Improving Child Health through Technology-Supported Active Transport: A Survey of Parent Perspectives

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ABSTRACT

Urban and suburban communities around the world have experienced a significant decrease of children moving around independently relative to just a decade or two ago. Child independent mobility (CIM) refers to that freedom of children to be away from constant direct adult supervision as they move in their communities. CIM has a demonstrable positive impact on a child's physical, social, and emotional health, yet a considerable decline in its prevalence persists. This paper presents a survey of parents' attitudes, experiences, and behaviors related to their school-age children and their (independent) mobility. We posit that pervasive computing technology has the potential to play a role in bolstering CIM and therefore improving the health of children; to that end, the survey also investigates parent's attitudes, experiences, and behaviors relating to their child's use of pervasive computing technologies. Finally, the survey reports on parents responses to hypothetical technology-supported CIM scenarios, using these results to make recommendations related to research in technology-supported CIM.

CCS CONCEPTS

• **Human-centered computing → Mobile devices**; *Ubiquitous and mobile computing design and evaluation methods*; • **Social and professional topics** → *User characteristics*;

KEYWORDS

child independent mobility, mobile devices, user survey, families and technology, health and technology

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1 INTRODUCTION

Child independent mobility (CIM) refers to the freedom and capability of children to move in local neighborhoods without direct adult supervision. Over the last several decades, CIM has dropped dramatically [1, 10], with a demonstrable negative impact on children's health [19] including their physical, social, and emotional well-being [33]. Our long-term goal is to investigate the use of lightweight devices to encourage increased child independent mobility and improve child health across several dimensions without sacrificing a parent's peace of mind or directly exposing a child to a screen.

To assess this potential, we elicited parent perceptions of the relationships of their children to independent mobility, technology, and their integration. Parents place limits on CIM for many reasons, including concerns about traffic [11]; these concerns justify the US Department of Transportation's Safe Routes to School program [36]. In addition, 31% of parents cite "stranger danger" as the primary reason for driving children to school [20]. Statistics showing overall declining crime rates seem to do little to ease parents' fears. In areas where CIM is more accepted, integration and engagement of children with the community directly promotes CIM [3]. Child independence, which is important for social and emotional development, is fostered by a child's *mobility* and neighborhood social interactions [24]. Increased social engagement is not just good for kids; it also fosters parents' comfort with CIM [22]. *Walking buses* and *bicycle trains* [26], in which groups of children are accompanied to school by one or more adults, address several of these concerns: children are socially connected and group movement eases parental concerns [32]. Further, providing limited adult supervision in the neighborhood during children's transit to and from school increases CIM more generally (even outside of school transit hours), as it bolsters both parent and child comfort [27].

While pilot efforts have used pervasive computing devices and e-games to increase home-to-school mobility in elementary age children [4, 5, 35], these have not been founded on a disciplined discovery of parental attitudes and motivations. In this paper, we report the results of a survey on exactly these attitudes; our intent is to relate future efforts to parents' perceptions about children and technology and to directly target parental concerns related to independent mobility of children. When created to directly alleviate these concerns, we expect that pervasive computing technologies can contribute to an increase in CIM and therefore to improving the health of children. In the next section, we examine previous related studies, both with and without technology; we use these existing efforts to motivate our survey. Section 3 describes our survey, its goals, and its distribution. The subsequent sections explore: the basic survey results, including demographics, current child mobility patterns, and current child usage of technology (Section 4); parent feedback about concrete child independent mobility scenarios (Section 5); and our analysis of the implications of these results on hardware and software solutions for enabling increased CIM and improving the health of children (Section 6).

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2 RELATED WORK AND MOTIVATION

A significant amount of work has measured child independent mobility and its benefits, largely through surveys and questionnaires [25, 27, 37]. CIM is directly tied to decreased incidence of obesity [6], improved cardiovascular fitness [13], and myriad other physical, social, and emotional health benefits [9, 30]. Some existing projects take limited advantage of directly sensing children, specifically in measuring mobility, e.g., via accelerometers [18, 21]. There have also been efforts to create targeted interventions to increase child mobility [8, 14], focusing on journeys between home and school. While several studies show the potential for these benefits to extend beyond home-to-school trips, such interventions are limited [18, 27]. Further, one takeaway from several studies is that *independence* increases the amount of time that children are active, yet existing work focuses almost exclusively on increasing movement, rather than independence or a combination of the two.

Our survey aims to determine whether and how we can leverage pervasive computing technology to encourage healthy CIM. The possible technologies are wide ranging: we can sample accelerometers or step counters and apply activity recognition to identify physical activities (e.g., walking, running, climbing, jumping rope) [12]; we can also measure less obvious factors, such as contacts between individuals, social interactions [2], or physiological signals of emotional state, comfort, or stress [29, 34]. The ability to monitor, collect, store, and share this data requires different levels of sophistication in hardware and software, ranging from unobtrusive lightweight sensors to smartphones with complex communication capabilities. For this reason, we believe it is necessary to determine the level of comfort parents have with their children wearing or carrying varying types of devices.

Technologies available to help parents keep a close watch on children are vast. Solutions range from simple and inexpensive proximity detecting devices [23, 31] to more expensive cellular-based trackers that require monthly service contracts [7, 16]. The former only detect disconnection of the device from a parents' smartphone (basically allowing no independent movement); the latter are effectively digital collars that enable parents to directly track children all of the time (thereby allowing a semblance of independent movement without true independence). A further major disadvantage of many of these solutions is their reliance on a third party to maintain information about children. Not only does this have potential privacy implications, but it is inflexible because it limits the parent to application capabilities provided by the device manufacturer. The third party service must be active for monitoring to work (i.e., if there is a transient failure, there is a disruption in the reliability of monitoring). Furthermore, if the manufacturer fails permanently, the required third party service will most likely disappear[1].

