No Touch Pig!

Investigating Child-Parent Use of a System for Training Executive Function

Kiley Sobel, Kate Yen, Yi Cheng, Yeqi Chen, Alexis Hiniker
{ksobel,yenk,chengy23,yeqic,alexisr}@uw.edu
University of Washington, Seattle, WA, USA

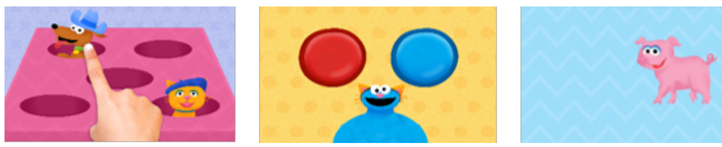

Figure 1: Three mini-games in PBS Kids and Sesame Workshop's *Cookie Monster's Challenge* that require inhibitory control.

ABSTRACT

Strengthening early executive function (EF) skills has the potential to improve an individual's quality of life throughout their lifetime, a fact that has led to many EF-training suites. In this work, we empirically investigate how children and parents engaged with *Cookie Monster's Challenge* (CMC), a tablet game designed to train EF in preschoolers. Through analysis of child-parent co-play with CMC, we describe children's and parents' thematic behaviors, documenting their effective and ineffective strategies for engaging with the game, particularly when it challenged children's EF skills. We further show that these behaviors led to a small but significant short-term increase in an unrelated EF task. Drawing on these patterns of interaction, we propose design directions for EF training interfaces, such as increasing contextual relevance and specific forms of scaffolding. Our work is the first illustration of how preschoolers exercise their EF and inhibitory control by collaboratively using a commercial tablet app together with a parent.

CCS CONCEPTS

• Human-centered computing → Empirical studies in HCI; **Empirical studies in collaborative and social computing**; **• Social and professional topics → Children**.

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1 INTRODUCTION

Executive function (EF) is an umbrella term used to refer to a composite set of skills that collectively enable an individual to engage in goal-directed behavior. EF is composed of working memory (holding information in mind while completing tasks), cognitive flexibility (shifting attention among competing tasks), and inhibitory control (regulating and refraining from acting; also known as self-control and self-regulation) [22, 23, 64]. Together, these subskills support an individual in setting and achieving goals by taking purposeful action and suppressing distractions.

EF is critical for learning and development and predicts academic and career success, as well as health and wellbeing [10, 28, 29, 48, 69]. Conversely, poor EF in childhood is associated with reduced earnings and increased health risks later in life, even controlling for IQ, gender, social class, and other factors [65]. Because of the consequentiality of EF for children's long-term outcomes, researchers have worked to develop early interventions and training programs to help young children develop their EF skills [22–24], and a number of computer-based trainings have been shown to be effective in increasing children's EF (*e.g.*, [7, 40, 44, 46, 56, 71, 74]).

Despite these feasibility proofs, there is much more to understand about how to design effective EF training systems. For example, computerized interventions have had little success supporting younger children (ages 4 to 6), improving inhibitory control, or producing gains that transfer to untrained tasks (*e.g.*, [22, 24, 71, 74]). And although research prototypes have been shown to train EF, these studies have not yet examined EF training through popular, commercially available apps for children [77], leaving open questions of how state-of-the-art interaction design might best reproduce these gains at scale.

Further, prior work has shown that social interactions and support–particularly from parents–have a significant impact on the development of EF [8, 20, 38, 67], but most research on technology-based programs for training EF exclusively examines a solitary training context (*e.g.*, [7, 40, 44, 46, 56, 71, 74]). As families frequently view and use computers, TV, and tablets together [54] and routinely learn from one another in this setting [73], there remains an understudied design opportunity to leverage parent support in this context.

In this study, we analyzed how children engage with *Cookie Monster's Challenge* (CMC) [1]–a tablet-based EF skill-building game for preschoolers–together with their parents to examine in detail how the design of the experience draws on children's executive function. We recruited 37 preschoolers and their parents to play either *Cookie Monster's Challenge* or an active control [57] for 15 minutes in the lab together, and we measured children's short-term fluctuations in EF before and after gameplay.

Through video interaction analysis of children's play sessions, we found that children used a systematic set of strategies to complete in-game tasks, and that parents organically employed a common set of strategies to support children, some of which are known to be ineffective and appeared to undermine children's progress. By examining the strategies that children and parents used while playing CMC, we explore how children, parents, and the app worked together or against one another to move forward in the game. We further saw a significant short-term increase in EF after playing CMC compared to an active control. With a new understanding of child-parent game use, we discuss how design may open additional opportunities for EF development in family contexts with parental intervention.

2 RELATED WORK

Strategies that Support EF Development

Due to the impact EF has on children's development and later life outcomes, executive functioning in young children has been studied extensively in neurology and psychology. For example, prior work documents how particular neural regions correlate with EF development (*e.g.*, [80]), how "private speech" or internalized conversation with oneself [76] mediates EF [3], and how language is key to EF [11]. One of the most well-known studies of children's EF is commonly referred to as the "Marshmallow Test." In this classic lab study, Mischel *et al.* [63] measured how long preschoolers could delay gratification (an inhibitory control skill) or, specifically, resist the smaller, immediate reward of eating one marshmallow now in favor of eating two marshmallows later.

