



Reducing distracted pedestrian behavior using Bluetooth beacon technology: A crossover trial

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ABSTRACT

Background: The number of fatal pedestrian injuries in the United States has steadily increased over the past decade. Multiple factors likely contribute to this trend, but the growth of pedestrians distracted by mobile devices is widely hypothesized to play a major role. Existing strategies to reduce distracted pedestrian behavior are few and mostly ineffective. The present study evaluated StreetBit, a mostly-passive primary prevention program to reduce distracted pedestrian behavior by alerting distracted pedestrians directly on their smartphone when they approach an intersection, reminding them to attend to traffic as they crossed.

Methods: 385 individuals who regularly crossed a target street corner at an urban university downloaded StreetBit on their phones and participated in a crossover design study whereby the app was inactive for 3 weeks (baseline behavior phase), actively provided alerts for 3 weeks (intervention phase), and then was inactive again for 4 weeks (post-intervention phase). User distraction while crossing the intersection was collected electronically for a total of 34,923 street-crossing events throughout the 10-week study.

Results: In crude (unadjusted) models, participant distraction was similar across all phases of the research; this result was maintained after adjusting for potential covariates as well as after conducting a sensitivity analysis limited to data from only week 3 of each study intervention phase. In a model stratified by phone/warning type and baseline distraction rates, Android phone users who received a warning that blocked the full screen and had a high baseline distraction rate ($\geq 75\%$ distracted crossings) had a 64% decreased odds of distraction during the alert phase (OR 0.36, 95% CI 0.25–0.51) and a 52% decreased odds of distraction during the post-intervention phase (OR 0.48, 95% CI 0.25–0.94). Users reported positive impressions about the StreetBit app in a post-intervention survey.

Discussion: StreetBit, an innovative app designed to prevent distracted pedestrian behavior through a mostly-passive primary prevention strategy relying on intrusive reminders, proved effective among smartphone users who received a warning blocking the full screen and who were frequently distracted at baseline, but not among other users. The results appear to reflect the confluence of two influencing factors. First, due to software development limitations, visually-distracted Android users received a highly intrusive app warning that blocked their smartphone screen whereas iOS users received a less intrusive banner notification blocking a small upper portion of the screen. Second, most users were curious to see if the app was functioning properly, creating artificially-inflated estimates of distraction as users purposefully watched their phones when crossing. Thus, our results indicate promise for StreetBit as an effective intervention and warrant continued software development and empirical testing.

1. Introduction

The number of fatal pedestrian injuries in the United States has steadily increased over the past decade from 4,109 (crude rate 1.34) in 2009 to 6,681 (crude rate 2.04) in 2019, the latest data available (CDC,

2021). A variety of factors likely contribute to this alarming public health trend, but the growth of pedestrians distracted by mobile devices is widely hypothesized to play a major role (Fischer, 2015; Ralph and Girardeau, 2020; Retting and Rothenberg, 2015). Pew Research data suggest US mobile phone use has increased quickly and steadily over the

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past 15 years (<https://www.pewresearch.org/internet/fact-sheet/mobile/>), and well over 90% of American adults under age 50 currently own a smartphone.

A substantial body of research confirms that distracted pedestrian behavior is widespread and that distracted pedestrians take greater risks when crossing the street than undistracted pedestrians (Ralph and Girardeau, 2020; Simmons et al., 2020; Stavrinou et al., 2018). Cognitive science research offers a theoretical basis for the risk-taking that occurs, as attempts to multitask by completing two or more cognitively complex tasks simultaneously are widely documented to be attempted even though they cause attention to and performance on the tasks to decrease (Kahneman, 1973). Use of mobile devices, whether through phone conversations, texting, or internet browsing, requires cognitive load and therefore may reduce an individual's ability to focus cognitive effort on the street-crossing task (Stavrinou et al., 2018). Beyond cognitive distraction, some types of mobile phone distraction (texting, internet browsing) diminish visual attention on the street environment and others (listening to music, phone conversation) diminish aural attention (Stavrinou et al., 2018).

Despite the strong evidence that distracted pedestrian behavior is widespread and impacts safety, there are surprisingly few published reports evaluating interventions to reduce distracted pedestrian engagement. Attempts to warn pedestrians about distracted pedestrian behavior with stenciled warnings at the curb-cut are generally unsuccessful in real-world tests, especially over time (Barin et al., 2018; Kim et al., 2021; Violano et al., 2015), although laboratory-based experiments demonstrate some potential for using such systems and indicate the need for further research (e.g., Larue et al., 2020). Similar warnings with lighted and audio signals at railroad crossings yield encouraging results (Larue et al., 2021), with those individuals showing higher levels of behavioral intention to use warning signals demonstrating the highest level of behavior change (Larue and Watling, 2021).

A program designed to offer experiential learning about the risk of texting while immersed in a virtual pedestrian environment, plus widespread social and traditional media on an urban college campus, yielded some change in self-reported behavior among a subsample exposed to the experiential simulation, but no changes in community-wide observed behaviors (Schwebel et al., 2017). Prototypes of a comprehensive smartphone-based warning device have been developed and subject to initial testing, but rely on relatively imprecise GPS-tracking and, in some cases, downloading of an app by drivers as well as pedestrians to function (Won et al., 2020). Prototypes to detect traffic noises and warn pedestrians have also been tested but will require substantial refinement and evaluation prior to broad implementation (Xia et al., 2019). Finally, policymaking has been attempted in a few jurisdictions, but not subject to rigorous empirical investigation. Novel, theory-driven and scalable strategies are needed; the present study represents that sort of intervention.