Yet, research has demonstrated that child independence and appropriate parental monitoring positively impact child health and behavior [28]. Parents anecdotally express many concerns related to giving children access to technology, and parents constantly balance technology intrusion against a child's engagement with others. The same is true with independence; parents navigate a tightrope of allowing children some freedom while ensuring their safety. Healthy CIM requires a balance of parent comfort and monitoring while empowering children (contributing to increased independence), facilitating parent-child communication, and building trust. Therefore, identifying the details behind parent's concerns related to privacy controls on pervasive computing devices is a significant concern. There is hope; efforts globally have started to promote not only healthy child movement, but also increased agency and independence, even in elementary aged children [15, 17].

[1]Finley, K. (April 2016). Nest's hub shutdown proves you're crazy to buy into the Internet of Things. *Wired (online)*.

Table 1: Relevant Personal and Family Background

D1	What is your age? [numerical]
D2	What is your sex? (Male, Female, Other [specify], Prefer not to answer)
D3	Do you own a smartphone? (Yes, No)
D4	How would you rate your comfort with technology (e.g., computers, smartphones) relative to your peers? (Above average, Average, Below average)
D5	How many children do you have? [numerical]
D6	[For each child] How old is your child in years? [numerical]
D7	[For each child] How does your child usually get to school (choose the most frequently used method)? (Walk without adult, Bike/scooter without adult, Walk/bike/scooter with adult, Car, School bus, Other [specify])[2]
D8	[For each child] Does your child have technology or devices that they wear or carry on a regular basis (e.g., a smartphone, Gizmo, smart watch, activity tracker, etc.)? (Yes, No)
D9	[If Yes] What kind of device does your child have?
D10	[If Yes] What was the age at which your child first had this device? [numerical]

Given this existing work and motivation for change, we performed a survey of parental attitudes and behaviors related to technology-support CIM to answer three research questions:

(RQ1) What are current habits and perceptions of parents and children related to child independence and mobility?

(RQ2) What kinds of high level applications (i.e., software) would support parents and children in increasing levels of CIM?

(RQ3) What hardware device capabilities are suited to supporting these applications and palatable to parents and children?

3 SURVEY DESIGN AND METHODOLOGY

Our survey aimed to gain insights into the current status of CIM in communities and to understand the views of parents related to CIM and technology. Our ultimate goal is to determine opportunities for pervasive computing technologies to increase child mobility and independence and thereby increase child health and well-being. In this section, we present the structure of the survey, the targeted and actual participants, and the data collection methodology.

3.1 The Survey Instrument

Our survey was divided into five sections: (*i*) relevant personal and family background; (*ii*) community profile; (*iii*) technology and children; (*iv*) software for child independent mobility; and (*v*) technology for child independent mobility.

[2]For our participants, "scooter" implies a child's standing kick-scooter rather than a motorized vehicle.

Table 2: Community Background

C11	How would you describe your community? (Urban, Suburban, Rural, Other [specify])
C12	How far do you live from the nearest public park? (Less than 1/2 mile, Between 1/2 to 1 mile, More than 1 mile)
C13	My community is a safe place for children to play outdoors. [5-point Likert scale (agree/disagree)]
C14	My community is a safe place for children to walk or bike. [5-point Likert scale (agree/disagree)]
C15	In my community, automobile traffic is a threat to child safety. [5-point Likert scale (agree/disagree)]
C16	In my community, my child is in danger from adult strangers. [5-point Likert scale (agree/disagree)]
C17	In my community, my child is in danger from other children. [5-point Likert scale (agree/disagree)]
C18	At what age would you allow your child to play in a public space in your neighborhood (e.g., a public park or playground) with one or more friends of the same age but no direct adult supervision? [numerical]
C19	At what age would you allow your child to bike or walk to school alone? [numerical]
C20	At what age would you allow your child to bike or walk to school with a friend or sibling? [numerical]
C21	At what age would you allow your child to bike or walk to a friend's house alone? [numerical]

Relevant personal and family background. The first section asked participants about themselves and their families. We also asked participants to self-assess their comfort with technology relative to their peers. We then asked a series of questions about child(ren): how many children they have, each child's age, how each child gets to school, and whether the child has a mobile device. The questions in this part are shown in Table 1.

Community background. We asked participants about the communities where they live. We asked how far they live from the nearest public park, how far they live from their child's elementary school, and how safe they feel their communities are for various activities. We asked at what ages they would allow their children to engage in a variety of independent mobility activities. The questions for this section are given in Table 2.

Software for Child Independent Mobility. We showed participants two CIM scenarios and a mockup of a mobile app for parent-monitored CIM. For each scenario, the survey asked participants to watch a series of simulations of the scenario "in action" and then answer related questions. These scenarios and the questions are described in more detail below.

Technology and Children. Because there is much anecdotal evidence indicating that parents have significant concerns related to children and technology, including concerns related to the impact of technology on a child's health, we asked about behaviors and motivations related to technology and children. We asked participants how comfortable they felt with their children possessing various devices, and we asked what reasons they used to justify their children having (or not having) devices. The questions for this section of the survey are in Table 3.

Technology Capabilities for CIM. In the final section we asked participants to imagine their child was "allowed to move about your local neighborhood without direct adult supervision." The participant was asked to assume the age of the child to be the participant's response to question **C18**. We then asked participants about capabilities they would want in a device their child wears or carries. The questions for this section are given in Table 4.

