
People Transitioning Across Places: A Multimethod Investigation of How People Go to Football Games

Environment and Behavior


XX(X) 1–28

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DOI: 10.1177/0013916511412589

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Abstract

Stokols and Shumaker suggested that places can be characterized in terms of whether they are occupied primarily by individuals, aggregates, or groups. The authors propose a fourth type of place, one occupied primarily by groups within an aggregate. This research used a multimethod approach to examine whether people go to football games alone or with others and, if with others, how many others. Observations of cars entering parking lots or parking decks indicated that on average each vehicle contained about 2.5 individuals. Surveys of individuals about to enter the stadium also indicated that on average people were in groups of about four. Computer vision tracking of pedestrians next to the stadium about 2 hr before the game indicated that, although about one quarter of the pedestrians were alone, groups averaged about four. Thus, the results suggested that informal groups became larger as a function of proximity to the stadium. Analyses of the space occupied by groups of different sizes indicated that as groups got larger, the amount of space per person

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got smaller. These results, which indicate that people go to football games in small groups, have implications for the built environment and security.

Keywords

small groups, group space, American football, stadiums, computer vision tracking

Behavior settings are particular places in which specific individuals engage in patterns of activity (Barker, 1968; Wicker, 1987). The assumption behind this approach to environmental psychology is that behavior can be understood only by considering the context in which it occurs. In their theoretical extension of research on behavior settings, Stokols and Shumaker (1981) provided a typology of places and people. In this article, we focus on their typology of places, suggest an addition to their model, and then apply it to a specific series of places, the transitions people make when they go to a college football game in the United States.

Typology of Places

Stokols and Shumaker (1981) suggested that places can be characterized in terms of the composition and organization of the people who use those places. Their model consists of three types of places. Places that are typically occupied by a single person are *individual-oriented places*. A library carrel and an individual's bedroom are examples of such environments. *Aggregate-oriented places*, those that are typically occupied by coacting individuals, are composed primarily of strangers or minimally related individuals who are performing the same kinds of actions parallel to but not in interaction with each other. Such environments include pedestrian malls, parking lots, and subway stations. *Group-oriented places* are those that are typically occupied by people who know and regularly interact with each other. Such places are usually focused on the activities of organized groups. These environments include a family backyard, the practice field of an athletic team, and the meeting place of a club.

The distinction that Stokols and Shumaker (1981) make regarding aggregates versus groups concerns whether people behave independently of one another or behave as a unit. When people interact with each other in ways such that they influence and are influenced by each other, they are a group (Shaw, 1981). Stokols and Shumaker suggest that an audience at a Broadway play constitutes an aggregate, whereas a family going on a picnic constitutes a group.

Our research suggests that a fourth type of place should be added, and this relates to Stokols and Shumaker's (1981) example of the Broadway play. Rather than a collection of coacting individuals, audiences are primarily collections of small groups who attend the event together (Ruback, 2010). Thus, a fourth type of place would be *groups nested within aggregate-oriented places*. That is, there are large numbers of coacting individuals (the aggregate orientation), but within this aggregate are numerous small groups. Many aggregate-oriented places, such as pedestrian malls and subway stations, may be better understood in terms of a *groups nested within aggregate-oriented places* orientation, if the composition of the aggregate is small groups, in addition to coacting individuals. Environments in which there is an audience, including plays, movies, and athletic events are likely to be *groups nested within aggregate-oriented places*.

In this study, we examine football games as an example of this fourth type of place. On a typical fall Saturday afternoon at 40 stadiums around the United States, more than 50,000 fans gather to watch a college football game; at 9 of those stadiums there are more than 90,000 people, and at 4 of those stadiums there are more than 105,000 people (see <http://www.scribd.com/doc/334171/2006-National-College-Football-Attendance-NCAA>). Even at smaller colleges, tens of thousands of people attend football games. These large crowds come to watch the game, but they also come to support their college, to bond with friends and family, to connect with other fans, and to enjoy food and drink.

In this study, we were concerned with how people go to football games, specifically whether they attend games alone or with others, and, if they are with others, how many others. We also suggest that going to football games involves a transition between individual, aggregate, group, and group within aggregate places. We hypothesize that these transitions affect group size, and that the small groups become larger as people get closer to the stadium. We test these ideas using multiple research methods: observation, surveys, and computer vision tracking.

Informal Groups in Public

For 60 years, social scientists have examined the size of naturally occurring groups in different locations. Across informal locations like sidewalks, stores, playgrounds, carnivals, receptions, swimming pools, basketball game intermissions, church socials, and train depots in Portland and Eugene, Oregon, James (1951) found that groups ranged in size from two to seven, with the average being 2.41. Coleman and James (1961) suggested that the distribution

of small groups observed by James (1953) could be explained by a stochastic process involving the tendency of a group to lose a member at a rate proportional to its size and to gain a member at a rate proportional to the number of single individuals who could join a group. They suggested that their general model could be extended to understand the situation in which groups got larger by making the parameter for the acquisition rate of members an increasing function of time. In the present article, we suggest that increasing group size can be best understood as an increasing function of proximity to the goal.

Two decades after James' (1951) initial work, Bakeman and Beck (1974) replicated the earlier study in Austin, Texas by examining eating in dining halls, studying in an undergraduate library, relaxing in a coffee shop in a student union, shopping in a shopping mall, and playing in a municipal swimming pool. Bakeman and Beck found an average group size of 2.56. In both studies, groups were defined as individuals who were interacting with each other, as indicated by proximity, gestures, gaze, or talking.