Although environmental factors and the longer-term implications of the original Marshmallow Test have been questioned (*e.g.*, [27, 45, 60]), this original study spurred a deluge of follow-up studies that tested children's delay of gratification in other contexts and attended to the strategies that children used to help them exercise self-control. Children's successful strategies included distracting themselves from the situation [58, 62, 68], covering the reward [63], focusing on abstract properties of the reward (*e.g.*, marshmallows are fluffy clouds) rather than properties that draw attention to the reward's desirability (*e.g.*, marshmallows are delicious treats) [62], and reducing the emotional tension created by waiting (*e.g.*, talking to oneself or calling for a parent) [58].

These follow-up studies also report on the common strategies children employ that undermine their ability to wait. Focusing on the demands of the waiting task and the reward itself makes the task more difficult [58], and younger children (4 and under) set up "self-defeating dilemmas" for themselves by creating tempting environments [61]. When examining the behaviors of children in our study, we used this backdrop of prior work to understand the behaviors that indicate children are actively drawing on their EF and whether their strategies are likely to be successful.

Parents' Impact on Children's EF

There is also research consensus that children's early EF is connected to parents' and other caregivers' behaviors [8, 9, 31, 38, 49, 55, 59, 67]. A significant body of literature explores how adults' (mainly mothers') behaviors, parenting styles, and use of specific strategies affect children's EF. Past literature has found, for example, that mothers' early verbal scaffolding [49] and elaborative utterances in response to their child [8] can impact children's cognitive flexibility and working memory in the short term [8] and later in life [49].

Despite the importance of parent behaviors, prior work has also shown that parents are often unaware of how they might support children's EF. For example, Hom and Knight [41] and Mauro and Harris [58] found mothers were not knowledgeable about effective strategies for delaying gratification and encouraged their children to use the least effective strategies for waiting. In these studies, mothers were more likely to focus on the reward or task itself (*e.g.*, "don't touch!" or "remember, you can't open the present") rather than promoting effective waiting strategies like distraction. However, in a minority of cases, mothers taught their children effective strategies [19, 58], such as telling children to do something physical (*e.g.*, dance), think about something else (*e.g.*, their favorite book), or take deep breaths [58]. Here, we expand

Table 1: Participant demographic information. *Parenting style scale ranges from 1-7 where 7 is more "ineffective." Factors of scale include laxness, over-reactivity, and verbosity.

	CMC (N=19)	Control (N=18)	Overall (N=37)
Child Gender	14M, 5F	10M, 8F	24M, 13F
Child Age	4.26 (0.82)	4.46 (0.90)	4.36 (0.86)
Child Race	16 white, 3 mixed	11 white, 7 mixed	27 white, 10 mixed
Parent Gender	3M, 16F	2M, 16F	5M, 32F
Parent Age	37.2 (4.11)	35.5 (3.10)	36.4 (3.70)
Parenting Style [4]*	2.8 (0.50)	2.7 (0.57)	2.8 (0.53)

on this work by examining the strategies parents suggest in a digital context and considering how designers might support parents in guiding children toward effective ones.

EF and New Media

Researchers have designed and studied many computerized trainings for EF, including [7, 40, 44, 46, 56, 71, 74]. The most well-known and well-studied, CogMed®[24], has been critiqued for its lack of transfer effects [71, 74], limited success with preschool- and kindergarten-aged children, and inability to train inhibitory control [24, 25]. Further, the mentoring component of the system [25] appears to incite the system's positive impacts, not the CogMed® games themselves [20]. Thus, although some studies have shown that computer-based training can support the development of EF, current state-of-the-art designs are known to have limitations and to produce inferior results relative to non-digital training approaches [22, 24, 40, 46, 74].

Prior work has also examined popular off-the-shelf digital media and its role in EF development. Some of this work has examined whether children's media can support EF. For example, Bryant *et al.* [13] found that the television show *Blue's Clues* had positive impacts on children's cognitive flexibility. Liu *et al.* [53] tested the impacts of the touchscreen game Fruit Ninja (which involves inhibitory control) on four-year-olds' inhibitory control and reasoning abilities. They found that training with Fruit Ninja led to improvements in the trained game and saw a modest suggestion that it might improve reasoning ability outside the trained task.

Other work has examined popular media as a potential risk factor inhibiting children's EF development. Lillard and Peterson [52] discovered that fast-paced television cartoons had immediate negative effects on the executive functioning of four-year-olds. Zimmerman *et al.* [81] found that viewing entertainment television programming (but not educational programming) before age three predicted disordered attention later in life. However, Cliff *et al.* [16] found four-year-olds' computer use and electronic game use were not associated with self-regulation at six-years-old.

Finally, researchers have also focused on how families co-engage with new media together (*e.g.*, [15, 34, 39, 50, 70, 72, 79]). This is because when parents mediate their children's time with technology, they are scaffolding the experience [75], or guiding and helping their children learn and grow. Here, we conduct the first study of digital EF training not by children alone but with the support of their parents.

3 METHODS

In this study, we qualitatively analyzed children's and parents' behaviors during co-play with *Cookie Monster's Challenge*, a tablet game published by Sesame Workshop and PBS Kids, for 15 minutes in a lab setting. We also measured changes in children's EF before and after this play session, relative to children who played an active control app.

Participants

We recruited 37 families (see Table 1) with a child between the ages of 3- and 5-years old (inclusive) to participate in this study. All children had experiences with smart devices, but no families reported having experience with the two apps in the study. Two children had developmental delays that may affect their EF. Five children did not complete one or more elements of the study and were only included in the components of our analysis to which they contributed data. Families were randomly assigned to either an experimental (N=19) or an active control (N=18) group. Here, we refer to child participants as C1-C37 with annotations, where the subscript indicates the child's gender ("M" or "F") and the superscript indicates their age (#y#m = # years # months).