Table 3: Technology and Children

Rate your agreement with each of the following [5 point scale]	
T22	I am comfortable with my child carrying a smartphone when he/she is not with me.
T23	I am comfortable with my child carrying a device that can make and receive phone calls and texts to a limited set of contacts.
T24	I am comfortable with my child carrying a device that allows me (or other designated adults) to track the device's position.
How important is each of the following in your decision for your child to **have** a device? [5 point scale]	
T25	It gives me peace of mind.
T26	It makes my child feel safer.
T27	It makes my child happy.
T28	It gives my child independence.
T29	It is more convenient for me.
T30	It is fun.
T31	It can be used to improve my child's health.
How important is each of the following in your decision for your child to **not have** a device? [5 point scale]	
T32	I'm afraid my child will lose or break the device.
T33	It is inconvenient for me and/or my child to remember to charge the battery of the device.
T34	I do not trust the technology to work all the time.
T35	I do not trust the privacy promised by the device, e.g., others may be able to track my child, even if the device claims that they can't..
T36	I am afraid the technology might not be safe for my child.
T37	I think my child would resist wearing or carrying the device.
T38	I'm afraid my child would routinely forget the device.
T39	I'm concerned the device would distract my child.

3.2 The Survey's CIM Scenarios

A significant portion of the survey asked participants a series of questions, given descriptions and animations of two real-world CIM scenarios. The first scenario focused on a child's trip to school while chaperoned on a *walking school bus*; the second scenario entailed children alone (i.e., without an adult) at a neighborhood park.

3.2.1 Scenario 1: Walking School Bus. In the first scenario, the participant was presented the following prompt; a static view of one of the associated animations is shown in Figure 1:

Imagine your child, who is 10[3] years old, participates in a "walking school bus", in which a chaperone "picks up" your child outside your home and walks with your child and a group of other children to school. In the videos that follow, the adult chaperone is depicted by a larger purple circle, your child is depicted with a small green circle, and other children are depicted as small blue circles. Students are registered to the walking school bus in advance; any registered students who are within the large green shaded circle are considered "on the walking bus". In the videos there is also a phone that represents your personal phone where you can receive alerts and messages.

[3]For the age value, we used the participant's response to **C20**.

Table 4: Technology Requirements for CIM

	Rate how important each of the following features is to you in an ideal device for your child to have at any time that he/she is unattended in your local neighborhood. [5 point scale]
R40	The device can make/receive phone calls.
R41	The device can send/receive text messages.
R42	The device has a limited set of contacts for calls and text.
R43	The device can be tracked to within a city block.
R44	My child can use the device to alert me in an emergency.
R45	The device alerts me when my child arrives at or leaves school.
R46	The device is inexpensive.
R47	The device should have a long battery life (days/weeks).
R48	The device can keep track of my child's activity levels (e.g., counting steps or active minutes).
R49	The device allows discretely listening to its surroundings.
R50	The device can allow me to sound a buzzer to alert a nearby adult that my child may need help.
R51	I can speak to my child through a speaker on the device.
R52	Rank the relative importance of the following non-technical characteristics in order from most important to least important; omit any characteristics that do not matter to you. (long battery lifetime, low cost, waterproof/drop-proof/etc., wearable, small size, reliable)

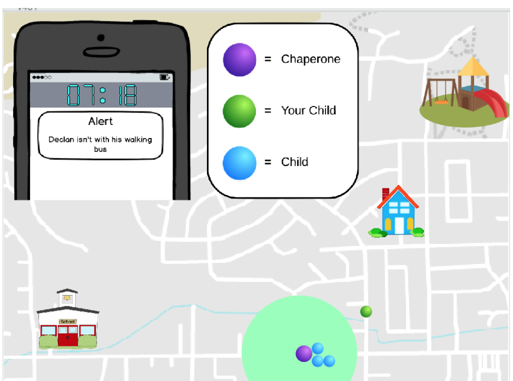

Figure 1: Walking School Bus Scenario. The child in question has "left" the walking school bus (designated by the large green circle), and the parent has received a notification.

We asked participants to consider the following "rule": "Between the hours of 7-8am, my child should either be at my house, on the walking bus, or at school." We showed a video in which the rule was followed and asked whether the respondent believed the rule was followed. We then showed two videos in which the rule was violated, but different notifications were sent (i.e., only to the chaperone or only to the parent). Finally, we asked participants about an additional video in which the rule was not technically violated, but the child walked along a different route than the chaperone.

3.2.2 Scenario 2: Public Park. As a second scenario, we gave the following prompt (a view of the animation is in Figure 2):

Imagine your 12[4] year old is allowed to go to a neighborhood park and play as long as he or she adheres to a rule you have defined.

[4]For the age value, we used the participant's response to **C18**.

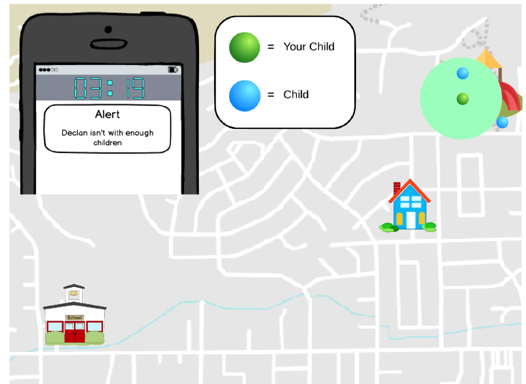

Figure 2: Example of independent children in the park. The child in question is playing with only one other child at the park, which violates the parent's rule.

This "rule" was: "At all times, the child must be on the way to or from the park or at the park playing with at least three other known children." We showed the participants variations of the scenario and asked whether the rule was violated. We also asked participants about their preferences for finding out about rule violations.

Finally, we also asked participants several open-ended questions about the kinds of rules they would themselves write to govern their child's transit to school (whether with an adult, another child, or alone), or independent mobility more generally.

3.3 Survey Distribution

We recruited participants for a web-based survey through social media and parent forums in a large metropolitan area in the United States using local parent-teacher organizations and the municipality's Safe Routes to School program. Participants were required to be a parent of a child enrolled in elementary school (i.e., roughly between the ages of 5 and 11). However, data was collected about *all* of a participants' children, regardless of age. The first 100 participants were offered a $20 gift card. Participants were not required to finish the survey in a single sitting, though the format encouraged completing entire sections together. The first responses were collected in December 2017, and the last response was in the middle of January 2018. We received 90 completed surveys.