Specifically, the present study was designed to implement and evaluate a mostly-passive intervention to reduce distracted pedestrian behavior. Passive interventions are theorized to be highly effective in changing health behavior because they require less active engagement by the individual; users passively receive behavior change mechanisms. Passive interventions have demonstrated efficacy in other domains of safety and injury prevention (Gielen and Sleet, 2003, 2006).

To deliver the intervention, Bluetooth beacons were placed in multiple locations on a busy street corner to send unidirectional signals to study participants' smartphones. The smartphones were loaded with StreetBit, an app that functioned in the background and was triggered only when the user approached the street corner to cross the street. If the phone was in use at that timepoint, the user received an alert, reminding them to cross the street undistracted. Alerts were both visual (broadcast on the screen if users were looking at their phone) and aural (broadcast orally if users were listening to music or engaged in a phone conversation). Consistent with a passive intervention, they were intrusive and salient but dismissed quickly by users through a simple

acknowledgment. The system functioned on both Android and iOS platforms, although with differences across platforms due to software permissions. The mostly-passive nature of the intervention was designed to create lasting behavior change by altering individual habits without requiring substantial action or behavior by the individual on a consistent basis.

Efficacy of StreetBit was tested using a crossover research design with three phases; we hypothesized distracted pedestrian behavior would be reduced during the intervention phase of the design compared to baseline, and that behavior changes would be largely maintained during a no-alert retention phase following the intervention phase.

2. Methods

2.1. Participants

We recruited 437 individuals ages 17 and over who reported that they crossed the target street corner regularly (at least four times/week; most crossed the intersection considerably more often), were willing to install the StreetBit app on their smartphone, and could communicate fluently in English. 385 of the 437 participants (88%) actively engaged in the study by leaving the StreetBit app installed on their phone and crossing the target intersection with some frequency.

The 385 individuals with active study participation were an average of 25 years old (SD = 9.6), 67% female, and mostly of White (42.1%) or African-American/Black race (27.1%). They owned either iOS (78.2%) or Android (21.8%) smartphones (See Table 1). There was no statistical difference for these characteristics between those who did and did not actively participate in the study. Most participants were University of Alabama at Birmingham (UAB) students or employees, but university affiliation was not required and the street corner was on city rather than university land. Participants provided informed consent to participate and were reimbursed for their time (\$25 upon enrollment and \$25 upon completion). The protocol was approved by the Institutional Review Board at UAB.

2.2. Research site

The research occurred at the corner of 14th Street South and University Boulevard, a busy intersection near the UAB campus in Birmingham, Alabama. UAB is an urban university where students, staff, and faculty cross streets frequently. In recent research with 138 UAB undergraduates, students self-reported walking an average of 10.63 blocks per day (Schwebel, unpublished data). Traffic at the intersection

Table 1

Characteristics of 437 subjects by whether they actively participated in the study after enrollment (i.e., had at least one crossing).

	At least one crossing (n = 385)	No crossings (n = 52)	p-value ^a
Mean age, years (SD)	24.9 (9.6)	27.4 (9.5)	0.0889
Gender (%)			
Female	256 (67.0)	31 (63.3)	0.6003
Male	126 (33.0)	18 (36.7)	
Race/Ethnicity (%)			
African American/Black	103 (27.1)	14 (29.2)	0.8046
Asian/Pacific Islander	70 (18.4)	9 (18.8)	
Hispanic	22 (6.8)	2 (4.2)	
Native American/American Indian/Alaskan Native	3 (0.8)	0 (0.0)	
White	160 (42.1)	18 (37.5)	
Other	22 (5.8)	5 (10.4)	
Phone operating system (%)			
Android	84 (21.8)	–	–
iOS	301 (78.2)	–	

^a Estimated from a chi-square and *t*-test for categorical and continuous variables, respectively.

was recently reported to be 69 pedestrians/hour and 856 vehicles/hour (Schwebel et al., 2017).

2.3. Overview of StreetBit

The StreetBit intervention we tested in this research relies on a simple but elegant strategy: distracted pedestrians are warned directly on the distracting device when they approach a potentially-dangerous street corner. Thus, users who are looking at their smartphone receive a visual alert reminding them to pay attention to traffic as they approach the corner to cross the street. Users who are listening to either music or a telephone conversation on their smartphone as they approach the corner are alerted aurally to pay attention. In all cases, users receive the alert approximately 8 m from the street corner and can click a button to remove the alert. It appears just once for each crossing of the intersection (including instances when the pedestrian crosses both streets to reach the caddy-corner side of the intersection). From a health behavior intervention perspective, we consider StreetBit as a mostly passive primary prevention strategy. It works to prevent a risky health behavior (distracted pedestrian crossings) through the intrusive strategy of blocking the smartphone screen, is passive in that the user has no active part in the intervention once the app is downloaded (although the act of putting the distracting device aside while crossing must be engaged in actively), and it is primary in that it designed to prevent injuries before they occur. Our foremost goal was long-term behavior change: we sought to change user behavior via the alerts so that they developed a habit of putting their phones away before they reached an intersection.