Materials

Cookie Monster's Challenge (CMC). Families in the experimental group played CMC. The purpose of this app is to provide young children with opportunities to practice and build skills related to EF, including self-control, focus, memory, following directions, and problem solving [1]. The game includes 12 levels, where each level is composed of a series of 10 structured mini-games (see supplementary material). These mini-games require the player to pay attention to details and recall them, discriminate among subtly different objects, and engage in focused tasks under time pressure. Though the themes, mechanics, and graphical treatment of the mini-games remain consistent across the game's 12 levels, they progressively increase in complexity. For instance, mini-games that require matching one or two items in early levels require the player to match several items in later levels. Likewise, the player must discriminate among increasingly subtle details and perform more tasks in a shorter amount of time as levels increase. Cookie Monster (a.k.a. Cookie), a character from the long-running, popular television series for preschoolers, *Sesame Street* [33], narrates the game.

Our supplementary material provides screenshots and descriptions of each of the 10 mini-games in CMC; here, we describe three mini-games that were particularly challenging to participants. The first is a go/no-go task [35] styled as a Whac-A-Mole game (*i.e.*, a popular arcade game in which players try to force fake moles back into holes they pop out of by hitting them with a mallet) (Figure 1, Left). Players must respond to some stimuli and ignore others, like tapping "only dogs with hats" as a variety of animals with *and* without hats appear sporadically on screen. This requires the player to differentiate non-target stimuli from target stimuli and suppress the impulse to tap non-target stimuli.

The second mini-game of interest (Figure 1, Middle) is also a no/no-go task: a button-tapping game in which Cookie tells the player to tap either a red or blue button when they see a target stimulus (*e.g.*, a cat with stripes). Like the Whac-A-Mole mini-game, as complexity increases, non-target stimuli (*e.g.*, non-cats or cats without stripes) begin to appear.

Finally, the third mini-game (Figure 1, Right) requires cognitive flexibility and delay of gratification, where "gratification" is the ability to tap. In the earliest level, Cookie tells the player to, "Touch pig!" Later, as complexity increases, Cookie tells the player, "When you see pig, NO touch it!" In the final levels, Cookie first tells the player not to touch the pig but, after some amount of time, tells the player to touch the pig. In all versions, the pig walks across the screen and back, wiggling its tail, shaking its behind, oinking, and blinking. Of the 10 mini-games, this mini-game most closely resembles the Marshmallow Test.

Daniel Tiger's Neighborhood (DT). Families in the active control group played another PBS Kids game entitled *Explore Daniel Tiger's Neighborhood* (DT) [2]. DT provides an open-ended world with embedded mini-games. We selected this app as the active control because it has many characteristics in common with CMC: it was created by the same publisher, has a familiar main character (Daniel Tiger, the protagonist of the popular cartoon series for preschoolers, *Daniel Tiger's Neighborhood*), targets preschoolers, and includes various small games that can be played again and again (*e.g.*, in the bakery, players can collect baked goods and decorate a cake). However, unlike CMC, its explicit goal is not to build EF, and the game design does not demand that the player remember, focus, or discriminate details.

Minnesota Executive Function Scale (MEFS). In addition to engaging with their assigned game, all children also completed the Minnesota Executive Function Scale (MEFS), a comprehensive measure of executive function [14]. MEFS is administered on a tablet and includes a series of increasingly difficult card-sorting tasks. Successful sorting requires remembering a set of rules, attending to target stimuli, and suppressing responses to irrelevant stimuli. MEFS is a standardized instrument that has been used in numerous academic studies (*e.g.*, [47, 51, 59, 66, 78]) and has strong test-retest reliability (ICC = 0.93) [6]. The measure treats EF as a unitary construct and tests working memory, cognitive flexibility, and inhibitory control in conjunction, and it is designed to detect short-term fluctuations in EF. All members of the research team who administered MEFS completed training with the test creators and passed a certification examination.

Procedures. Families participated in a one-hour lab session at our institution, which was audio and video recorded. Before the study began, parents consented to their and their child's participation, and completed a screening survey of parenting style [4] and demographic questions.

During the session, the child first completed the MEFS assessment. After, children in the experimental group played *Cookie Monster's Challenge* for 15 minutes next to their parents. We told parents they could play together with the child as much or as little as they liked and that they were free to help the child if they wanted. The researcher remained in the room but did not participate in gameplay or intervene in any way. After 15 minutes, gameplay stopped, and the researcher administered the MEFS assessment a second time (in both MEFS cases, with the parent on the other side of the room). Children in the control group engaged in all of the same procedures, except they played *Explore Daniel Tiger's Neighborhood* in place of CMC. Children in the experimental *and* the active control group played CMC with their parents for 7-15 minutes in a second follow-up lab session, allowing us to include all participants in the qualitative interaction analysis. After finishing the activities described here, all families completed additional procedures as part of a larger study, which are outside the scope of this work. At the conclusion of the study, each family received US$50 and a tablet computer as a thank you for their participation in the larger study. Families also received a complimentary copy of their assigned game.

Data Analysis

Qualitative Analysis. Drawing on grounded theory [17] and a theoretical framing informed by the related literature, we used video-based interaction analysis [21, 43] to examine all parent-child play sessions with *Cookie Monster's Challenge*. After watching and content logging the recordings, the team met to discuss analytical notes and emergent themes. Using these emergent themes as a guide, we reviewed the content logs, transcribing and coding key interaction sequences that identified patterns that built on our emerging arguments and aligned with related work. Our analytic units focused on interactions between each child and the application, parents and the application, and child-parent or parent-child interactions (orientation, posture, gesture, talk, *etc.*). This analytical process resulted in 31 codes, with 46 sub-codes (*e.g.*, *parent: instruction guidance for child, changing wording of app*; *child: looking to parent for reassurance, physical*). Here, we discuss seven overarching themes, regarding patterns of interaction that are relevant to children's EF and parents' roles in supporting EF. In our findings, our illustrative transcripts integrate verbal and nonverbal behavior of children, parents, and the application itself, and employ select transcription conventions from Jefferson [42].

