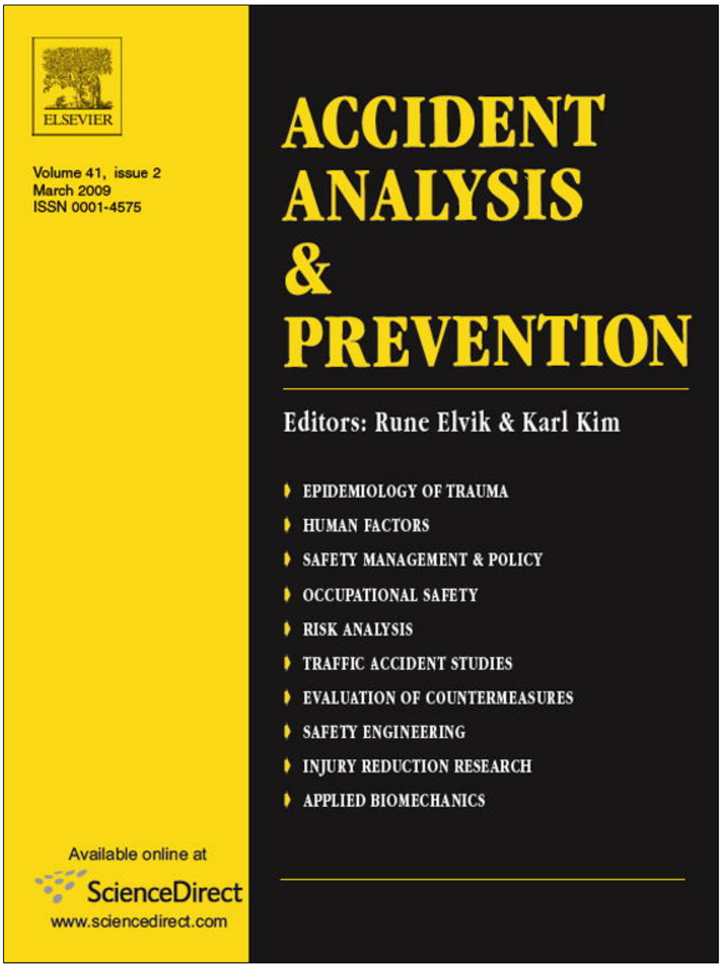
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The influence of carrying a backpack on college student pedestrian safety

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ABSTRACT

University students walk frequently, and individuals ages 18–22 have among the highest rates of pedestrian injury among any age group in the United States. These injuries are caused by a wide range of individual, interpersonal, and environmental factors, but one factor that has not been previously considered carefully is the influence of wearing a heavy backpack on pedestrian safety. Backpacks are known to slow walking speed and disrupt perception of one's environment, so it is reasonable to question whether they might also influence safe pedestrian behavior. Ninety-six college students engaged in 20 street-crossings within a virtual pedestrian environment. Half the crossings were completed while bearing a backpack weighing 12% of their body weight; the other half were completed without any burdens. Results suggest that participants walked more slowly, left less safe time to spare after crossing the virtual street, and experienced more frequent hits or close calls with traffic when crossing while carrying the backpack. They also missed fewer safe opportunities to cross while carrying the backpack. Our tests of several demographic characteristics, pedestrian behaviors, and backpack use, as covariates suggest the finding holds across all subsamples included in our study. Implications for pedestrian safety and future research are discussed.

1. Introduction

Most students at colleges and universities walk frequently. They walk daily to and from classes, and frequently also to stores and restaurants, bars and parties. Not surprisingly given their increased exposure to traffic compared to most other age groups, nearly 20,000 Americans ages 18–22 suffered serious pedestrian injuries in 2006; over 300 suffered fatal pedestrian injuries (NCIPC, 2008). The crude rate for nonfatal pedestrian injuries is higher among Americans ages 18–22 than for any other developmental stage. On urban college campuses such as our own, the risk of pedestrian injury is particularly high. Over the last two years for which data are available (2004–2006), 16 students on our campus suffered serious pedestrian injuries (T. Webb, UAB Police Department, personal communication, 31 March 2008).

At all ages, pedestrian injuries are caused by a combination of factors. These factors, some of which have been examined carefully in research and others of which have not, appear to include driver behavior, pedestrian behavior, and characteristics of the traffic environment (Barton and Schwebel, 2007; Duperrex et al., 2002). One factor that remains poorly understood, but which may contribute to increased risk of pedestrian injury among college students, is the fact that students tend to carry heavy backpacks.