2.4. General protocol

Participants were recruited to the study through a range of social and traditional media efforts on campus, word-of-mouth, and targeted recruitment in classrooms and orientation sessions. Following consenting, participants completed a brief questionnaire (detailed below) and then downloaded the StreetBit app onto their smartphone. The app remained active on the participant's phone for the subsequent 10 weeks (the full Fall 2019 academic semester), following a standardized crossover design schedule of three phases: (a) 3 weeks of no alerts (baseline phase; typical behavior), (b) 3 weeks of StreetBit providing alerts at the target intersection (intervention phase), and then (c) 4 weeks of no alerts (post-intervention phase; assess retention of learned behaviors). Following the 10-week period, participants completed a follow-up questionnaire remotely and received compensation for their time.

2.5. StreetBit: Technical specifications

Technical details concerning StreetBit programming and functioning are available elsewhere (Hasan et al., 2020, 2021). Briefly, the StreetBit app relies on two pieces of hardware, Bluetooth beacons and the user's smartphone. Powered by batteries, Bluetooth beacons are one-way wireless broadcast communication devices that function on short range to transmit low-energy Bluetooth signals. Any Bluetooth-enabled device – which includes all standard smartphones – can detect signals from the beacons to identify the device and the distance from where the signal has come from.

We developed both Android and iOS versions of the StreetBit app. Both apps run passively in the background, activating only when they are at close range to the accompanying Bluetooth beacons. The Android and iOS versions of the app receive signals similarly from the beacons, but due to restrictions on the operating systems they provide alerts to users in different ways. When a pedestrian approaches the intersection with the directionality and speed that indicates they intend to cross the street and while distracted visually, the Android application displays the visual warning through a dialogue box that overlies a large portion of all currently-active apps (full-screen warning; see Fig. 1). To continue using the phone, the user must click the “cancel” button acknowledging

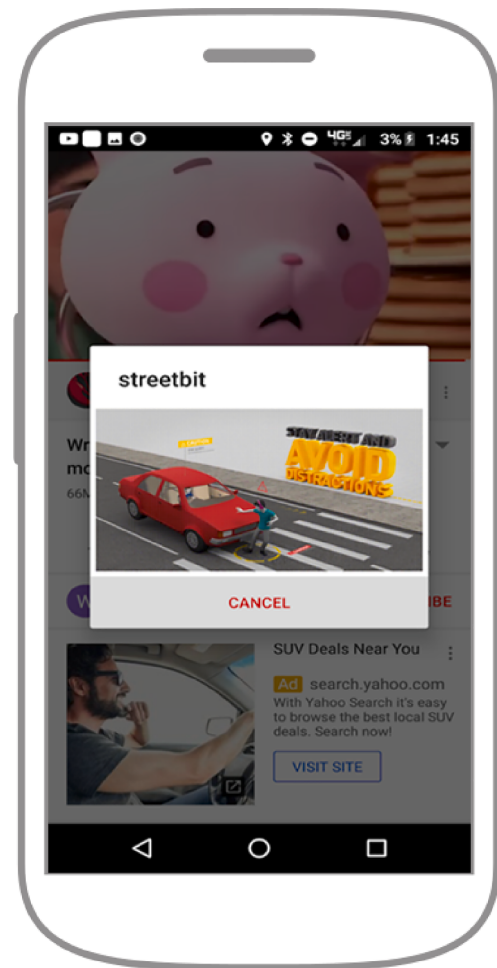


Fig. 1. StreetBit warning on Android platform. Note that the warning fully blocks the center of the phone's screen.

receipt of the warning. The iOS application functions similarly, but instead of a full-screen warning it displays a banner notification that blocks only a small portion of the upper part of the phone's screen (banner warning; see Fig. 2). If the notification is clicked, it triggers a warning dialogue; otherwise the notification serves as the only reminder to users and disappears after a few seconds.

The two apps work similarly for audio alerts, which overlie any music or voice being played or listened to on the phone. A professional with a male voice recorded the audio warning, “Watch out. Look and listen for traffic as you cross the street,” which was played at the system's current volume level.

As shown in Fig. 3, beacons were placed on lampposts or street signs at each corner of the intersection, as well as on stakes hidden in shrubbery in the median of University Blvd., the broader cross-street. Beacons further from the corner served as “helper beacons” that supported the “main beacons”, which were located directly on each of the four street corners. The helper beacons activated the app in a radius of about 20 m around the intersection, preparing the app to communicate with main beacons, which communicated with smartphones to issue alerts based on the user's speed and angle of approach about 8 m from the street corner. Information from triangulation of the beacons indicated whether the user was intending to cross the street rather than turn right or left at the intersection without crossing. Due to the layout of the campus geography and the popular campus destinations at the target intersection, over 90% of interactions with the beacons were related to pedestrians crossing one or both streets rather than turning right or left at the intersection without crossing a street. Pilot testing among our

