously with the sometimes-challenging shift from play-centered care to kindergarten and grade school. Data from recent studies claim that children who are below average and show shortfalls in inhibitory control in toddlerhood may struggle more in adjusting to school settings (Eisenberg et al., 2010). Temperament is a contributing factor to classroom success, and studies claim that children with a higher capacity for inhibitory control in the toddler and preschool years grow to be well internalized, have a higher moral self, and better moral cognition (Kochanska et al., 1997). Similarly, teachers report that achievement in kindergarten is associated with students who can pay attention, follow directions, and not be disruptive to their peers (Blair and Raver, 2015), all skills that depend on
inhibitory control. As reviewed in Blair and Raver (2015), deficits in inhibitory control in toddlerhood translate to poor school readiness. In the long-term, competent goal-directed self-imposed delay of gratification is important to the prevention of developmental and mental health problems (Mischel et al., 1989). These problems extend to lack of resilience, conduct disorders, low social responsibility, and addictive and antisocial behaviors (Mischel et al., 1989, Casey et al., 2011). Finally, another study followed subjects for 40 years to examine longitudinal associations in early childhood delay of gratification to later life inhibitory control. They assert that decreased ability to delay gratification in early childhood is associated with a decreased ability to delay in adulthood and a greater tendency towards impulsivity (Casey et al., 2011).

Understanding how insufficient sleep affects inhibitory control and self-regulation is important, as this information may be valuable for interventional targets to improve these skills, as well as developmental and life outcomes. For the great majority of toddlers, total sleep need is achieved through nighttime sleep and a daytime nap, characterizing these children as biphasic sleepers. Through development, sleep patterns change and are distributed differently: as children age, their nighttime sleep remains stable, but there is a decline in total sleep duration primarily due to the reduced number of hours and amount of time children spend sleeping during their daytime naps (Iglowstein et al., 2003). These changes in naps reflect both maturing biological systems regulating sleep and environmental constraints, including napping policies in daycare/preschools and family demands. In this period of life, even small restrictions of sleep, such as missing a daytime nap, may negatively influence development of self-regulation behaviors in early childhood.
Sleep plays an integral role in regulatory processes in childhood (Sadeh et al., 2002), adolescence (Baum et al., 2013), and into adulthood (Mauss et al., 2012; Pilcher and Huffcutt, 1996). For example, poor sleep is associated with deficits in self-regulation skills and executive functioning skills such as attention (Gregory et al., 2002, Bernier et al., 2010). Although sleep is recognized as an important factor in optimal self-regulation and performance in adolescence and adulthood, there is limited evidence for the role of sleep in inhibitory control and overall self-regulation through early childhood. Closing this gap in the literature is important to promote understanding of modifiable factors in development that affect self-regulation and later life outcomes.

Experimental studies have reported that during the toddler and preschool years, sleep restriction impairs emotion regulation capacities, especially in challenging contexts (Berger et al., 2012, Miller et al., 2015). In adolescence (age 14-17), acute sleep restriction was associated with worse mood and emotion regulation (Baum et al., 2014). These outcomes suggest sleep is critical to problem solving – an everyday skill from early childhood into adulthood. Although it is important to understand modifiable factors in this relationship, well-controlled, experimental studies in the developmental science field are scarce. The current study may help fill part of this gap by directly addressing the relationship between acute sleep restriction, behavior, and self-regulation strategies in 30-36 month olds – a sensitive period of early development. Considering prior evidence relating sleep restriction to behavior and control, it is hypothesized that compared to being well rested after a nap, missing a daytime nap will result in children being less able to effectively control their impulses and engage in mature self-regulation strategies.
Materials and Methods

All data were previously collected as part of NIH-sponsored 4-year longitudinal study (2011-2015).