3.4 Threats to Validity

Before describing the results, we highlight some threats to validity so the results can be viewed in that context. As with any opt-in survey, participants may self-select based on interest. Most of the respondents live in a single metropolitan area, where demographic similarities may influence results. In particular, the participants reached through our distribution likely live in communities with low levels of poverty and crime. This could affect modes of transport to school, whether children have devices, and parents' concerns about safety. 47% of the respondents classified their neighborhoods as "Urban"; 50% as "Suburban", and 3% as "Rural".

We received more responses from females (87%) than males (13%), likely due to a higher level of activity of mothers in our distribution forums. While there may be variations between mothers and fathers, we assume that, responses within a family would not differ

Figure 3: The percentage of children of each age whose parents report they have some portable device (e.g., smartphone, activity tracker, etc.). The rates of children with devices increase steeply in late elementary and middle school.

greatly. Finally, the questions were presented in the order above. This order could bias responses to later questions (e.g., technology and children) given earlier questions (e.g., scenarios for CIM).

4 THE BASICS: CHILDREN, MOBILITY, AND TECHNOLOGY

In this section, we answer the first research question: *What are current habits and perceptions of parents and children related to child independence and mobility?* Subsequent sections examine the potential for technology to increase CIM and improve child health.

4.1 The Children

We received 90 completed responses, 78 from mothers and 12 from fathers. These represent a total of 195 children. We removed data about 47 children as a result of them being too young (younger than 5) or too old (older than 18). Of the remaining 148 children, 124 were elementary schoolers (i.e., between ages 5-11, inclusive); 17 were middle schoolers (i.e., between ages 12-14, inclusive), and the remaining 7 were high schoolers (i.e., 15 and older). The bias towards younger children is a direct result of our inclusion criteria: respondents were required to have an elementary school aged child.

Of the 148 children, 29.1% of them have their own device of some form. Smart phones were most common; 18.9% of the children have a smartphone. Another 5.4% have an activity tracker (e.g., a Fitbit or vivofit), while another 4.7% have some other device (e.g., a dedicated child tracking device, a connected watch, or an MP3 player). The percentage of children with devices dramatically increases in upper elementary and middle school, as shown in Figure 3.

The participants were nearly evenly split between urban (47%) and suburban (50%), with a small number of rural participants (3%). Figure 4 shows how neighborhood type correlates with distances to the nearest park (left) and elementary school (right)[5]. Figure 5 shows parents' perspectives on safety, sliced by neighborhood type. We show the percentage of respondents that answered either "Strongly agree" or "Somewhat agree" to questions **C13** and **C14**. Our survey respondents overwhelmingly perceive their neighborhoods as safe. As another look at parent perceptions of safety, we ask at what age parents are comfortable with their children performing various activities. Figure 6 shows a violin chart of the kernel density estimate for the *youngest* age at which a parent thought each activity was allowable. The median minimum age for all activities was 10. Figure 7 depicts the same results as a cumulative distribution function for the allowable ages for each activity.

[5]Because the colloquial unit of distance in the United States is the mile, our survey used miles for distances; one mile is equivalent to 1.6 kilometers.

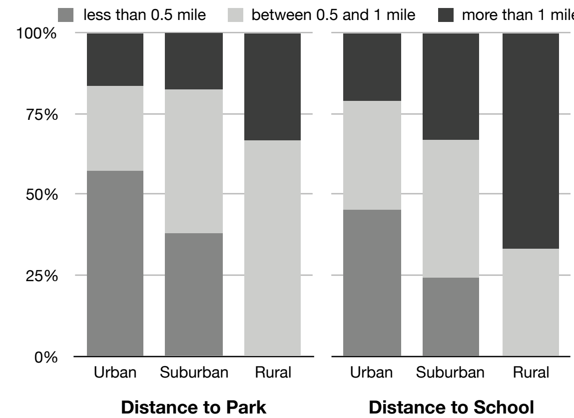

Figure 4: The correlation between types of neighborhoods and distances from the nearest park and to school. Urban children live closer to local parks and elementary schools.

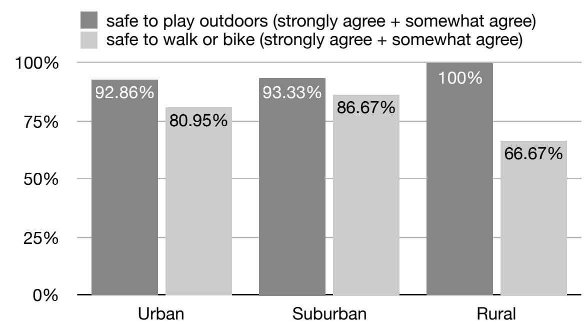

Figure 5: The relationship between parent views on neighborhood safety, given the neighborhood type. Our participants by and large believe their communities are safe places for their children to play outdoors and to walk or bike.

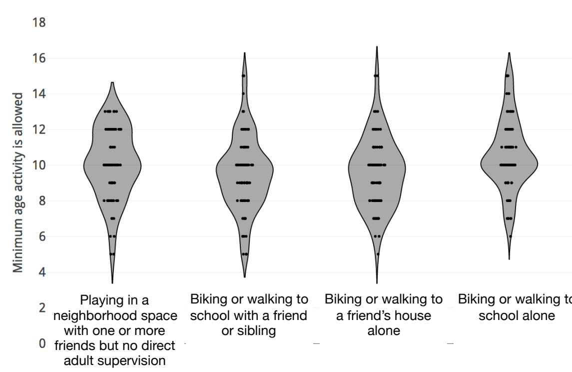

Figure 6: Violin plot showing the kernel density estimate for the youngest acceptable age for CIM activities.