Quantitative Analysis. The MEFS software automatically calculated scores for each participant. As part of this process, scores were normed against a national dataset. Each child's normed score was a function of both the child's birthdate and the child's performance data. Because of our small N in each group, we conservatively used non-parametric statistical tests to reduce the risk of type II error.

4 RESULTS

Children's Behaviors and Strategies

Reinforcing Directions. One common strategy that children employed to successfully complete EF-related tasks was to reinforce the rules of the mini-games. They did this by verbally repeating directions and physically enacting these rules. For example, during the "no touch pig" mini-game in which the child must resist the temptation to touch a cartoon pig as it walks across the screen (Figure 1, Right), $C13_M^{4y1m}$ crossed his arms and shook his head no, exclaiming aloud, *"When I see him [the pig], I go like this."* In doing so, the child used his physical posture as an inhibition strategy and also announced his awareness of this choice. Similarly, $C15_M^{5y7m}$ said aloud, *"Noooo touch,"* and $C26_M^{5y3m}$ shook his head "no" as the pig walked by. $C10_F^{4y1m}$ exhibited physical and verbal reminders of the task demands during the same mini-game:

Mother:	What did he [Cookie Monster] say?
C10:	((In a Cookie Monster voice)) DON'T TOUCH PIG! ((Points at pig.))
Mother:	((In same voice)) Don't touch pig!
C10:	((Crosses hands in 'x' over the screen; points at pig; crosses hands.)) Don't touch the pig! ((Shakes head; looks at mother; moves mother's hands away from screen.))

While playing the Whac-a-Mole mini-game (Figure 1, Left), in which the child must tap objects with certain properties while simultaneously refraining from tapping objects with other properties, $C25_M^{4y3m}$ yelled, *"NO!"* at the screen each time a non-target stimulus appeared. When Cookie said, *"Tap all cats,"* in the same mini-game, $C33_F^{5y10m}$ repeated, *"That's a cat,"* each time the target stimulus appeared. And $C7_F^{4y7m}$ repeated, *"Just dogs!"* aloud after Cookie instructed to tap only dogs. By externalizing these rules verbally and physically, children appeared to reinforce mini-game instructions as a strategy for completing the tasks.

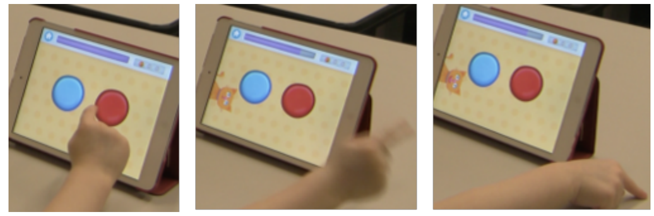

Figure 2: $C30_M^{3y6m}$ hovers above the red button to wait for the target stimulus but moves his finger away from the screen when a non-target stimulus appears.

Physical Positioning to Prepare for Task. Children also physically positioned themselves in ways that would prepare them to successfully complete the mini-games. For instance, in the button-tapping mini-game (Figure 1, Middle), in which the child must press the correct button in response to a target stimulus and ignore distractors, children frequently hovered above the correct button with their index finger, positioning their hand in anticipation. $C1_M^{4y}$ held his finger above the blue button, waiting for a dog to appear, and $C30_M^{3y6m}$ held his finger above the red button as he waited for a cat wearing a hat to appear (Figure 2, left). However, each time a cat without a hat appeared on screen, $C30_M^{3y6m}$ moved his finger away, and returned it to the hover position once this distractor disappeared from the screen (Figure 2). Keeping their hands and fingers close to the screen enabled children to be ready to respond quickly; keeping their hands away from the screen added an extra barrier to touching it, thereby supporting inhibitory control.

During the "no touch pig" task, children also positioned their bodies in ways that would help them refrain from tapping the pig. $C12_M^{4y6m}$ moved his hands away from the iPad and gripped the table, potentially reducing the temptation to touch the wiggling pig. Comparably, after his father repeated the directions to him, $C27_M^{3y5m}$ moved his hands quickly to his face, held them together, and pressed them to his mouth while he waited for the pig to finish walking across the screen. $C4_M^{5y7m}$ briefly put his hands over his eyes as a physical barrier to the tempting pig.

A few children also solicited physical support from their parents to complete this inhibitory control task. For example, $C6_M^{3y7m}$ reached out and held his mother's hand during the entirety of the time the pig was on screen, ultimately kissing her hand when the activity ended. Here, his mother served as both emotional and physical support in keeping him from touching the screen. In an analogous case, $C10^{4y1m}_{F}$ elicited and utilized physical support from her mother by holding onto her mother's hands during the same mini-game.

Figure 3: $C26^{5y3m}_{M}$ employing physical strategies that focus on temptation, i.e., pig he is not supposed to touch. Left: Putting left thumb on screen. Middle: Moving right thumb closer to pig. Right: Finally tapping pig with right thumb.