Recruitment and Screening of Participants. Recruitment of children involved flyers, online advertising, and interacting personally with families at community events. Interested participants were screened with questionnaires and a phone interview. To be included, children were required to be 30-36 months at study start and follow a consistent, biphasic sleep schedule (≥10.5 hours at night with a nap opportunity ≥45 minutes). Children were excluded if they did not fall asleep during their nap opportunity at least 3 times per week. Additionally, children were excluded for: 1) co-sleeping (e.g. with a pet, parent, or sibling); 2) variation in sleep schedule >2 hours; 3) travelling beyond 2 time zones within 3 months prior to study start; 4) taking medications that could affect sleep or circadian rhythms; 5) diagnosed sleep problems; 6) sickness during assessments; 7) diagnoses that affect testing performance (e.g. color blindness); 8) developmental disabilities; 9) chronic medical conditions (e.g. infections, lead poisoning, or severe head injury); 10) pre or post term delivery; 11) low birth weight (<5.5 lbs); 12) clinically significant scores on the Child Behavior Checklist (CBCL); or m) family history of sleep disorders (e.g. Narcolepsy) or mental health disorders (e.g. Bipolar Disorder).

Participants. 25 healthy toddlers (11 males) aged 30–36 months (M = 34.1 months; SD = 2.3 months).
**Trainings and Protocol.** Families completed in-home training visits to gradually introduce the study design and protocols to the subjects and parents. In these visits, children were introduced to and began wearing the actigraph (model Actiwatch 2 or Actiwatch Spectrum; Philips Respironics, Murrysville, PA), and parents were informed in how to use and care for the actigraph and to complete the sleep diary.

Subjects completed an 11-day protocol. As shown in Figure 1, the black bars represent sleep and white represent waking hours. The study began on day 1 in the afternoon and then children’s sleep was tracked for the subsequent 11 nights and 10 days (including naps). Subjects completed assessments on study day 6 and 11. Day 6 served as the baseline assessment and the behavioral assessment was completed after a normal, napping day. On day 11, acute sleep restriction was achieved with one day of nap deprivation. The behavioral assessment was conducted after the child was kept awake during their normal, scheduled naptime. Between assessments, there is a sleep stabilization period to reset sleep history in the subjects. 5 days leading up to each assessment (nap condition and no-nap condition), children followed a strict, consistent sleep schedule. This schedule was structured and individualized so that each subject had a sleep opportunity for at least 12.5 hours each day. This schedule was used for the duration of the 11-day protocol; however, in the sleep restriction

![Figure 1](image_url)  
**Figure 1.** Sample protocol (11 days) for a child with a structured sleep schedule with a 20:00 hours bedtime, an 07:00 hours rise time and a 12:30–14:00 hours afternoon nap opportunity (12.5 h time in bed per 24-h day). Black bars represent time in bed; grey boxes represent the challenge task assessments on nap and no-nap days.
assessment, the child did not have an extended sleep opportunity. They went to bed and woke up the next morning at the same, scheduled time, but were kept awake during the scheduled nap period. This strict schedule promotes stabilization of sleep and circadian rhythms so that effects observed between the two trials can be attributed to the experimental manipulation: nap deprivation. Sleep stabilization is achieved when the child follows the consistent schedule and is measured using the parent-report sleep diary and actigraph to verify. In-home assessments were counterbalanced across subjects. Half of the subjects completed the protocol as shown in Figure 1: with baseline assessment on day 6, and sleep restriction on day 11. The other half of subjects completed the assessments in the opposite order so that they completed first the sleep restriction assessment on day 6, and on day 11 the napping condition.

Researchers communicated with parents via e-mail or phone call daily to ensure no protocol violations occurred. If the protocol was violated by: 1) an accidental nap outside of the scheduled opportunity; 2) deviating from the sleep schedule by greater than 15 minutes; 3) sickness; or 4) use of medications affecting sleep and alertness; 5) caffeine consumption; or 6) children did not fall asleep during their nap opportunity ≥5 of days leading up to the assessment, the inhibitory control assessment was rescheduled and the 5-day stabilization period was repeated. These factors disrupt the stabilization of sleep, introduce variation in the sleep schedule, and/or present unstable sleep histories which could skew the effects observed. Prior to the administration of the assessments, protocol compliance was verified by reviewing actograms and sleep diary entries. Assessments were completed 1-hour past individual’s scheduled nap wake time to account for possible sleep inertia effects on children’s self-regulation.
“Forbidden Toy” Task. This task is designed to measure inhibitory control and self-regulation strategies. Children were presented an age-appropriate attractive toy and allowed to play with the toy before task rules were presented. After trying the toys, the child was instructed not to touch the toy while the researcher left the room. Children were left alone for a 3-minute waiting period that was video recorded. Alternate forms of this task were administered in the baseline and sleep restriction conditions with two different, but similarly attractive toys. Videos were coded for latency to touch and 11 discrete self-regulation strategies (Table 1).