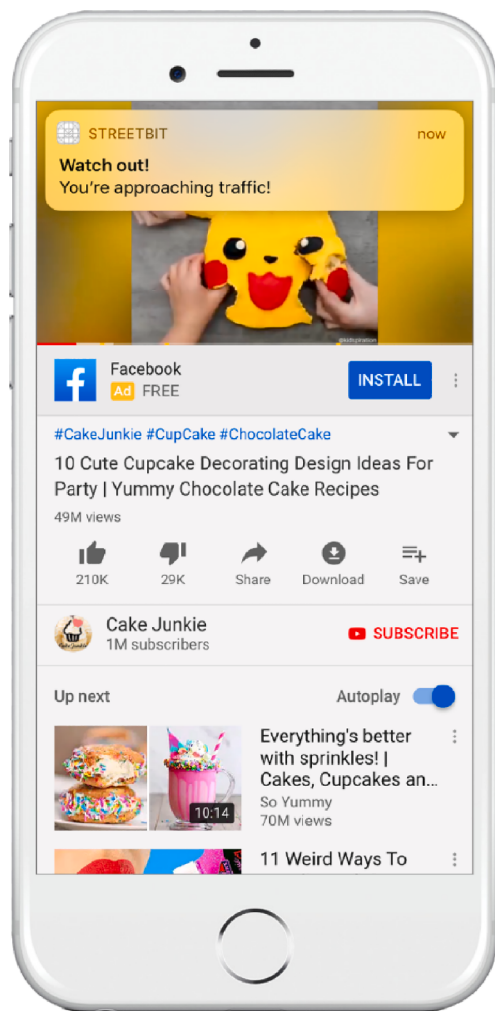


Fig. 2. StreetBit warning on iOS platform. Note that the banner warning blocks only a small portion of the original material, at the top of the phone's screen.

internal team indicated extremely high reliability of the app's functioning, as detailed elsewhere (Hasan et al., 2020).

2.6. Measures

Participants completed a brief self-report demographic questionnaire at baseline and a brief questionnaire concerning perceptions about StreetBit at the end of the study. All other measures were collected electronically throughout the full trial, including during phases when alerts were not actively produced. We measured participants' distraction as they crossed the intersection through a three-step process, with data collected at least once per second whenever the smartphone was located within the beacons' radii (that is, within 20 m of the intersection).

For data analysis purposes, behavior from the first data collection instant when the participant entered the street was used, and that measurement continued until the last instant before they reached a sidewalk. User location was calculated based on triangulation of signals from the multiple beacons placed on each corner of the intersection. Assessment of user distraction was conducted through three steps. First, the StreetBit app checked if the pedestrian's phone screen was on or off. If off for the entire street crossing, the user was recorded to be undistracted. Second, if the screen was on, StreetBit checked the audio manager status to identify whether the user was talking, listening to music, or watching a video. If the user was talking, listening to music, or watching a video at any point during the crossing, distraction was

recorded.

Third, StreetBit measured the phone's orientation and position. This was conducted through a complex algorithm that used 10 independent data points each second from the phone's accelerometer and gyroscope sensor to identify whether the phone was in an in-use position. Each datapoint was then converted and merged to detect the angle at which the user was holding the phone. The angle identified an in-use position using the K-Nearest Neighbor (kNN) clustering algorithm, which was applied during data analysis. Specifically, the kNN algorithm used a coordinate system aligned with the pedestrian's body axes to detect x-y-z coordinates defined as: (a) x-axis (roll), aligned with the user's body; y-axis (pitch), aligned to both the X and Z axes; and z-axis (yaw), aligned with gravity when the smartphone is flat on a table. StreetBit used these measures to function like a right-handed coordinate system. If the user changed the phone orientation from flat to vertical in the same direction with the clock, then the pitch value increased from 0 to 90 degrees. The value would be negative if the direction was opposite to the clock. By merging these data, we were able to identify if the pedestrian was carrying their phone at an angle that would facilitate visual viewing while walking across the street (in which case distraction was recorded) or not (that is, the phone was carried at an angle inconsistent with visual distraction).

Note that simultaneous aural and visual distraction was possible (for example, for someone watching an online video with dialogue, or for someone listening to music and also texting). The two distraction modalities were measured independently, and if both were present, then both warning messages were delivered.

2.7. Data analysis

Baseline characteristics were examined descriptively, and then primary analyses were conducted using general estimating equation logistic regressions to account for the dependence of crossing events within participants. The models estimated odds ratios (ORs) and associated 95% confidence intervals (CIs) for the association between the study intervention phase (i.e., pre-intervention, intervention, and post-intervention phases) and distraction. Models were adjusted for age, race, distraction prevalence during the pre-intervention phase, and type of warning (i.e., full-screen on Android or banner on iOS). Given potential for user curiosity at the start of each phase creating changed behavior, a sensitivity analysis was conducted to evaluate for robustness of the findings by comparing behavior from only the third week of each phase rather than behavior across the full phase (Thabane et al., 2013).

Next, since anecdotal evidence suggested users were curious about how the alert functioned and therefore used their phone purposely as they approached the intersection, creating artificial datapoints, we conducted analyses stratified by extent of baseline distraction. Finally, we recognized the Android and iOS platforms offered very different alerts to pedestrians, so analyses were conducted to examine whether effect modification by both the prevalence of pre-intervention distraction and type of warning was meaningful by including a three-way interaction of intervention phase, distraction category, and warning type in an age- and race-adjusted model examining stratified ORs.