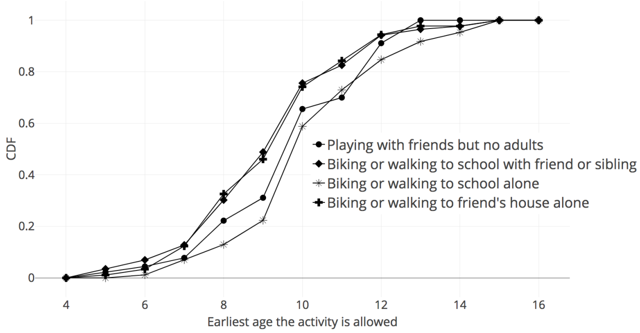

Figure 7: Cumulative Distribution Function for ages for allowable CIM activities.

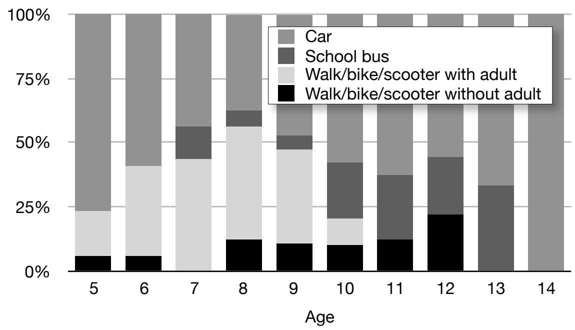

Figure 8: Means of home-to-school transportation for the participants' children, divided by age.

4.2 Transit to School

Significant efforts have focused on increasing active transport to school (e.g., Safe Routes to School programs in the United States and similar efforts in other countries). Yet, anecdotally, many children are still driven to school, resulting in increased traffic, decreased air quality, and less physically mobile children [11, 20]. We asked respondents how their children most commonly transit to school. We focus only on elementary and middle school children (i.e., we removed the 7 high school students), as high schoolers tend to live farther from school and may even drive themselves. We also removed five children who are schooled at home, leaving 136 children. Figure 8 shows the basic home-to-school travel means for these children. A very large percentage of children (more than 55%) arrive at school by car. It is worth taking a deeper look at this data to determine the mobility mechanisms for children at different distances from school or in neighborhoods with different levels of safety.

Figure 8 shows that a large number of children of all ages arrive at school by car and very few are independent in transit to school. Figure 9 slices this data by both distance from school and the parent's perception of whether the neighborhood is safe for children to walk and bike. While children who live closer to school do tend to use non-automobile means of transportation to school more frequently, more than 37% of students who live within a half of a mile (i.e., 800 meters) of school still arrive by car, *even though parents believe the neighborhood is a safe place to walk and bike.*

Dropping children at school by car may often also be a factor of convenience: while the neighborhood is safe, parents do not feel comfortable allowing children to transit to school alone, so parents

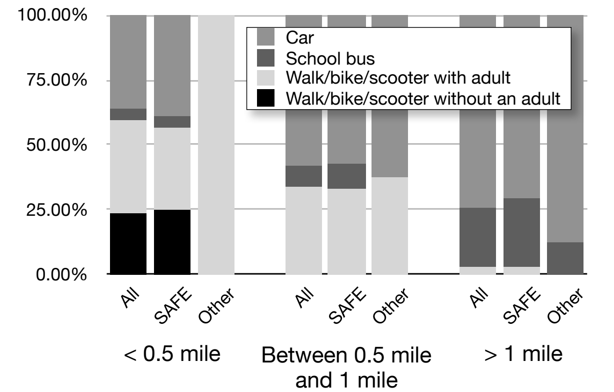

Figure 9: Means of home-to-school transportation, in terms of distance from the elementary school.

drop them off on their own way to work. We take one last look at this same data, accounting for children who are above the age their parents believe is old enough to walk or bike to school alone. Consider, for instance, a 10 year old who arrives at school by car, even though the child's parent believes both that the neighborhood is a safe place for a child to walk and bike and that a child over the age of 8 is old enough to walk or bike to school without an adult. Among our survey respondents, 32 of the children were older than the minimum age at which their parent thought it was safe for a child to walk or bike to school without an adult. Of these children, 13 (40%) were driven to school by car anyway; 11 of these 13 live within one mile (1.6km) of school. It is worth noting that approximately half (6) of these children have younger siblings who did not meet their parent's safety threshold, indicating the child may effectively be "catching a ride" with a younger sibling.

The takeaway is that at least 10% of children could arguably be independently mobile from home to school, yet they are driven to school by car. This motivates our investigation into how technology can be used to increase both child mobility and child independence. To understand the potential of software, we next asked parents about hypothetical technology-supported CIM scenarios.

5 SCENARIOS

We next describe the responses to specific CIM scenarios to answer the question: *What kinds of high level applications (i.e., software) would support parents and children in increasing levels of CIM?*

5.1 Scenario 1: Walking School Bus

In our first scenario, we asked participants whether the following rule was followed in each of a set of the animations: "Between the hours of 7-8am, my child should either be at my house, on the walking bus, or at school." In the first animation, a working walking bus, a chaperone passed by the child's house, "picked up" the child, and they stayed together until they arrived at school[6].

We asked whether the participant thought the animation showed the rule being followed; 96% of the participants responded "Yes". Only one of the four negative responses included a justification, which was "School doesn't start until right before 8am. Not sure if

[6] Video available at https://goo.gl/5GVd5q.

the school is open that early to accept students." This points to a need relating to *timing*; in particular, relative timing may often be more important or useful than absolute timing (e.g., a child should be at school within 15 minutes before school starts; a child should return home within 30 minutes of the end of a school event, etc.).