1.1. Influence of backpack carrying on walking and perception

There are both physical and perceptual consequences of carrying a heavy backpack. Physically, carrying a backpack causes a decrease in walking speed, as evidenced by research in samples of adolescent girls (Chow et al., 2005) and college students (Wang et al., 2001). This decrease results from a combined tendency for backpack-wearers to take shorter steps (reduced stride length), to take fewer steps per minute (reduced cadence), and to spend more time on both feet (double support time) rather than just one foot (single support time). Perceptually, carrying a backpack appears to alter perception of steepness and distance (Bhalla and Proffitt, 1999; Proffitt et al., 2003). In one study, for example, college students wearing a backpack weighing 16–20% of their body weight perceived distances to be farther than matched participants not carrying a backpack (Proffitt et al., 2003).

Available psychophysiological evidence that suggests carrying a backpack may disrupt walking speed and perception has critical implications for pedestrian safety, since some aspects of safe pedestrian behavior require very rapid perception and processing of one's walking speed with respect to the distance, speed, and acceleration/deceleration of approaching vehicles from multiple directions. If carrying a backpack disrupts both walking speed and perception, and pedestrians do not make the appropriate cognitive and perceptual adjustments for those disruptions, then carrying a backpack might also influence pedestrian safety.

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1.2. The present study

The present study was designed to compare pedestrian safety in college students while carrying a backpack and walking without carrying anything. Because carrying a heavy backpack disrupts normal walking behavior and perception, we hypothesized students who carried a heavy backpack (12% of their body weight) might demonstrate riskier pedestrian behaviors. Specifically, we predicted a slower walking speed and misperception of the environment would cause students to choose smaller and riskier traffic gaps to cross within, and to experience more close calls and collisions while crossing streets carrying a heavy backpack. We also predicted they might wait a shorter time to cross the street because they were eager to remove the heavy load they were bearing. As a secondary topic of interest, we tested whether demographic and behavioral covariates (gender, age, body mass index (BMI), backpack-carrying habits and walking habits) might influence the effect of carrying a backpack on pedestrian safety. The research was conducted in a semi-immersive, interactive virtual environment designed to study pedestrian behavior without placing study participants at risk of actual injury.

2. Methods

2.1. Participants

Ninety-six college students were recruited and eligible to participate in this study from introductory psychology courses at the University of Alabama at Birmingham. Students participated in the research as one way to fulfill a course requirement. All participants provided informed consent to participate, and all study protocols were approved by the university IRB.

As shown in Table 1, the sample was 62% female and racially diverse (51% Caucasian, 30% African American, 6% Hispanic, 5% Asian American, and 7% multiracial or of other racial/ethnic groups). Mean age was 21.65 years (S.D. = 5.15).

2.2. General protocol

Following informed consent procedures, anthropometric measurements (height and weight, plus weight of actual backpack/bag(s) being carried) were taken. A standard backpack was filled with textbooks and notebooks to weigh 12% of the participants' body weight; this backpack was used for the remainder of the session with that participant. The 12% of body weight figure was chosen for three reasons: (a) it is a weight that most people who are not accustomed to carrying heavy packs can manage without substantial pain or fatigue; (b) it is a weight typical of that carried by student backpack-users; and (c) it is a weight similar to that used in previous research (Proffitt et al., 2003; Wang et al., 2001).

Participants were then taken to a straight hallway and asked to walk along a line eight times, at the speed they would normally use to walk across a street. For four of those walks, participants carried the backpack weighing 12% of their body weight; the other four walks were completed without carrying anything. Order of walks (four with backpack and four without) was randomly counter-balanced across participants. Walking times were recorded by stopwatch, and the average of the four crossings in each condition was used for pedestrian trials within the virtual environment.

Participants were then taken into the virtual environment, where they were exposed to two demonstration trials, four familiarization trials, and then two sets of 10 test trials (10 trials consecutively with the backpack and 10 trials consecutively without, randomly counter-balanced across participants). Details of the virtual reality protocol appear below. Between the sets of test trials, participants completed three short questionnaires: a demographics report, a report of typical pedestrian behaviors, and a report of typical backpack use behaviors. Details of the measures appear below.

Table 1
Descriptive data (*N* = 96).