Finally, descriptive data from the brief questionnaire participants completed at the end of the study concerning perceptions about the StreetBit app were considered, and comparisons by type of phone operating/warning system (i.e., Android full-screen warning system vs. iOS banner warning system) were made using a chi-square test.

3. Results

Across the entire study, distraction occurred in 74.3% of all crossings. In crude (unadjusted) models using all weeks of the study phase, compared to the pre-intervention phase the likelihood of distraction was no different for either the intervention alert (OR 1.06, 95% CI 0.88–1.27) or the post-intervention (OR 1.00, 95% CI 0.82–1.22) phase

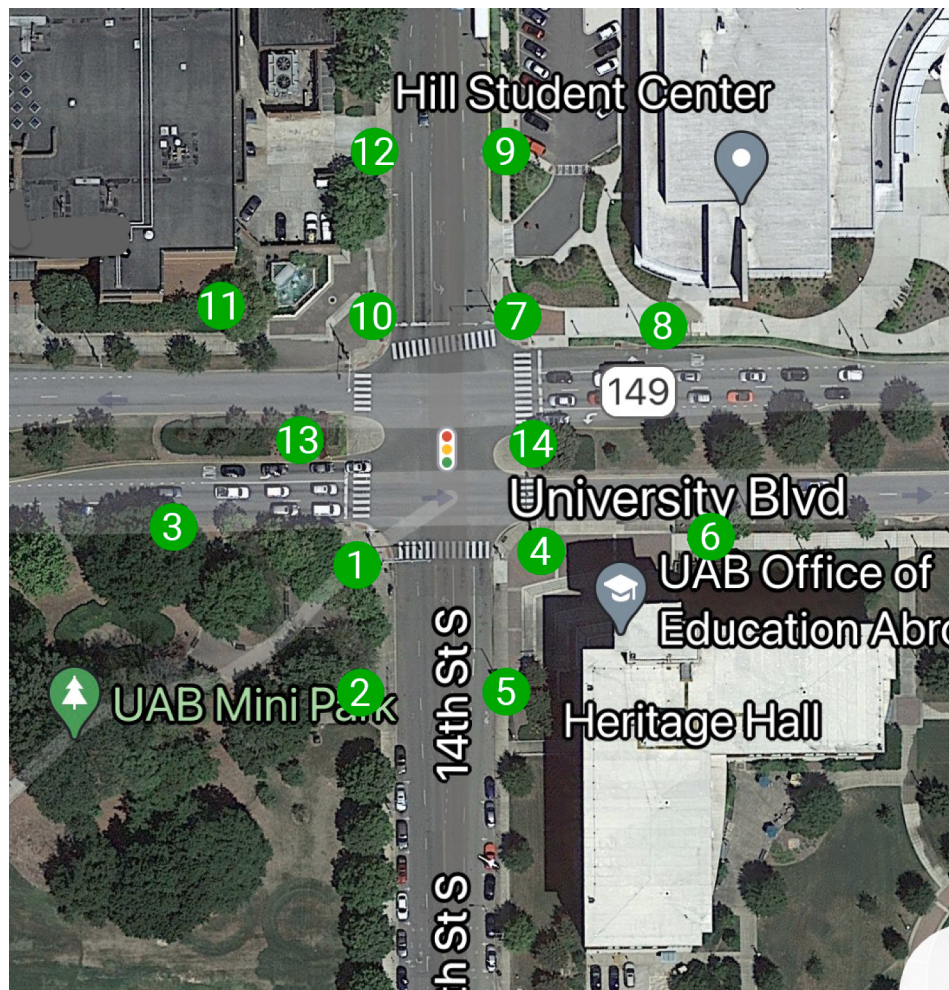


Fig. 3. Satellite photo of intersection, with beacon locations marked by green circled numbers. Imagery ©2021 Maxar Technologies, U.S. Geological Survey, USDA Farm Service Agency. Map data © 2021. Used with permission. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 2

Odds ratios (ORs) and associated 95% confidence intervals (CIs) for the association between distraction during street crossing and study intervention phase.

	Total crossings during phase (% with distraction)	Crude OR (95% CI)	Adjusted OR [†] (95% CI)
ALL WEEKS IN PHASES			
Pre-phase	11,597 (74.0)	Referent	Referent
Alert	11,133 (75.0)	1.06 (0.88–1.27)	1.11 (0.96–1.29)
Post-phase	11,085 (74.0)	1.00 (0.82–1.22)	1.18 (1.04–1.33)
THIRD WEEK OF PHASES ONLY			
Pre-phase	4,067 (72.4)	Referent	Referent
Alert	3,720 (73.2)	1.04 (0.88–1.23)	1.04 (0.84–1.30)
Post-phase	2,855 (75.0)	1.15 (0.94–1.39)	1.28 (0.96–1.69)

Note. Estimated from a general estimating equation logistic regression to account for dependency of crossing events within subjects.

[†] Adjusted for subject age, race, prevalence of distracted crossings during pre-intervention phase, and phone type (i.e., Android or iOS).