We next showed participants two cases in which the child started walking with the chaperone, then left the group. In one, a notification was delivered to the parent[7]; in the other, the notification went to the chaperone[8]. We asked participants which they prefer and why. The majority (86%) of participants believed that *both* parties should be notified. Of the 3% of respondents who thought only the parent should receive the notification, none gave a justification for not notifying the chaperone. On the other hand, for the 11% of respondents who indicated the notification should go only to the chaperone, the reasons were unanimously related to the fact that the parent might be unnecessarily alarmed. For instance, many respondents said something like "If I trust the chaperone enough to do this, I should trust that he or she will take care of the problem, and contact me if necessary." or "The chain of custody has shifted from me to the chaperone." Several parents (6%) indicated a concern about too many notifications causing "needless" worry.

Many parents (27%) indicated that the chaperone should be notified immediately, but the parent could be notified later (e.g., out-of-band). In addition, two respondents suggested the chaperone be notified first, but if the child remained "lost" for a specified time (e.g., 2-5 minutes), the parent could then be notified: "The chaperone is able to respond more immediately to the violation and get the child back on track. If I get notified, my first response is to try and notify the chaperone so that they can do just that, but the response would be delayed. If we both got notified immediately, I would be worrying, probably needlessly. I would prefer for the chaperone to have a set amount of time to rectify the violation before I am alerted." These comments indicate a need for flexible notifications.

We showed participants another animation in which the child technically followed the rule (i.e., the child's device stayed "within range" of the chaperone's device), but the child took a different path to school. Figure 10 shows a view of this scenario[9]. We again asked whether the rule was violated. When presented this situation, 81% of respondents believed the rule was violated.

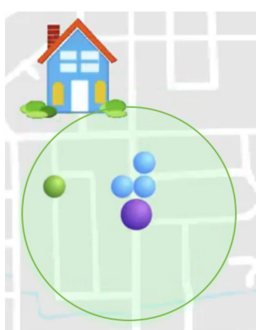

Figure 10: Walking school bus in which a child follows a different path but technicaly stays "on the bus."

The reasoning given indicated that participants thought that taking a different route equated to not being on the walking bus. This indicates that technology used to sense aspects like proximity needs to be carefully tied to application goals (e.g., generic wireless connectivity as a proxy for "on the bus" is insufficient). This is further bolstered by the free responses, such as "If the area of the walking bus allows my child to be on a separate block, the area is too large to be useful." Interestingly, several participants had justifications similar to, "My child should be with the chaperone. That is the rule." The definition given for "on the bus" was "within wireless range of the chaperone's device"; these responses indicate a need for rules to be written in a language that the user understands rather than in terms of the technologies. This is further supported by the fact that several participants observed that, while the letter of the rule was not violated, the spirit was: "Technically no because he was still within the green circle. As a parent, I would not be happy that the child is out of eyesight of the chaperone."

Finally, we asked parents to write their own rules to govern their child's transit from home to school. The answers ranged from highly constrained to permissive:

- (S1) "My child should be visible at all times, in the company of a trusted adult until he arrives at the school and custody of my child is turned over to the school."
- (S2) "Guardian must know where kids are at all times."
- (S3) "My child should arrive at school no more than 15 minutes after leaving the house."
- (S4) "The child must walk directly to school on the shortest route safely possible."
- (S5) "My child should bike straight to school, observe stop signs and other traffic signals and not stop at other destinations."
- (S6) "The child should proceed directly to the destination, unless s/he contacts the parent to let them know of a change in plan."

While some parents of elementary school children are only comfortable with continuous adult supervision, a significant number of participants wrote rules that indicated they were comfortable with their children being unsupervised on the route to school, given the ability to verify that the child followed some constraints. To continuously verify the needed aspects of child mobility, children and their neighborhoods would need to be associated with a variety of sensing and communication devices. We discuss these needs further at the end of this section; first we discuss the second scenario.

5.2 Scenario 2: Public Park

In this scenario, we asked participants about children playing independently at a neighborhood park. We used the following rule to define expected behavior of children: "At all times, the child must be on the way to or from the park or at the park playing with at least 3 other known children." As above, we first showed the participants an animation of children following the rule[10].

We first asked simply whether the rule was followed in the animation. To our surprise, 11% of the survey respondents thought the rule was not followed. We discovered that a lack of clarity in the rule was the primary contributor. For instance, one respondent said, "The child goes to the park by himself and leaves by himself. There is time when he isn't with a friend." All of the rationale associated with "No" responses to this question were similar. This indicates that software that allows parents to write rules defining "safe" behavior of children must use precise language; further, the ability to demonstrate to parents what is and is not acceptable given a rule (e.g., via a behavior simulator) could be quite useful.

[7]Video available at https://goo.gl/FQoaAu
[8]Video available at https://goo.gl/Bn8PWx
[9]Video available at https://goo.gl/vb2JiP.
[10]Video available at https://goo.gl/ekcUHP.

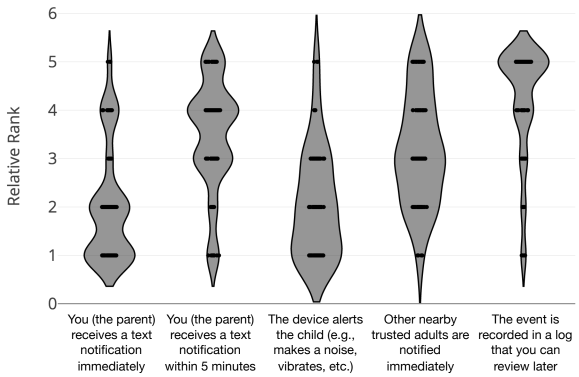

Figure 11: Violin plot for the kernel distance estimates of relative priorities of the five notification options for an independent child in a neighborhood park.