Intentional Near-Misses. We also observed that children allowed themselves to nearly—but not quite—engage in tempting activities. This appeared to make these tasks more difficult for children, and many children who tempted themselves in this way were unsuccessful in completing the mini-games. For example, children often hovered their fingers above on-screen objects that they knew they were not supposed to touch. Consistently employing temptation strategies that hindered his ability to succeed, $C26^{5y3m}_{M}$ had a difficult time with the "no touch pig" mini-game (Figure 3):

Mother: ((Whispering.)) Don't touch it.
C26: ((Holding tablet with hands. Laughing.))
Mother: Don't touch it this time please. ((Taps her son with index finger.))
C26: ((Laughing, looking at his mother))
Mother: Please. ((Points to table.)) __drool__
C26: ((Still laughing. Looks at screen. Moves left thumb off tablet case so that it is touching the screen, slightly left of the pig.))
Mother: ((Puts hand on her son's forearm.)) Don't touch it. Don't touch the pig, please.
C26: ((Looks up at his mother, looks back at screen. Puts right thumb onto screen to the right of the pig's head.))
Mother: Please don't.
C26: ((Lifts right thumb up and down, barely missing pig. Moves right hand away from screen.))
Mother: Please don't.
C26: ((Laughing. Right thumb hovers at the bottom-right corner of the screen. He puts it down on the screen and slowly slides it up toward the pig.))
Mother: Don't do it.
C26: ((Quickly moves thumb to pig, before the pig goes completely off-screen. Squeals.)) ((Lifts thumb up and down onto pig before it's gone, failing the mini-game. Laughs, tilts head back, looking at his mother.))
Mother: ((Sighs))

Likewise, $C5^{5y8m}_{M}$ practiced tempting strategies that hampered his progress in the "no touch pig" mini-game, leading him to fail nine times in a row. He allowed himself to tap the screen in circles all around the pig, hover his finger over the pig as if he were about to touch it, and tap the screen in the space directly in front of and behind the pig. However, these replacement rewards were insufficient, and he ultimately gave in and touched the pig.

Parents' Behaviors and Strategies

Reinforcing Directions. Parents supported their children by giving them verbal and physical reminders of the task directives. When parents repeated the directions verbatim, they often did so at the start of a mini-game, immediately after Cookie said them aloud for the first time. In the button-tapping mini-game, $C7^{4y7m}_{F}$'s mother repeated Cookie, saying, *"When you see the cat, press the blue button."* In a memory game in which the child had to remember where an animal was located, $C4^{5y7m}_{M}$'s mother directed, *"Open the tent hiding the penguin!"* and $C19^{3y9m}_{M}$'s mother exclaimed, *"Find the penguin! Where's the penguin?"* During the "no touch pig" mini-game, $C10^{4y1m}_{F}$'s mother repeated, *"Don't touch pig wearing hat!"* in a voice that resembled Cookie's. $C33^{5y10m}_{F}$'s mother whispered, *"Don't. . . "* and $C29^{3y5m}_{F}$'s mother said, *"Did you hear what he said? 'When you see the pig, don't touch it.' "*

In another case, $C22^{3y5m}_{F}$'s father repeated the directions (*"Don't touch this pig"*). His daughter asked why, and he answered, *"Because the monster doesn't want you to touch this pig."* After his daughter asked again, he stated, *"I don't know why. It's just what Cookie Monster wants."* Here, C22's father tried to reinforce the goals of the game by repeating Cookie's directions. However, the lack of contextualization or motivation for the goal made it difficult for him to explain why she should employ her inhibitory control skills. Yet, even without a clear guiding purpose underscoring the game's rules, parents chose to repeat and reinforce them. However, as C22's father shows here, without situated motivation from the game, parents had little to work with as they attempted to guide children and solicit their buy-in.

In the same way that parents reminded, repeated, or decomposed the mini-game directions for their children, they also reminded children to focus on the overall game itself, particularly when the children seemed to be distracted or not concentrating on Cookie's words. Parents mainly did this by verbally reminding them that they had to pay attention or listen by saying things like, *"You gotta follow directions!"* (mother of $C26^{5y3m}_{M}$), *"You gotta listen! He's [Cookie Monster's] giving you clues!"* (mother of $C29^{3y5m}_{F}$), and *"Are you watching to see what's in there?"* (mother of $C4^{5y7m}_{M}$).

Parents also physically moved their children's fingers and hands to prevent them from acting before hearing Cookie's directions. For instance, when $C22^{3y5m}_{F}$ moved her hand up to the screen in a memory game before Cookie told her which animal to find, her father brought her hand down toward her lap. In the same mini-game, $C9^{3y2m}_{M}$'s mother pushed her son's hand down to the table and said, *"Wait until he [Cookie Monster] says which one he wants [you to find]"* when C9 had his hands near the screen. $C13^{4y1m}_{M}$'s mother also pushed her son's finger away when he went to tap the red button in the button tapping game before Cookie gave the instructions. In this way, parents consistently reinforced the idea of following game directions. This strategy also mimicked children's strategy of moving their own hands away from the screen when they wanted to resist the temptation to touch it.

Recognition of Difficulty. Parents consistently validated children's struggles to complete these tasks that drew on their EF. For instance, during the "no touch pig" mini-game, the mother of $C24^{5y8m}_{M}$ asked her son, *"It's kind of hard, right?"* (to which he responded, *"Yeah"*). Similarly, the father of $C5^{5y8m}_{M}$ told his son, *"I know it's tempting,"* and the mother of $C4^{5y7m}_{M}$ said, *"This one's tricky."* After $C4^{5y7m}_{M}$ replied, *"Because you want to touch it,"* she went on to say reassuringly, *"I know!"*

A more prolonged interaction occurred between $C13^{4y1m}_{M}$ and his mother after he went back and forth hovering over the pig on-screen. During the first time he played in the session, $C13^{4y1m}_{M}$'s mother asked her son, *"Is it hard not to touch it?"* and he nodded *"yes."* The next time he played the same mini-game, she asked similar questions:

C13:	It's a piiiiggy! I'm not scared of… _____ not touching him.
Mother:	((Looking at son. Nods.)) Is it hard not to touch him?
C13:	((Nods.))
Mother:	Especially when he shakes his rump?
C13:	((Nods. Completes mini-game.))
Mother:	Good job, that was hard. ((High-fives son.))