<table>
<thead>
<tr>
<th>Behavior</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visual Inspection</td>
<td>Child visually fixates on or inspects the object and focuses on it with some degree of intensity</td>
</tr>
<tr>
<td>Self-Soothing</td>
<td>Child uses comforting behaviors such as sucking thumb, hair twirling, biting nails, rocking back and forth</td>
</tr>
<tr>
<td>Talk About Task Rules</td>
<td>Child repeats rules or instructions for task</td>
</tr>
<tr>
<td>Irrelevant Speech</td>
<td>Child makes comments about anything non-task related</td>
</tr>
<tr>
<td>Unintelligible Speech</td>
<td>Child makes utterances that cannot be understood</td>
</tr>
<tr>
<td>Fidgeting</td>
<td>Child stands up, is squirming around, taps their hands on the floor or engages in any repetitive small movement</td>
</tr>
<tr>
<td>Removing Self</td>
<td>Child moves away from forbidden object to create distance between themselves and the forbidden toy</td>
</tr>
<tr>
<td>Physical Restraint</td>
<td>Child tries to restrain their hands by sitting on them, folding them, clasping them, putting them in their lap</td>
</tr>
<tr>
<td>Passive Waiting</td>
<td>Child does not focus on the delay object, sits waiting, is zoned-out, or fixes gaze on another object in room</td>
</tr>
<tr>
<td>Object Distraction</td>
<td>Child may pick up another object and play with it to entertain themselves</td>
</tr>
<tr>
<td>Social Bids</td>
<td>Child leaves room to go make contact with guardian or RA, or calls out for help</td>
</tr>
</tbody>
</table>

Parent-Reporting Screening Questionnaires. The Child Behavior Checklist (CBCL) assess youth behavior problems – both internalizing and externalizing. Through a 99-item questionnaire, T-scores are defined as within normal limits (T <60), at-risk (T = 60–69) or clinically significant (T ≥70). The CBCL has sufficient reliability and validity for clinical instruments (Achenbach and Rescorla, 2000).

The Children’s Sleep Habits Questionnaire (CSHQ) is 33-item measure for assessing sleep difficulties in early childhood (Owens et al., 2000). Previous findings support the use of the CSHQ as a clinical screener in 2–5-year-olds’ sleep (Goodlin-Jones et al., 2008).
Assessment of Children’s Sleep Schedules. Parents completed daily sleep diaries recording sleep and data that may affect sleep to be compared with the actigraph recordings and sleep data (e.g. lights out, lights on, time in bed, sleep efficiency, etc.). These data were used to determine whether the stable sleep schedule was maintained and to determine if there were any differences in the sleep opportunity, quality, and duration in the 5 days leading up to the inhibitory control assessments.

Observational Coding of Self-Regulation Strategies. Videotapes of inhibitory control assessments were coded in 10-second intervals for 11 self-regulation strategies that were not mutually exclusive (Table 1). Subjects could employ several strategies at any given time. Coded self-regulation strategies were based on previous work. (Miller et al., 2015, Manfra et al., 2014) Strategies were identified and marked if subjects employed the strategy at least once in the 3-minute delay period. Additionally, strategies were coded for the percentage of time the subject spent using each strategy by dividing the number of intervals a strategy was used by the total number of 10-second intervals in the delay period. The coder was blind to the condition and consulted with an expert reviewer (a developmental psychologist with observational coding expertise, also blind to condition) for coding help and questions as needed.

Hypotheses. The overall objective of this study was to determine the immediate effects of acute nap restriction on toddler’s inhibitory control and self-regulation the same day as the sleep restriction. It was hypothesized that after missing one daytime nap, that subsequent afternoon, children would be more likely to touch the forbidden toy and
have a shorter latency to touch than after a normal nap. Additionally, after acute nap restriction, immediately following the missed nap, children would resort to more maladaptive, non-verbal self-regulation strategies as compared to a normal, napping day.