(Table 2). In adjusted models, the lack of association remained for the intervention alert phase (OR 1.11, 95% CI 0.96–1.29), but the post-intervention phase was associated with a significant increase in the likelihood of distraction (OR 1.18, 95% CI 1.04–1.33). Similar associations were observed in the sensitivity analysis that analyzed only data from week 3 of each study intervention phase, though the increased association with the post-phase no longer remained statistically significant (OR 1.28, 95% CI 0.96–1.69).

We next considered two key aspects of our research design. First, we recognized through anecdotal observation that many users were quite curious about the app and therefore purposely looked at their phone as they approached the intersection, wondering whether they would receive an alert or not. This created artificial data points, whereby participants appeared to be distracted when in fact they were purposely and carefully using their phones out of curiosity to see if an alert would appear. We recognized this behavior was likely to impact data concerning infrequently-distracted pedestrians more than frequently-distracted pedestrians, as the frequently-distracted individuals would have no need to artificially use their phones out of curiosity when crossing – they were in the habit already of using their phones when crossing. We therefore stratified the sample into those who were fairly infrequently (<50% of the time) distracted during the baseline phase, those who were frequently (50–75% of the time) distracted, and those who were nearly always (75% or more of the time) distracted. Second, we recognized that Android phone users received a more intrusive full-

screen visual alert than did iOS users, who received only a banner alert, and reasoned we might therefore see a stronger response among Android than iOS smartphone users.

As shown in Table 3, with data stratified by phone/warning type and baseline distraction rates, among Android phone users and in adjusted models those with infrequent baseline distraction were over 60% more likely to be distracted during the intervention phase (OR 1.64, 95% CI 1.12–2.39), and those with frequent (51–75%) baseline distraction prevalence had no difference in the likelihood of distraction (OR 1.02, 95% CI 0.73–1.44). These results seem to reflect user curiosity about the app. Those with the highest baseline distraction prevalence (75% or more of the time), however, had a near-65% decreased odds of distraction during the alert phase (OR 0.36, 95% CI 0.25–0.51), an association that was maintained during the post-intervention phase (OR

0.48, 95% CI 0.25–0.94).

Among iOS phone users, who received the banner warning only, both the intervention and post-intervention phases were associated with significant, over two-fold increased odds of distraction among those with infrequent baseline distraction; a significant near-70% increased odds of distraction for both phases (OR 1.69 for the alert phase and 1.64 for the post-phase) among those with frequent baseline distraction prevalence; and no change in the likelihood in either the intervention or post-intervention phase for those who were nearly always distracted at baseline.

Table 4 shows descriptive data from the questionnaire completed at the end of the study concerning perceptions of the StreetBit program for

Table 3

Odds ratios (ORs) and associated 95% confidence intervals (CIs) for the association between distraction during street crossing and study intervention phase by initial distraction prevalence and phone type.

	Total crossings during phase (% with distraction)	Crude OR (95% CI)	Adjusted OR† (95% CI)
ANDROID - FULL SCREEN WARNING			
≤50% crossings distracted			
Pre-phase	1,168 (23.7)	Referent	Referent
Alert	998 (36.0)	1.81 (1.23–2.66)	1.64 (1.12–2.39)
Post-phase	1,368 (21.9)	0.90 (0.42–1.91)	1.01 (0.51–2.01)
51–75% crossings distracted			
Pre-phase	885 (60.5)	Referent	Referent
Alert	912 (62.8)	1.08 (0.82–1.42)	1.02 (0.73–1.44)
Post-phase	374 (50.8)	0.75 (0.50–1.12)	0.74 (0.49–1.13)
>75% crossings distracted			
Pre-phase	753 (86.9)	Referent	Referent
Alert	844 (70.0)	0.36 (0.25–0.51)	0.36 (0.25–0.51)
Post-phase	466 (75.5)	0.47 (0.23–0.95)	0.48 (0.25–0.94)
IOS – BANNER WARNING			
≤50% crossings distracted			
Pre-phase	861 (56.4)	Referent	Referent
Alert	830 (73.9)	2.22 (1.48–3.32)	2.20 (1.48–3.26)
Post-phase	725 (77.2)	2.63 (1.94–3.56)	2.53 (1.88–3.40)
51–75% crossings distracted			
Pre-phase	1,495 (71.2)	Referent	Referent
Alert	1,438 (80.3)	1.66 (1.32–2.08)	1.68 (1.34–2.12)
Post-phase	1,532 (79.6)	1.58 (1.30–1.93)	1.64 (1.35–2.00)
>75% crossings distracted			
Pre-phase	6,435 (86.4)	Referent	Referent
Alert	5,924 (84.5)	0.87 (0.72–1.04)	0.87 (0.72–1.05)
Post-phase	6,019 (87.8)	1.14 (0.94–1.38)	1.16 (0.95–1.40)

Note. Estimated from a general estimating equation logistic regression to account for dependency of crossing events within subjects.

† Adjusted for subject age and race in addition to inclusion of a three-way interaction of phone type, pre-intervention distraction prevalence, and study intervention phase.

Table 4

Responses to post-survey questionnaire by type of phone/warning system.