This example also demonstrates how parents sometimes focused on what made this mini-game even more difficult: the enticing way the pig moves and sounds, ostensibly trying to lure the player into touching it. As shown above, $C13^{4y1m}_{M}$'s mother mentioned how the pig *"shakes his rump."* In another instance, she also told her son, *"He's a cheeky little pig, isn't he?"* and her son called the pig *"mean."* Acknowledging the same action, $C33^{5y10m}_{F}$'s mother told her son, *"He [the pig] shook his little tush at you!"* and $C7^{4y7m}_{F}$'s mother mentioned how the pig is *"doing a little dance too."* These comments and others suggest that parents provided support by empathizing with their child's struggle.

Intervention and Co-Play. Parents also participated in the actual gameplay of *Cookie Monster's Challenge* along a spectrum of involvement, ranging from purposefully not engaging, to providing just-in-time support, to collaboratively sharing activities with their children. For example, during the teeth brushing mini-game, $C34^{3y5m}_{F}$ told her mother to brush the teeth for her; however, her mother replied, *"It's for you,"* instead of stepping in. Similarly, $C35^{3y6m}_{M}$ struggled with the teeth brushing mini-game and asked his mother to help. His mother told him, *"You're doing great… you're doing it so well. A little more on the bottom and you're good,"* and the boy successfully completed the task. In these and other examples, parents intentionally refrained from intervening and encouraged children to persist independently.

However, parents did not always support children's autonomy in this way, and many parents intervened to help their children complete mini-games. For instance, after $C3^{4y}_{F}$ missed the first cat she was supposed to tap in the Whac-A-Mole mini-game, her mother completed the mini-game for her. Similarly, the father of $C22^{3y5m}_{F}$ told his daughter to *"brush the teeth,"* but when she shook her head no, he brushed the monster's teeth for her. In the same vein, parents often physically prevented children from failing by blocking their fingers and hands, interrupting incorrect actions.

This occurred many times in the "no touch pig" mini-game when parents pulled their children's fingers and hands away from the screen and/or told their children not to touch the pig when it seemed the child was unable to exercise self-control. For instance, $C22^{3y5m}_{F}$ brought her hand out toward the pig after Cookie said not to touch it; then her father pulled her hands back and let go. Although $C22^{3y5m}_{F}$'s hands inched forward slowly toward the screen, she did not touch the pig. $C19^{3y9m}_{M}$'s mother said, "Don't touch it!" when he moved his hands to the screen. This led to him to pull his hands back.

In an extreme case, $C26^{5y3m}_{M}$'s mother tried to use negotiating tactics to encourage her son to complete the "no touch pig" mini-game. On his fifth attempt (of six), his mother tried to help him exert inhibitory control physically and verbally:

Mother:	Don't touch.
C26:	((Laughing))

Mother: The pig.
C26: I will!
Mother: Do you love me? ((Grabbing her son's left hand. Lets it go.))
C26: ((Puts out index finger from left hand to touch pig.))
Mother: Nice, please be nice. ((Grabs his left hand.))
C26: ((Gets hand out of her hold and reaches for the pig.))
Mother: Please be nice! ((Pulling his arm back so that he can't touch the pig with his left hand.)) Please ____.
C26: ((Touches pig with his thumb on his right hand, which his mother is not grabbing.)) ((Laughing))
Mother: ____ I'm so done playing this.
C26: ((Laughing))
Mother: Okay.

Finally, in a few rare instances, parents and children collaborated to complete the mini-games. While not the intention of Cookie Monster's Challenge, they appropriated the game to be a two-player experience by either taking turns or otherwise sharing the activities. By the end of the session, $C6^{3y7m}_{M}$ and his mother shared the responsibilities of some of the mini-games, taking turns instructing one another and performing the physical actions. For example, when they played the Whac-A-Mole mini-game, they were required to tap only cats wearing hats. Each time a cat appeared, his mother asked, *"This one?"* and he replied yes or no, tapping when the answer was yes. After he incorrectly tapped a hatless cat, his mother called out, *"Noooo! He didn't have a hat!"* When $C6^{3y7m}_{M}$ got the opportunity to retry the mini-game, he pushed the iPad to his mother, telling her what to do instead:

C6: ((Cat with hat appears)) Tap it!
Mother: ((Taps))
C6: ((Hatless cat appears)) No, don't tap it!
C6: ((Hatless cat appears)) Don't tap that one!
C6: ((Cat with hat appears)) Tap that one!
Mother: ((Taps))
C6: Only the ones with hats!