**Results**

**Sleep Restriction Effects on Inhibitory Control.** 19 subjects touched the toy in the baseline condition and 18 touched the toy after acute nap deprivation (Figure 2). There were no differences in acute nap restriction effects on whether children touched the forbidden toy (McNemar Test, X-squared = 0, p = 0.50). Mean ± SD latency to touch in baseline was 70 ± 60.74 sec. and decreased to 65 ± 71.62 sec. after nap deprivation (Figure 3, 5). There was no difference in the latency to touch between conditions (one-tailed paired t-test, t = 0.28, p = 0.40).

**Table 2** Number of subjects who employed each self-regulation strategy and percentage of time toddlers exhibited self-regulation strategies during the inhibitory control task.

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Nap Mean (% time) ± SD</th>
<th>% of subjects who used the strategy</th>
<th>No-Nap Mean (% time) ± SD</th>
<th>% of subjects who used the strategy</th>
<th>Number of Uses</th>
<th>Percent Time</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td></td>
<td></td>
<td>Mean (%) time ± SD</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Visual Inspection</td>
<td>27.45 ± 29.6</td>
<td>68</td>
<td>25.05 ± 31.2</td>
<td>56</td>
<td>0.34</td>
<td>328.84</td>
</tr>
<tr>
<td>Self-Soothing</td>
<td>4 ± 20</td>
<td>4</td>
<td>1.4 ± 5.3</td>
<td>8</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Talk About Task Rules</td>
<td>0</td>
<td>0</td>
<td>1.78 ± 6.75</td>
<td>12</td>
<td>1.418</td>
<td>-0.177</td>
</tr>
<tr>
<td>Irrelevant Speech</td>
<td>1.5 ± 3.89</td>
<td>16</td>
<td>1.54 ± 6.71</td>
<td>8</td>
<td>0.189</td>
<td>-0.332</td>
</tr>
<tr>
<td>Unintelligible Speech</td>
<td>3.41 ± 8.13</td>
<td>20</td>
<td>3.02 ± 8.23</td>
<td>20</td>
<td>0</td>
<td>0.5</td>
</tr>
<tr>
<td>Fidgeting</td>
<td>21.47 ± 27.08</td>
<td>48</td>
<td>18.29 ± 25.58</td>
<td>44</td>
<td>0</td>
<td>0.384</td>
</tr>
<tr>
<td>Removing Self</td>
<td>7.33 ± 14.63</td>
<td>76</td>
<td>4 ± 11.19</td>
<td>84</td>
<td>0.125</td>
<td>1.03</td>
</tr>
<tr>
<td>Physical Restraint</td>
<td>15.45 ± 26.43</td>
<td>44</td>
<td>8.73 ± 21.57</td>
<td>28</td>
<td>0.781</td>
<td>1.638</td>
</tr>
<tr>
<td>Passive Waiting</td>
<td>23.66 ± 21.25</td>
<td>60</td>
<td>19.05 ± 26.32</td>
<td>44</td>
<td>0.721</td>
<td>0.799</td>
</tr>
<tr>
<td>Object Distraction</td>
<td>4.21 ± 9.61</td>
<td>24</td>
<td>8 ± 19.29</td>
<td>16</td>
<td>0.125</td>
<td>1.169</td>
</tr>
<tr>
<td>Social bids</td>
<td>4.57 ± 14.77</td>
<td>12</td>
<td>4.67 ± 13.19</td>
<td>12</td>
<td>0</td>
<td>-0.026</td>
</tr>
</tbody>
</table>

**Sleep Restriction Effects on Self-Regulation Strategies.** Acute nap restriction effects on the number of subjects who employed each strategy was assessed with a McNemar test (Table 2). One-tailed paired t-tests showed no difference in percent of time spent for each strategy between conditions (Table 2).
There were no significant differences in the results due to counterbalancing conditions (analysis of variance, $p = 0.81$).

Statistical tests were performed in RStudio statistics version 1.0.136 (RStudio, Inc., Boston, MA).

**Figure 2** Differences in the number of children who touched the forbidden toy under baseline and sleep restriction conditions ($X^2 = 0, p = 0.5$). There is no difference in the likelihood of a 2-year-old touching the toy after missing one nap as compared to a napping day.

**Figure 3** Differences in the latency to touch the forbidden toy under baseline and sleep restriction conditions ($t = 0.275, p = 0.393$). There is no difference in the average latency to touch of a 2-year-old after missing one daytime nap as compared to a napping day.