	N (%)			p-value ^a
	Overall (N = 373)	Android Full- Screen Warning (n = 70)	iOS Banner Warning (n = 264)	
Do you think using the StreetBit app caused you to think more carefully about crossing streets while distracted?				
Yes	245 (75.4)	51 (72.9)	194 (73.5)	0.7989
No	60 (18.0)	14 (20.0)	46 (17.4)	
Not sure	29 (8.7)	5 (7.1)	24 (9.1)	
Since using the StreetBit app, do you think you have changed your behavior when crossing streets?				
Yes	173 (51.8)	29 (41.4)	144 (54.5)	0.1369
No	106 (31.7)	26 (37.1)	80 (30.3)	
Not sure	55 (16.5)	15 (21.4)	40 (15.2)	
Do you think using the StreetBit app was a worthwhile experience to improve your health and safety?				
Yes	235 (70.4)	49 (70.0)	186 (70.5)	0.9800
No	36 (10.8)	8 (11.4)	28 (10.6)	
Not sure	63 (18.9)	13 (18.6)	50 (18.9)	
Would you recommend other people try using the StreetBit app?				
Yes	234 (70.1)	48 (68.6)	186 (70.5)	0.1037
No	37 (11.1)	4 (5.7)	33 (12.5)	
Not sure	63 (18.9)	18 (25.7)	45 (17.0)	
Did you have any trouble using the StreetBit app?				
Yes	62 (18.6)	19 (27.1)	43 (16.3)	0.0336
No	254 (76.0)	45 (64.2)	209 (79.2)	
Not sure	18 (5.4)	6 (8.6)	12 (4.5)	
Did you ever find the StreetBit app to be annoying because it interrupted you or constantly appeared?				
Yes	53 (15.9)	17 (24.3)	36 (13.6)	0.0532
No	268 (80.2)	49 (70.0)	219 (83.0)	
Not sure	13 (3.9)	4 (5.7)	9 (3.4)	

^a Estimated from chi-square test.

the full sample, as well as for the sample stratified by phone type/warning received. As shown, participants generally reported positive feelings about the program and its potential, though the Android users receiving the full-screen warning had somewhat more difficulty using the app compared to iOS users receiving the banner warning (27.1% vs 16.3%, $p = 0.0336$) and found the app's alerts somewhat more frustrating (24.3% vs 13.6%, $p = 0.0532$).

4. Discussion

StreetBit offers an innovative and novel app designed to prevent distracted pedestrian behavior. It functions through a mostly-passive primary prevention strategy relying on intrusive reminders: if pedestrians approach the intersection while distracted, they receive a reminder to attend to the crossing rather than their smartphone. Reminders are delivered visually and aurally, depending on the mode of distraction. The software functions on both Android and iOS smartphone platforms, with distinctive differences between the two, and alerts are triggered by Bluetooth Beacons placed at intersection corners.

In this first empirical evaluation of StreetBit, we found it was effective in reducing distracted pedestrian behavior among Android users who were nearly always distracted at baseline. Unlike iOS users, Android users received a full-screen rather than banner warning. Among that group of often-distracted Android users, there was a 64% decrease in distraction during the alert phase, a reduction that was largely maintained after the alerts stopped during the post-intervention phase (52% decrease in distraction from baseline). Changes in distraction among individuals who were less distracted at baseline, and for iOS users (who received only a banner warning), were smaller and mostly null.

In a survey at the end of the study, users reported positive impressions about the StreetBit app. About three-quarters of users felt StreetBit caused them to think more carefully about crossing streets while distracted, and about half reported they changed their behavior while crossing streets. They tended to perceive StreetBit as worthwhile, easy to use, and recommended it for others. These findings match results from related research evaluating other strategies to reduce distracted pedestrian behavior, some of which indicate early promise of efficacy (e.g., [Larue et al., 2020](#)) and, in the cases of early concepts of augmented reality to improve pedestrian safety ([Tong and Jia, 2019](#)) and to use smartphones in communication with autonomous vehicles ([Holländer et al., 2020](#)), indicate high user acceptability.

Taken together, our study's results offer promise to continue developing and studying StreetBit as a means to reduce distracted pedestrian behavior, as it proved effective for the most distracted individuals using the Android smartphone platform that provided a more disruptive full-screen warning. Continued development is also supported by the theoretical and conceptual basis of the intervention, which provides a mostly-passive health-based reminder to individuals at the precise time and place when the reminder is needed but works unobtrusively in the background otherwise. One might liken this type of intervention to seat belt reminders, which buzz, light or beep when drivers fail to fasten their seat belt upon starting the vehicle but function only in the background otherwise. Such systems have proven effective ([Krafft et al., 2006](#); [Lie et al., 2008](#)).

We encountered two primary challenges in the implementation of StreetBit that must be addressed in future research. First, users appeared to be curious about how the app functioned. Anecdotal evidence – plus the finding that users were distracted during 74% of crossings at baseline in this study, much higher than in previous reports ([Basch et al., 2015](#); [Wells et al., 2018](#)) – suggested the participants wanted to see how the alerts worked and whether they were functioning correctly. This led to artificial datapoints in our data, especially among those users who were less frequently distracted at baseline. They watched their phone while crossing the street, appearing in our dataset to be distracted when in fact they were purposely and carefully watching to see if the app

responded properly. Second, software restrictions on the iOS platform prevented us from delivering the same sort of full-screen intrusive alert warning on iPhones that we delivered on Android smartphones. iOS users who were visually distracted received only a banner notification covering a small portion of the top of their screen whereas Android users received a much more substantial warning that blocked vision of the majority of the center of their smartphone screen. The Android notification was more effective in yielding the desired behavior change.