The Anti-Strategy: Intentionally Undermining Children. Lastly, in a few cases, parents tempted their children and tested their EF skills instead of working to support them. Although $C5^{5y8m}_{M}$ had difficulty with the "no touch pig" mini-game (as explained earlier), he and his father laughed when $C5^{5y8m}_{M}$ continually touched the pig and failed. In the boy's seventh (but not last) consecutive attempt, his father leaned the iPad closer to his son's finger. Similarly, $C2^{5y7m}_{F}$ had no difficulty

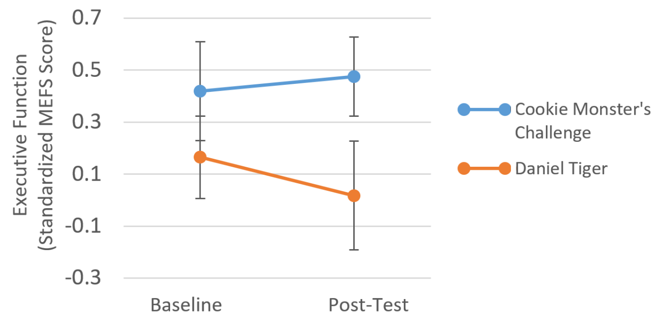

Figure 4: Standardized MEFS scores before and immediately after playing CMC and DT for 15 minutes. Standardized MEFS scores are z-scores, calculated as a function of age.

in completing all of the mini-games, but her father tried to test the limits after Cookie exclaimed not to touch the pig:

Father: ((Arms crossed on table. Shakes head no and wags his finger.))
C2: ((Crosses arms on the table like her father, with her forearms covering her hands.))
Father: ((Reaches out his finger toward the pig on the screen. Whispers.)) Should I touch it?
C2: ((Whispers back)) No.

$C25^{4y3m}_{M}$'s father also challenged his son's understanding of the rules by attempting to his sabotage progress. When Cookie told $C25^{4y3m}_{M}$ to tap only dogs in the Whac-A-Mole mini-game, his father brought his own finger out to tap a penguin (*i.e.*, not a dog), and $C25^{4y3m}_{M}$ yelled out, *"No!"*

Short-Term Changes in Executive Function

We also compared children's performance on the MEFS test immediately before and after their 15-minute game session where they demonstrated the strategies and behaviors described above. To compare baseline performance by group, we ran a Mann-Whitney U test comparing pre-game MEFS performance in the experimental group with pre-game MEFS performance in the active control group. The two groups showed no baseline differences in composite executive function (U = 163, Z = 0.244, SE = 32.82, p = 0.82). To examine game-induced short-term fluctuations in EF, we next compared post-game MEFS performance between the two groups. This second Mann-Whitney U test revealed a marginally significant increase in composite executive function in the experimental group relative to the active control (U = 81.5, Z = -1.97, SE = 27.71, p = 0.049, r = 0.343). Baseline and short-term post-test performance by group is shown in Figure 4.

5 DISCUSSION

We saw that *Cookie Monster's Challenge* set up a context in which children were challenged and exercised their EF, demonstrating it is possible for a popular commercial game to prompt children to draw on known effective mechanisms for managing and extending EF. Given the value of practicing these skills and the accessibility of tablet games, this promise paves the way for broadly disseminating useful training experiences to children at a critical period of EF development.

Further, participants' EF scores on an untrained task (MEFS) increased after 15 minutes of playing CMC with the help of their parents. While the EF of those in the control group slightly decreased after playing DT (see Figure 4), we believe this finding is logical, considering the theory that activities that draw on EF are taxing and lead to weaker EF performance subsequently in the short-term [5, 30]. Thus, the fact that the MEFS scores of those who played CMC increased immediately afterward may imply that playing CMC with parental support could mitigate EF depletion. Still, existing studies of digital EF training have not yet shown improvements in inhibitory control on unpracticed activities [74] or to generate improvements through tablet (rather than computerized) applications [53]. Thus, our finding should be interpreted conservatively, given the small sample and scoped nature of our investigation; however, our qualitative and quantitative analysis together show a pathway by which concrete design decisions may lead to measurable EF gains.

Eliciting EF Strategies from Children

The behaviors and strategies that emerged in our study align with strategies employed in prior delay-of-gratification experiments, particularly those of Mauro and Harris [58] and Mischel and colleagues [61–63]. For example, children gave themselves reminders aloud, saying things like, *"Don't touch the pig,"* as they pushed themselves to succeed. They also utilized specific strategies to reduce the burden this challenge created, including positioning their bodies to maximize their inhibitory control, seeking physical support from parents, and asking parents for help. Prior studies of delay-of-gratification tasks have shown that children repeatedly remind themselves of both the reward they anticipate for waiting and the cost of failing to wait (*e.g.*, not getting a second marshmallow) when they are drawing on their EF. For instance, children make statements to themselves like, "If I wait, I get __, but if I ring the bell, I get __" [63]. Here, when Cookie gave children directions, children not only followed those directions but also verbally reinforced them and physically positioned themselves to maximize their likelihood of compliance.

However, children also employed ineffective strategies: tempting themselves by tapping next to the object of interest or holding their finger above it. These intentional near-misses did not appear to satisfy children, and instead led them to focus on the seductive aspects of the task and often fail. This strategy mirrors strategies that are known to be ineffective in non-digital contexts, such as looking at a treat without touching it [62].

Prior work has shown that at this stage of development, children often lack the metacognitive skills to know to distract themselves or cover their rewards, instead creating "self-defeating dilemmas for themselves" (p. 603) [61]. This is consistent with the behaviors of the preschoolers in our study; those who struggled with the inhibitory control task of not touching the pig frequently exhibited the ineffective strategy of nearly performing the forbidden action, and rarely employed any strategies to distract themselves from temptations. This suggests it might be useful to direct children away from the near-miss strategy and toward a distraction strategy. Such scaffolding might, for example, detect when the user is hovering above or touching spots on the screen near an item of interest. Then, it might prompt the child to think of distractions and fade these suggestions over time.