Next we showed an animation in which the child was with only one other child[11]. We asked what notification was preferable: the parent receives a text immediately, the parent receives a text within five minutes, the child is alerted (e.g., by the device vibrating), a nearby trusted adult (e.g., one in the park) is notified, or the event is logged for later review. Participants ranked the five options from highest (1) to lowest (5) priority. Figure 11 shows the kernel density estimate for the rankings. Immediate parent notification and immediately alerting the child were the two highest priority (mean rankings of 2.0 and 2.1, respectively). These were followed by alerting a nearby trusted adult (mean of 3.2), delayed parent notification (mean of 3.5), and logging (mean of 4.2).

When asked to write their own rules constraining CIM to, from, and in a neighborhood park, the responses were again quite diverse:

(P1) "Must be accompanied."
(P2) "Text me when you get to park and text when leaving."
(P3) "Stay on a designated route to and from the park. Do not go home with friends or anywhere else before coming home and discussing it with a parent first."
(P4) "Allow to be at home, on way to/from park, and engaging with at least one other child, with at least 3 other children present."
(P5) "Be back home by 5pm."
(P6) "Don't be on your device!"
(P7) "Go, play and return. That's it."

Supporting these rules would require fine-grained localization, the ability to detect proximity to other children and points of interest, the ability to measure time, and a means of activity recognition.

5.3 Scenario: Free Responses

Given exposure to our CIM scenarios, we asked participants to consider "rules" they might write to check their child's CIM behavior. Seventy-eight of the participants chose to respond to this optional question. Of these 78, two had negative responses:

(N1) "I'm actually not comfortable with tracking children using technology. While the technology is impressive, it's not a way I will personally choose to foster independence."
(N2) "I'd rather spend time with my child, their friends and other parents instead of finding more ways to be disconnected."

[11]Video available at https://goo.gl/rmL6Ae.

Table 5: Technology required for parent's CIM rules

Technology Requirement	Example Parent Rule(s)
fine-grained absolute location (e.g., GPS)	(S2) (S5) (S6) (P2) (F2)
infrastructure beacons (e.g., attached to locations of interest)	(S4) (S5) (P4) (F4) (F5) (F7)
proximity (i.e., relative to other people or points of interest)	(S3) (P4) (F2) (F4) (F5) (F8)
absolute time	(P6)
relative time or duration	(S3) (F1) (F6) (F8)
activity tracking (e.g., via accelerometer)	(S4) (S5) (P6) (P7) (F7)
communication (e.g., texts and notifications) in neighborhood	(S1) (F3)
communication out of neighborhood (e.g., with remote parent)	(S6) (P2)
ability to alert child	(F7)

The remaining 76 responses ranged from variations on our examples to entirely novel ideas. Several rules required the "buddy system", i.e., that multiple children stick together. Many responses included the need to check that the child is at a specific location (e.g., a friend's house, the local market, "inside the park") or NOT at a specific location (e.g., a dangerous intersection or a known unsafe area). These constraints extended to moving children, suggesting that they should stick to known routes, avoid particular routes, or even "use crosswalks". Participants noted the potential to assess the child's activity, requiring that they should not be stationary for extended periods of time or "not in a car" unexpectedly. Several participants also noted that rules depend greatly on a child's age. Some of the more diverse examples included the following:

(F1) "it should take no longer than x minutes for child to return from playground/school"
(F2) "ability to set short term, one-time targets, like the store or a friends house"
(F3) "coordination with other children to encourage social interaction and community among parents and kids"
(F4) "way-point style routes... e.g. after school he should go to piano practice, then home"

Some specific rules the participants wrote included:

(F5) "At all times, the child must be within a half mile of the house and in an area safe for pedestrians."
(F6) "Once a week, my child may go to the arcade for an hour."
(F7) "When my kid approaches an intersection without a crossing signal/crossing guard, he/she should pause to look both ways (buzz my kid if he/she is not showing signs of slowing down when approaching intersection, log for my review)"
(F8) "At all times, the child must be within a 1-mile radius of the house, within the neighborhood (defined by known children), with dog (who has a mobile device), and return within 45 min."

Combining the needs of of all of the rules created by the participants, we can generate a list of technology needs to support checking rules *in situ*; this list is given in Table 5.

6 TECHNOLOGY IMPLICATIONS: HARDWARE AND SOFTWARE

In this section, we consider the technology needs from the previous section in the context of parents' preferences related to their children and devices; we answer our final research question: *What*

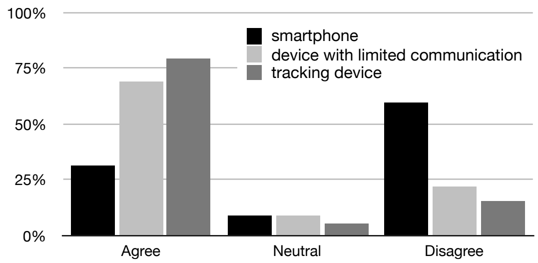

Figure 12: Participants' comfort with their children wearing or carrying devices with varying capabilities.

hardware device capabilities are suited to supporting these applications and palatable to parents and children?

Examining the requirements in Table 5, it is obvious that giving every child a smartphone would allow implementation of all of all the conceived-of rules. To understand whether this is a viable solution, our survey asked about the participants' agreement with the statement "I am comfortable with my child carrying or wearing a [device] when he/she is not with me", where [device] was, in turn, one of "smartphone", "a simple device that can make and receive phone calls and texts to a limited set of contacts", and "a simple device that allows me (or other designated adults) to track the device's position". Figure 12 combines the "Strongly agree" and "Somewhat agree" responses into "Agree" and "Strongly disagree" and "Somewhat disagree" into "Disagree". A significant percentage of participants (60%) are not comfortable with their elementary-aged child carrying a smartphone on a regular basis, though the vast majority were comfortable with their child having some sort of device—more than 85% of respondents answered "Strongly agree" or "Somewhat agree" to at least one of the three device types.