**Figure 4** Individual differences across subjects and whether or not they touched the forbidden toy between conditions. Over half the subjects touched the toy in both conditions.

**Figure 5** Individual differences across subjects’ latency to touch the forbidden toy during baseline and sleep restriction conditions. Each line represents an individual subject. Subjects delayed touching the toy for a variety of latencies.
Discussion

Earlier research has asserted that daytime naps and nighttime sleep is an important factor in optimizing self-regulation and that reduced sleep may impair these abilities (Hagger, 2010). Our findings, however, suggest that nap restriction in 30-36 month olds may not have as strong as an influence on inhibitory control or self-regulation as previously shown in other age groups and/or with other tasks. At this age, children are just beginning to develop self-regulation and control capacities, and these findings are interesting in relation to what was hypothesized and the current work in the field. It was hypothesized that after missing one daytime nap, that subsequent afternoon children will have less inhibitory control and resort towards more maladaptive self-regulation strategies. Findings from this study suggest that acute sleep restriction in 30-36-month-olds does not promote children having less inhibitory control or using less mature coping strategies in a delay of gratification “Forbidden Toy” task. Results are further discussed with respect to the relationship between sleep and inhibitory control, self-regulation, and individual differences.

Sleep and Inhibitory Control. Inhibitory control is an important skill in early childhood as children are given instructions and faced with everyday situations that require them to inhibit their impulses. For example, a child may need to refrain from running out into the middle of the street alongside parent instructions. This skill translates through early childhood to school readiness and later outcomes. We found that nap deprivation does not have significant immediate effects on inhibitory control in early childhood as the number of children who touched the toy between conditions stayed relatively constant.
Similarly, the latency to touch between conditions was not different between conditions (Figure 3). These results are in contrast to what we hypothesized, and the development of the pre-frontal cortex may help explain these findings.

Previous work has asserted that the pre-frontal cortex is mainly responsible for exerting inhibitory control (Miller & Cohen, 2001). The pre-frontal cortex is slower to develop in early childhood than other brain regions like the auditory or visual cortex. This evolutionary finding claims that it may be advantageous for toddlers to experience cognition with limited control because this allows children to experience a period of creative, flexible thinking. The pre-frontal cortex is associated with maintaining control to optimize performance; the immature pre-frontal cortex may allow children to focus less on outcomes of their behavior and actions to maximize their experiences and optimize learning. The pre-frontal cortex does not match the developmental progress of these other cortexes until approximately the fourth year of life (Thompson-Schill et al., 2009, Huttenlocher et al., 1997). Considering this evidence, the lack of effects seen with respect to acute daytime sleep restriction may be due to the relatively immature pre-frontal cortex in toddlers. Preliminary evidence from our team has shown that 3.5-4.0-year-olds’ inhibitory control was significantly affected by acute sleep restriction (missing their daytime nap and a 3-hour bedtime delay), and this sample not only was more likely to touch the forbidden toy, but also had significantly shorter latencies to touch after sleep restriction (Wong et al., 2017). The subjects of this study were ~4-years-old, the point when the pre-frontal cortex is developmentally “catching up” to other sensory cortexes. Although it may be adaptive for toddlers to experience a period of cognition with little control as the prefrontal cortex slowly develops in early toddlerhood, acute
Daytime sleep loss was previously shown to negatively impact toddlers’ adaptive emotion strategies in challenging contexts (Miller et al., 2015) and their elicitation of positive and negative emotions (Berger et al., 2012). However, in these experimental studies, the tasks were more emotionally charged and did not focus on inhibitory control. Thus, although one day of acute nap deprivation may not have immediate significant effects of inhibitory control, there may be other important emotion-related consequences of missing sleep at this age.