A Hybrid Approach to Training EF

This investigation allowed us to observe how parents supported (or failed to support) their children in completing these EF tasks. In many ways, this support appeared effective and suggests that *Cookie Monster's Challenge* prompted parents to augment the experience by participating and supporting children. By fostering joint media engagement between parent and child, CMC created an environment where the designed structure of the game combined with the real-time support of the parent to guide the child's behavior–a contrast from existing computer-based trainings, which are typically single-user experiences [40, 56, 74]. Prior work suggests that these combined supports are likely to increase learning gains above and beyond what we should expect from a digital experience alone [70, 73].

However, parents' behaviors were not always consistent or well-aligned with effective strategies. Parents provided varying degrees of support, sometimes stepping in before a child had a chance to attempt the task and sometimes failing to provide support even as the child struggled to the point of giving up. Parents occasionally employed strategies that undermined the child's efforts, such as focusing on tempting aspects of the task. And parents never suggested that children distract themselves or focus elsewhere during moments of temptation, despite the fact that this is known to be one of the most effective ways of succeeding in delay-of-gratification tasks [58, 62, 63, 68]. This suggests that although parents extend the value of the system in important ways, they might do so more effectively with more guidance. It would be useful to explore whether the system can scaffold parents' scaffolding [73] and guide parents toward supporting children productively.

Children's EF and Attention in the Context of Design

Beyond the context of this specific app, this work highlights broader considerations for designing experiences for young children. It may be useful not only here, but in apps for young children generally, to differentiate between successful strategies that are likely to be obvious to adults (*e.g.*, telling children to count the number of arms on a monster before deciding which shirt to give it) and those that are likely to be obscure (*e.g.*, telling children to distract themselves as the pig walks across the screen).

When strategies are obvious, the app may best serve the dyad by staying out of their way and allowing the parent to instinctively provide scaffolding. But when effective strategies are non-obvious, the app might do well to provide more direct support to the parent. For example, other work has shown that embedding on-screen, just-in-time instructions for parents during children's television episodes prompts parents to engage in active mediation and increases children's comprehension of content [32]. Similarly, apps and games might embed scaffolds for parents, such as on-screen text describing effective in-the-moment strategies, akin to the way Sesame Street character Elmo encourages dialogic reading between children and parents or grandparents when reading over video chat [70].

Training apps for EF or other skills might also benefit from increased narrative and contextual relevance. Here, we saw parents sometimes struggle to explain to children why they should feel intrinsically motivated to refrain from touching the pig. And other work has critiqued non-digital tasks like the marshmallow test as contrived (*e.g.*, [26, 27, 45, 60]). Designing experiences in which challenges and rewards are more naturalistic could provide a more meaningful context for engaging in these tasks. For example, a game might present a user with the choice between touching an immature plant now and killing it or waiting until the plant has grown larger (see design concepts in Figure 5).

More generally, the child development, media effects, and child-computer interaction communities have debated the effects of digital media on young children's self-control and attention in a number of contexts [18], and many studies have explored potential pathways between media use in early childhood and reduced attention span and self-control (*e.g.*, [52, 81]). While such pathways may in fact exist, this study adds to the existing body of literature showing that thoughtfully designed content need not erode children's self-control, and in fact, it can even promote it.

"Don't touch the grass; let it grow!" "Water and wait for the plants to grow!" "You waited, and the plants grew into trees! Now you can collect acorns."

Figure 5: Mockups of game mechanics that require contextually relevant inhibitory control, such as waiting to touch sprouting plants until after they have grown.

Limitations and Future Work

This work was conducted primarily with middle-class families, and prior work has shown systematic differences in both EF [37, 45] and parenting styles [12, 36] across socioeconomic divides. This study was also conducted with only 37 families, and a larger, more representative sample would undoubtedly yield new, robust insights.

In the future, research should further investigate how direct physical engagement with a tablet may affect changes in children's EF, in comparison to training suites on non-touch-based platforms. Future work should also consider analytically how children's baseline EF skills may influence how they play and how parents interact with their children (*i.e.*, [50]). Additionally, future research also remains to experimentally evaluate the effects of the behaviors we observed, such as (1) the usefulness of parents' support strategies (*e.g.*, [34]) according to parenting style or (2) the extent to which children's focus on temptation was the cause of, rather than a symptom of, their failure in challenging tasks.

6 CONCLUSION

We found that when playing *Cookie Monster's Challenge* (a tablet game designed to build executive function skills) together with a parent, children used systematic strategies to engage with the game. Some of these strategies align with known mechanisms for successfully drawing on EF, while others undermine it. Similarly, parents engaged in a common set of behaviors as they worked to support their children, using some techniques that are known to improve EF but neglecting to try other known effective strategies. These thematic behaviors suggest mechanisms by which designers might guide child users and the adults who support them toward productive techniques for developing EF. Despite common fears about technology eroding children's attention and self-control, this work suggests that with thoughtful design, it may be possible for digital experiences not only to avoid negative effects on children's attention but also to promote positive ones.

7 SELECTION & PARTICIPATION OF CHILDREN

We followed an informed consent process in accordance with the US Federal Policy for the Protection of Human Subjects (45CFR46.102f), and the University of Washington Institutional Review Board approved all study procedures. We recruited families with children ages 3 to 5 (inclusive) through an institutional database that maintains contact information for local families interested in participating in research. Parents read and signed consent forms before the study, consenting to their own and their child's participation. This form explained that the data collected would be confidential, stored securely, and not stored with the child's name. Participants were randomly assigned a condition, and played together like they would in any other setting. Children and parents could stop at any time they wanted.

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