Variable	Mean (S.D.)
Sex (% female)	62%
Race/ethnicity	
% White	51%
% African American	30%
% Other race/ethnicity	19%
Age (years)	21.65 (5.15)
Body mass index	24.78 (5.57)
Backpack weight[a]	1.35 (0.48)
Frequency: carry backpack[b]	1.64 (1.22)
Walking frequency (miles/week)	9.04 (5.97)

[a] 1 = Backpack used in the research was lighter/about the same as usual burden carried to classes. 2 = backpack used in the research was heavier.
[b] 1 = Everyday; 2 = usually; 3 = sometimes; 4 = occasionally; 5 = never.

2.3. Virtual reality protocol and measures

Specifics of the hardware, software, and experience within the virtual environment are published elsewhere (Schwebel et al., 2008). Briefly, participants are semi-immersed into an environment displaying a 180° perspective on three monitors arranged in a semi-circle in front of them. The environment includes a mid-block crosswalk, with traffic moving from both directions. Ambient and traffic noise is delivered through speakers. The environment is interactive, such that when the user steps off the curb, the perspective changes from first- to third-person and they view themselves crossing the street, witnessing the safety or risk of the crossing. The virtual environment has been shown to validly represent real-world pedestrian behaviors in both children and adults (Schwebel et al., 2008).

Following two demonstration trials by a research assistant (one resulting in a successful crossing and one purposely demonstrating a pedestrian being "hit" to reduce participant curiosity), participants completed four familiarization trials in the virtual environment. Data from these trials were not analyzed, but they permitted participants to gain familiarity with perception and use of the virtual environment.

Participants then completed 2 sets of 10 trials of street-crossing within the virtual environment, following study protocols identical to previous research (Schwebel et al., 2008). Ten of those trials were completed while wearing a backpack weighing 12% of body weight; the other 10 trials were completed without any burden. Order of trials (backpack vs. no backpack) was determined randomly between participants. Between trials, participants completed self-report questionnaire measures (described below).

Five indicators of pedestrian behavior, adapted from previous research (Barton and Schwebel, 2007; Demetre et al., 1992; Lee et al., 1984; Schwebel et al., 2008), were computed to assess pedestrian behavior: (a) average start delay (time in seconds after a car passes and before the participant initiates crossing), (b) average gap entered (time in seconds between the participant entering the street and the next vehicle arriving in the crosswalk), (c) average time left to spare (time in seconds between the participant safely crossing the street and the next vehicle arriving in the crosswalk), (d) missed opportunities (number of times when a safe gap to cross within occurred, but the participant chose not to cross within it; safe gaps were defined as gaps 1.5 times greater than the time the participant would need to cross the street, based on walking speed), and (e) hits/close calls (number of times when the participant would have been struck by a vehicle in the real environment, or when

Table 2
Means (S.D.) and paired-sample *t*-test results comparing pedestrian behavior with and without the backpack.

Variable	No backpack *M* (S.D.)	Backpack *M* (S.D.)	Change *M* (S.D.)	*t* (d.f. = 94)	Cohen's *d*
Walking speed (miles/h)	3.00 (0.41)	2.81 (0.41)	0.19 (0.16)	11.60**	0.45
Start delay (s)	1.06 (0.60)	0.96 (0.55)	0.10 (0.58)	1.65	0.17
Gap entered (s)	6.97 (1.22)	6.90 (1.32)	−0.07 (0.79)	−0.88	−0.04
Time left to spare (s)	4.16 (0.94)	3.90 (1.04)	0.26 (0.83)	3.02**	0.26
Missed opportunities (number)	0.22 (0.71)	0.07 (0.30)	0.15 (0.71)	2.01*	0.29
Hits + close calls (number)	0.42 (0.74)	0.61 (0.80)	−0.20 (0.94)	−2.07*	−0.26

* $p < .05$.
** $p < .01$.

the temporal gap between the participant and an oncoming vehicle was less than 1 s). We also considered the average walking speed in miles per hour, as assessed separately prior to engaging in the virtual environment.

For all analyses, pedestrian behaviors were averaged across tasks by condition. That is, the 10 start delay times when the participant carried the backpack were averaged into an average start delay score for the backpack condition. The process was repeated for trials completed without the backpack. Therefore, each participant had 5 scores (start delay, time left to spare, gap entered, hits/close calls and missed opportunities) by two conditions (backpack and no backpack). They also had two walking speed scores, one with the backpack and one without.

2.4. Questionnaire measures

Participants completed three questionnaires: a demographics report, a pedestrian behavior report, and a backpack report. The demographics report included items concerning gender, age, and race/ethnicity.