**Sleep and Self-Regulation.** Self-regulation has been shown to be a crucial predictor of school readiness as children transition from the toddler to the school-age years. Research has shown that the magnitude of self-regulation skills is important to school success (Blair and Raver, 2015); however, there is little evidence highlighting the different ways and strategies children may self-regulate. Contrasting what was hypothesized, we found that after acute nap deprivation, children did not change self-regulation strategies. Studies have shown that after missing one daytime nap, young children become less able to adaptively self-regulate and resort towards less cognitively engaging strategies like self-soothing and visual fixation, especially in challenging contexts (Miller et al., 2015). The capacity for inhibitory control as compared to dealing with challenging contexts and other behaviors that warrant self-regulation may involve different underlying mechanisms (e.g., emotion regulation). Further research determining these mechanisms and the age at which they mature is needed to fully evaluate the use of self-regulation strategies in early childhood.
**Individual Differences in Inhibitory Control and Self-Regulation.** We also observed considerable individual differences in whether the subjects touched the forbidden toy (Figure 4), as well as in their latency to touch (Figure 5). Such variability in our measures may also be accounted for by prefrontal cortex maturation, as this region develops slowly and differently in each child based upon ongoing experiences throughout development (Kolb et al., 2012). For example, in both conditions, 14 of the subjects touched the forbidden toy while 6 subjects did not touch the toy (Figure 4). With regard to self-regulation, our findings are also consistent with our previously published data showing that toddlers responded to nap deprivation differently (Schumacher et al., 2017). Some toddlers delayed and used self-regulation strategies with no changes between conditions. This suggests individual differences in the susceptibility to sleep loss, which are consistent with previous findings in older children and adolescents (Fallone et al., 2001; Randazzo et al., 1998). This study found large variations in the use of most of the self-regulation strategies coded (Table 3). In future work, it may be important to consider the experimental manipulation, and also individual characteristics of the subjects’ self-regulation and sleep restriction susceptibility.

**Limitations and Future Directions**

Given our well-controlled experimental design it was necessary to enroll healthy, good sleeping toddlers. Thus, our sample with respect to multiple developmental, health, and socio-demographic factors, was very homogenous. Because of these sample demographics, our results lack strong generalizability and thus, may not be applicable to more diverse samples.
Socioeconomic status (SES) may moderate sleep-dependent relationships, as children from resource-poor and lower income families may react to the delay of gratification task differently than those who are resource-rich (Sturge-Apple et al., 2016). Children from a moderately low SES may be disadvantaged in the development of their inhibitory control and self-regulation (Blair and Raver, 2015). Further, for children in resource-poor and impoverished areas, touching the toy may not necessarily reflect poor inhibitory control because the subjects may instead be them taking advantage of the opportunity and resources presented (Sturge-Apple et al., 2016). Further research is needed to fully understand this relationship and how different demographic factors influence inhibitory control and self-regulation in the context of sleep.

The “Forbidden Toy” task was developed from previous studies and there is ample evidence that it is an adequate measure of delay of gratification in children aged 2-4 (Manfra et al., 2014). Two variations of the toy were used in this study; however, five subjects received a form of the assessment with a toy that made noise and instructed the children to play or touch the toy. We realized this limitation and switched out the toy for an engaging, but quiet toy that would not provide supplementary instructions to confuse the subjects. Additionally, subjects were given slightly different instructions for the task each time. The inconsistencies in the task administration may decrease internal validity and thus, may have affected the results. Replication of these trials would be valuable to verify the findings of this study.

The present analysis is based on cross sectional data; therefore, we are unable to make claims about developmental changes in the effects of sleep restriction on
inhibitory control and self-regulation strategies. Additionally, it would be relevant to track individual differences throughout early childhood to observe the stability of these changes. Further work using longitudinal data is needed to assess these limitations to track individual differences, as well as determine if the findings of this study are due to the lagging development of the pre-frontal cortex, or limited study design. This future direction involves tracking changes in synaptic and neuronal density, growth of dendrites, and white matter volume through neuroimaging (Tsujimoto, 2008) to illuminate whether prefrontal cortex development may be the underlying mechanism in the relationship between age, development, sleep, inhibitory control, and self-regulation strategies. Finally, the next steps in this investigation include categorizing the coded strategies into adaptive and maladaptive composites (Schumacher et al., 2017). This will allow us to determine more comprehensively if acute nap deprivation effects the type of self-regulation strategy children employ in an inhibitory control task.

**Conclusion**

This study found that acute sleep restriction in 30-36 month olds had no immediate effects on inhibitory control or self-regulation. As children are rapidly developing, sleep may be a modifiable factor in a child’s ability to inhibit their impulses. Delay of gratification in early childhood is an essential skill and investigating how sleep, inhibitory control, and self-regulation develop and interact is important to understand early childhood cognition and development.
References


Wong et al. (2017) Sleep 40, A17