Given the high-level rules parents would like to enforce, it is not surprising that tracking capability is high on the list of parent's expected features. We asked a series of additional questions to investigate what other features (both functional and non-functional) are important to parents in devices for their independently mobile children. We first asked participants about their high level motivations for and against their children having devices. The participants' ratings of the importance of these reasons are shown in Figure 13.

The strongest opinions are related to parent peace of mind, a child's feeling of safety, and child independence, all of which are reasons that more than 50% of respondents gave in favor of their child having a device. None of the reasons against garnered more than 50% support, though privacy and the potential for distraction rated quite highly. These concerns were also echoed in a few of the written responses to the previous section of the survey (see, for instance, response (P6): "Don't be on your device!"). More broadly, Figure 13 shows stronger support among our survey respondents in favor of children having some form of device rather than against.

Finally, we asked participants to envision an ideal device to integrate with software to support their child's independent mobility. We asked participants to consider a set of attributes and their perceived level of importance of those attributes being present in a device for their child. Figure 14 shows the results. Emergency notification and tracking were clear leaders in this rating, but also notice that battery life and cost factors were rated with a higher importance than the ability to make and receive phone calls.

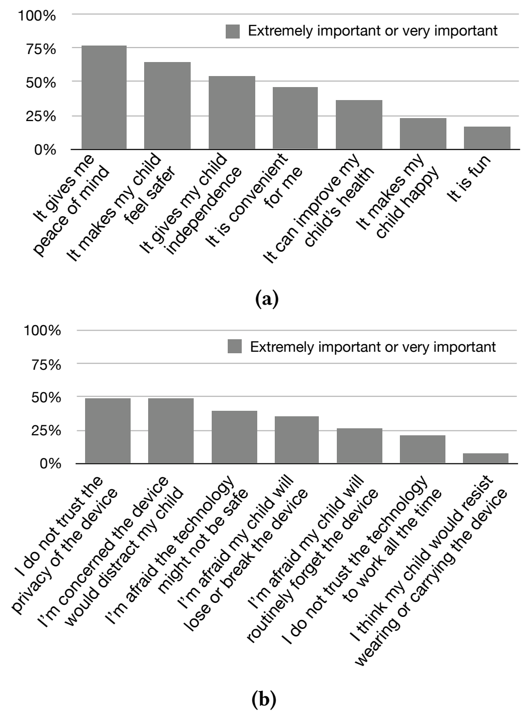

Figure 13: Reasons parents have FOR (a) and AGAINST (b) their children having devices; the figure shows the sum of the responses for which participants rated the attribute Extremely important or Very important.

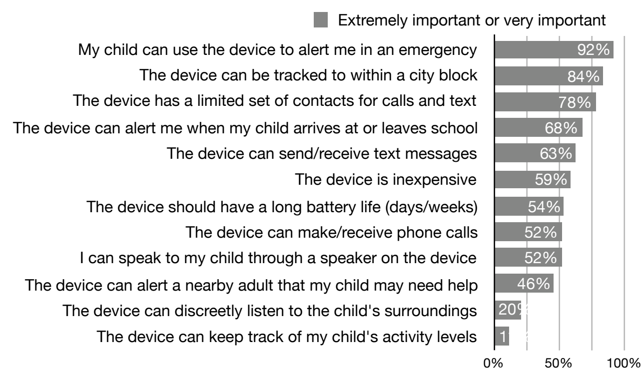

Figure 14: Device attributes that survey participants rated as Extremely important or Very important.

While most parents are reasonably comfortable with their children having *some* device, most are *not* comfortable with that device being a smartphone. The key implication is that there is a need for innovation in devices and, in turn, software for those devices, to engage parents and independently mobile children. These devices will not be off-the-shelf smartphones but will rather directly consider the needs of children and their parents, including both functional capabilities (e.g., tracking and proximity detection) and nonfunctional ones (e.g., privacy, energy efficiency, and cost). The "right" software similarly does not exist yet and must consider community integration (e.g., via proximity beacons on local points of interest), a parent's need for visibility into a child's activities and safety, and the need for the child to be more independent and mobile.

Finally, this initial survey looked only at parent perceptions of CIM. These solutions must also be designed with the children in mind, so additional investigations into devices and applications that would encourage and motivate a child are also needed.

7 CONCLUSIONS

The literature points to an alarming decline in child independence and mobility; lower rates of CIM are directly linked to negative impacts on physical, social, and emotional health and development. These trends and their impacts have been well-documented, and interventions have also been explored. However, decades of knowledge about the trend have done little to impact it. However, emerging pervasive computing technologies offer a novel opportunity that has not yet been explored. The work in this paper sought to understand the potential for pervasive computing technologies to improve children's physical, social, and emotional health by promoting safe CIM. We framed our approach around three research questions and used an in depth parent survey to elicit results.

A significant number of children are not independently mobile, even though their parents feel they are old enough and that their neighborhoods are safe enough. This indicates the potential for an intervention targeting both parents and children. To uncover what kinds of high-level application software is most useful, we presented a set of mocked real-world scenarios. Because we targeted elementary-aged children, we favor approaches that keep technology as transparent as possible. That is, we biased our example applications with an assumption that we do not want children's faces buried in screens. We found that parents are open to creating "rules" that could be automatically checked by some underlying computational system and that parents have wide-ranging ideas of the types of constraints they would place on their children, given the ability to check these constraints. Finally, we sought to "close-the-loop" to determine whether parents' desired rules could be realized using devices that are both feasible and palatable given parents' perceptions of technology use by their children. We found that giving children smartphones is far from viable, and our results paint a picture of what capabilities an ideal device might have.

In summary, the results of our survey indicate that, in our survey cohort, CIM is, indeed, surprisingly low and much lower than it could be, given parents' perceptions of their children, neighborhoods, and safety. Further, there is significant space for pervasive computing technology to help reverse the decline in CIM, but there is also a very real need for innovation in both devices for children and software applications to support interaction and awareness among children, their parents, and their communities.

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