For future research, the solution to the first challenge may be to demonstrate the app's functioning when it is downloaded, allowing users to overcome their curiosity and function normally when crossing the street. A longer intervention period may also help, allowing users to revert to typical behavior over time. The solution to the second challenge – software development regulations on the iOS platform – is difficult. One possibility is exploration of alternative strategies to display full-screen warnings to iOS platform users within the imposed software limitations.

Conceptually, we expected the StreetBit app would lead to reduced distracted pedestrian behavior through behavior change. We anticipated users would grow tired of receiving repeated warnings about pedestrian safety as they approached a street-crossing, motivating them to adjust risky habits and put their phone away before they reached an intersection. Our study design and the automated assessments of user behavior tested this hypothesis. An alternative possibility is that distracted pedestrian behavior change is not lasting, but rather the StreetBit app prompts behavior change primarily or only on an immediate basis. That is, behavior might change each time a user approaches an intersection while distracted, but that warning does not lead to long-term change of behavior or habits. Our data suggested 69% of distracted Android users receiving the full-screen alert warning, and 16% of distracted iOS users receiving the banner warning, acknowledged receiving those warnings during the alert phase of the study. Our study methodology did not allow us to determine whether those users then crossed the street undistracted after acknowledging the warning, or whether they continued to use their phone in a distracted manner following the alert acknowledgement. Future research should investigate this question.

Another question for future research is to examine the specific effects of different types of warnings. Is a full-screen, more invasive warning necessary to alter distracted pedestrian behavior, either immediately or to create long-term behavior change? Or could a banner-type warning be sufficient to elicit behavior change over the long-term in some cases? Would some intermediate level of warning be sufficient? Existing research on lighted signals, which are non-invasive and do not block distracting devices, show initial promise but have not yet been subject to large-scale empirical testing ([Larue et al., 2020](#); [Larue and Watling, 2021](#)). In other settings, highly invasive interventions are largely effective. Most of these comprise physical rather than visual barriers; examples include gates to block motorists from railroad crossings and drawbridges, fencing around swimming pools, and unidirectional doors that permit emergency exiting but not entrance. Less prohibitive and invasive barriers such as lighted signals rather than gates at railroad crossings are less effective in empirical testing ([Liu et al., 2015](#); [Shinar and Raz, 1982](#)).

We conducted our research on an urban university campus because it represents a high-risk population of young adults who frequently cross streets, and who frequently cross streets while distracted. Future research should evaluate StreetBit among other populations and other traffic environments that present different risks. Expansion to crossing areas near middle schools and high schools seems logical, as younger children may display different social patterns of behavior. Epidemiological data suggest pedestrian crashes are greatly elevated among intoxicated pedestrians ([Hezaveh and Cherry, 2018](#); [Pawlowski et al., 2019](#)), so evaluating StreetBit among pedestrians in urban entertainment districts near bars and nightclubs would be valuable. Last, there is substantial risk in urban business and commercial districts. Testing StreetBit in downtown business districts where individuals frequently

walk to and from their parking areas, and to and from lunch venues, would be worthwhile.

Over the long-term and thinking ambitiously, if StreetBit proves effective in continued testing, then it has potential to revolutionize pedestrian safety, following the pathway of other mostly-passive primary prevention safety devices like seat belt alerts, smoke detectors, and smartphone weather alerts. Beacons could transition from battery-driven temporary installation to electricity-driven permanent installation in lampposts and walk/don't walk signs. They might become an accepted and normal part of daily functioning, reminding pedestrians of risky behavior at the moment the risk is impending and encouraging long-term behavior change. Ultimately, StreetBit or its successors could be integrated into vehicle-to-pedestrian and pedestrian-to-vehicle autonomous vehicle operations, reducing risk of autonomous vehicle-pedestrian crashes and alerting distracted pedestrians not just to safety when crossing current roadways but to road-crossing safety in a future environment when autonomous vehicles are commonplace.

Our research represented early-stage research to evaluate novel technology to reduce distracted pedestrian behavior, and it therefore suffered from limitations. We relied on a fairly small sample, primarily young adults, crossing at a single urban intersection. A portion of the recruited sample (12%) never engaged in the study. We implemented a crossover design, which offers the distinct advantage of controlling between-subjects differences but also creates limitations in that there may have been confounds of time (behavior changed later in the academic semester, or because of colder late autumn weather) or behavior (frustration with the app over time, leading to drop-out). We were unable to measure whether participants removed aural distractions by removing headphones or earbuds from their ear to cross the street but leaving the audio playing on their phones. We also faced the limitations discussed above: user curiosity about the app functioning, software development limitations on the iOS platform, and inability to measure presence or absence of distraction immediately following acknowledgement of an alert.

Despite these limitations, our results offer promise that StreetBit might be an effective strategy to reduce distracted pedestrian behavior, especially when the intervention is more disruptive, with alerts covering the full-screen, and for more frequently distracted pedestrians. Future software development and larger trials with more diverse types of pedestrians and in more diverse types of street-crossing environments are recommended.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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