The pedestrian behavior report asked participants how often they walked to three different destinations (classes or other on-campus locations; stores; and other places) as well as how often they walked or ran for exercise. Average distances walked (or ran) were also recorded. Frequency of walking was multiplied by distance walked, on average, to obtain an overall measure of average distance walked per week. Participants reported walking a mean of 9.04 miles (S.D. = 5.97, range = 1.13–30.38) per week, a large distance for most Americans but not surprising given the urban nature of our campus.

The backpack report included just a few items. The first several addressed discomfort experienced while carrying the backpack during the experimental protocol. No participants reported more than "a little discomfort" from carrying the backpack (most reported no discomfort), so these data were not considered further. We also asked whether participants felt the backpack used in the virtual environment was heavier (coded as 2) or lighter/about the same (coded as 1) as the backpack or bags they usually carry to classes. Finally, we asked participants how frequently they carry backpacks on a 5-point scale from everyday (1) to never (5).

3. Results

The primary hypothesis, that carrying a backpack would influence safe pedestrian behavior, was tested using paired-samples *t*-test for each of the six dependent variables. Results of those tests, along with descriptive data, appear in Table 2. As shown, there were significant differences on four of the six dependent measures. Replicating previous work (Chow et al., 2005; Wang et al., 2001), participants tended to walk somewhat slower while carrying the backpack (M = 2.81 miles per hour, S.D. = 0.41) than while not carrying the backpack (M = 3.00, S.D. = 0.41). Carrying a backpack also resulted in less time to spare after safely crossing the street (M = 3.90 s, S.D. = 1.04 with backpack; M = 4.16, S.D. = 0.94 without), fewer missed opportunities (M = 0.07, S.D. = 0.30 with backpack; M = 0.22, S.D. = 0.71 without), and more hits/close calls (M = 0.61, S.D. = 0.80 with backpack; M = 0.42, S.D. = 0.74 without). Statistically significant differences did not emerge for two variables. Participants tended to start after a similar delay, about 1 s, whether they were carrying the backpack or not. Most telling perhaps,

Table 3
MANCOVA results (*F* scores) for pedestrian behavior change with and without backpack and possible covariates (N = 96).

Variable	Walk speed	Start delay	Gap entered	Time left to spare	Missed Opportunities	Hits/close calls
Main effect	132.86**	2.76	0.75	8.85**	3.80*	41.49**
Covariate effects						
Gender	3.49	5.05*	6.16*	6.12*	0.28	0.96
Random order	0.03	1.72	0.72	1.13	0.50	2.53
Age	0.34	4.94*	0.28	0.20	0.07	0.88
BMI	0.82	1.85	2.91	3.51	0.48	3.26
Backpack weight	2.66	0.12	2.34	1.70	1.68	0.42
Frequency: carry backpack	0.01	0.00	0.12	0.25	0.40	0.34
Walking frequency	1.12	4.29	1.07	0.81	0.71	1.44
Interaction effects						
Gender	0.09	0.12	1.14	0.91	0.01	0.02
Random order	0.78	1.51	2.16	2.42	0.26	4.16*
Age	2.43	0.71	0.02	0.03	0.00	0.35
BMI	0.43	0.45	0.03	0.00	0.27	0.38
Backpack weight	2.09	0.48	0.24	0.54	0.81	0.23
Frequency: carry backpack	0.05	1.85	0.29	0.30	0.12	0.18
Walking frequency	1.19	3.42	0.54	0.81	0.01	0.93

Note. All tabular entries reflect *F* statistics. Effect sizes for main effects are *partial* ε^2 = 0.60, 0.03, 0.09, 0.01, 0.04 and 0.32, respectively; other effect sizes are available from the first author upon request. Covariates were centered via standardization prior to entry. For gender, higher scores reflect female. For random order, higher scores reflect backpack condition first.
* $p \leq .05$.
** $p < .01$.

participants chose to enter the road with a similar gap size available to cross within whether they carried a backpack or not. Thus, they allowed similar time to cross the street but their risk was increased due to the slower walking speed while wearing the backpack.

Our primary hypothesis was supported. Results suggest participants behaved in a somewhat riskier manner while carrying a backpack in a simulated pedestrian environment than while not carrying the backpack. This risk seemed to be driven largely by the slower walking speed while wearing a backpack, and failure for participants to adjust for that slower speed in the context of our virtual environment. We next investigated our secondary hypothesis, whether demographic, pedestrian behavior, and backpack use covariates might influence that relationship. To do so, we constructed a single repeated-measures generalized linear model (GLM; see Table 3). Condition (backpack vs. no backpack) served as the repeated-measures component; the six pedestrian measures shown in Table 2 served as dependent variables. We also included seven covariates, all centered into standardized scores prior to entry in the model (Delaney and Maxwell, 1981): gender, randomized order in the study (backpack first vs. backpack second, in the virtual environment), age, BMI, perceived weight of backpack used in the research compared to their usual burden, frequency of carrying a backpack, and frequency of walking. Descriptive data for covariates (prior to centering) appear in Table 1. As shown, there were main effects for four of the six pedestrian safety measures, replicating the *t*-test analyses shown in Table 2. There was minimal influence from potential covariates, suggesting the main effect of more dangerous pedestrian behavior while carrying the backpack is not influenced greatly by the covariates studied. There was a scattering of notable findings regarding the covariates: men tended to have shorter start delays, shorter times left to spare, and shorter gap sizes entered than women; older individuals tended to have shorter start delays; and there was an interaction effect with random order and hits/close calls, such that a combination of wearing the backpack and lack of learning (first set of trials) created the greatest risk of being hit or having a close call.

4. Discussion

Results suggest carrying a heavy backpack might disrupt safe pedestrian behavior among college students. While bearing a backpack weighing 12% of their body weight, participants walked more slowly, left less safe time to spare after crossing the virtual street, and experienced somewhat more frequent hits or close calls with traffic when crossing. They also missed fewer safe opportunities to cross while carrying the pack. Our test of several covariates suggests the finding holds across all subsamples included in our study.

Of course, safe pedestrian behavior is multifaceted and we investigated only some portion of that behavior. We did not investigate route selections or perception of acceleration/deceleration in vehicles, for example. And although we found several significant behavioral differences when wearing and not wearing a backpack, we also discovered some behaviors that were similar in both conditions. Interpretation of null results is always a bit risky, but the non-significant main effect findings we discovered are worthy of comment. First, we found that individuals entered the street equally quickly whether they were wearing a backpack or not. In other words, cognitive processing of street safety did not appear to be altered by carrying a heavy burden, nor was the physical process of initiating crossing. Perhaps more interesting, the participants chose to enter equal-sized traffic gaps with and without the backpack. The risk they experienced while wearing the backpack was not due to choosing an unsafe gap while wearing a heavy pack but rather due to walking more slowly with the pack. Behavior in our virtual environment has been shown to match behavior in real-world settings (Schwebel et al., 2008), but participants in the virtual world do not have the opportunity to alter their walking speed partway across a street. Future research should evaluate aversive measures backpack-wearers might take in the real world that were not possible in our simulation. Pedestrians with heavy packs might, for example, quicken their slower walking speed mid-crossing to avoid potential collisions and close calls with oncoming traffic.

This study represents, to our knowledge, an initial inquiry into an unexplored domain of research. Previous work confirms the reduced walking speed among backpack-wearers (Chow et al., 2005; Wang et al., 2001), but does not consider or study the implications of reduced walking speed on pedestrian behavior and pedestrian safety. Replication is needed, but if our findings hold up in replication, they have implications for pedestrian safety interventions. College and university administrators, especially those on urban campuses, might consider the need for educational campaigns with students, alerting them of the need for increased alertness while crossing streets with heavy loads. Traffic engineers might consider the fact that walking speed is reduced in individuals carrying heavy packs, and adjust traffic and crosswalk signals accordingly. Drivers might also be educated, through mass marketing (e.g., billboards) or simply increased signage around campuses to reduce speed and watch for pedestrians.

Of course, college students are not the only ones who carry heavy backpacks; much has been written about the fact that school-aged children frequently carry heavy backpacks to school (e.g., Chow et al., 2007; Puckree et al., 2004). Although it remains empirically untested whether our findings might translate to younger children, one could presume they probably would, and that the same risks we discovered in college students might also hold true for young children carrying backpacks, including those in elementary school who also have inferior pedestrian safety skills (Barton and Schwebel, 2007).

Our research must be considered with respect to its strengths as well as its limitations. We used a within-subjects experimental design in an ethically safe virtual environment to test the effects of carrying a backpack on college students' pedestrian behavior. We controlled for several covariates, but there are others that might be considered in future research. These could include muscular strength and fitness; distribution of weight in the backpack and on the back; and personality differences. Also recommended for future work is translation of the findings into real-world settings and investigation of aversive actions pedestrians with heavy backpacks might take when partway across a street.

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