Both James (1951) and Bakeman and Beck (1974) found that the percentage of people who were alone varied by context, but the range of group size and mean group size were fairly consistent across locations. In particular, both studies found that when only groups were considered, dyads were the most common, followed by groups of three, and then groups of four. Bakeman and Beck suggested that this finding that groups of two and three people are the most common group sizes could be explained by a random factors model. That is, given a certain number of people and the possible ways that those people could be arranged in groups (i.e., groups of two, three, four, five), the distribution of group sizes would be what would be expected by chance (e.g., groups of two would be most common because there are more possible combinations of two people). Using observational data of five-man teams of aquanauts living in a habitat on the ocean floor taken 10 times an hour, 24 hr a day, during an 8-month period, Bakeman and Beck found that group-size distributions were what would be expected by chance.

However, the potential problem with this conclusion is that the sample of locations might not have been broad enough to include situations where larger groups are more common. That is, the kinds of environments observed in these studies may lead to certain sizes of informal groups (i.e., two or three) and not others. Thus, consistent with Stokols and Shumaker's (1981) typology of places, it is important to question the assumption that group size is unrelated to group location.

Desportes and Lemaine (1988) argued, contrary to James (1953) and Bakeman and Beck (1974), that group size is dependent on the environmental condition in which individuals find themselves. These scholars suggested that groups

are likely to be larger in environments conducive to social interaction (e.g., coffee shops, lounges) but smaller in environments that place a higher cognitive load on individuals (e.g., libraries, department stores). Consistent with that hypothesis, Burgess (1984) found that location did significantly affect group size, such that informal groups were significantly larger in amusement parks than in shopping malls and at a college quadrangle, and informal groups were significantly larger at these locations than in airports.

Given that location might be a strong predictor of group size, one question we were interested in is whether a social situation—going to a football game—might mean that larger groups are more common. In an unpublished study, McPhail (2009) found that 89% of people attending basketball games at the University of Illinois came with at least one other person, 52% with at least two others, and 32% with at least three others. In an online survey of 1,438 football fans, Wann, Friedman, McHale, and Jaffe (2003) found that 98% of fans said they went to games with at least one other person, 73% with at least two others, and 10% with three others. Overall, McPhail found that 58% of all groups were larger than two and Wann et al. found that 86% of all groups were larger than two, in contrast to James (1951), who found that only 29% of groups were larger than two and Bakeman and Beck (1974), who found, across seven locations, that only 34% of groups were larger than two.

Other research also indicates that people attending sporting events are likely to attend in groups. Based on their analysis of 623 surveys of individuals who had attended a Women's National Basketball Association (WNBA) basketball game, Funk, Ridinger, and Moorman (2004) found that 73% had attended in groups of two to four persons. These other individuals with whom people attended included children, adult friends, and spouses/partners. Moreover, bonding with friends and family were important reasons why people said they went to games.

Indeed, there may be a norm that people watch games in groups. For example, Buford (1992) in his description of English soccer fans, many of whom became violent, wrote: "I thought I'd go [to a game] on my own. I didn't know that it wasn't done, that lads went with lads or that lads went with dads" (p. 17). These fans also traveled together internationally. In Italy, Buford found himself among

Several hundred Manchester United supporters who all knew each other, had probably known each other for years, were accustomed to traveling many miles to meet every week and who spoke with the same thick accent, drank the same thick beer, and wore many of the same preposterous, vaguely designed, High Street clothes. (p. 50)

Even when people watch games on television, they often watch in groups. Data indicate that 46% of people watch the Super Bowl in groups of six or more people; only 9% watch the Super Bowl alone (Book of Odds, 2010).

Hypotheses

Aside from whether groups going to a football game might be larger than informal groups in other locations, we wondered whether the size of these groups might vary as a function of proximity to the stadium. Our hypothesis was that as people get closer to the stadium, they are more likely to be in larger groups because they are likely to meet people they know, either coincidentally or by plan, and they would then proceed in this larger informal group to the stadium. We also suspected that these groups at the stadium would be about four people in size. Hackman and Vidmar (1970) found that participants in one of three types of tasks found groups between four and five members to be the most satisfactory, being neither too big nor too small. Similarly, Frank and Anderson (1971) found that groups of three and five members were rated significantly more pleasant, warm, and cooperative than groups of two or eight.

These hypotheses about group size and increasing group size would be consistent with the framework Stokols and Shumaker (1981) proposed. That is, football fans are likely to arrive by car (an individual-oriented place), walk toward the stadium (an aggregate-oriented activity), and arrive at a tailgating site, where they might picnic with others (a group-oriented place). They might then walk to the game (an aggregate-oriented activity) and enter the stadium (a group nested within aggregate place). The answers to these questions have implications for environmental design, including the number of parking spaces needed and the amount of space needed for pedestrians. We examined these questions at football games at Penn State University, which has the second largest college football stadium in the country, regularly averaging more than 105,000 fans per game.

Study I

In our first study, we used two traditional methods of social science investigation, observation, and surveys, to learn about group size at football games. First, we observed cars entering parking lots and parking decks and counted the number of people in each car. Because the number of people in a car has implications for traffic and roadways, the Census Bureau reports how people go to work. Data from the 2000 U.S. census indicate that most Americans (75.7%) drive to work by themselves; the remainder carpool (12.2%), walk

(2.9%), take public transportation (4.7%), take a bike or motorcycle (1.2%), or work at home (3.3%; U.S. Bureau of the Census, Journey to Work, Table 5, 2004). Of the 87.9% who drive to work, 86.1% drive alone; thus, the average number of occupants for people going to work is 1.14. For shopping, the average number of occupants in a car is 1.79, and for recreational purposes, the average vehicle occupancy is 2.03 (Hu & Reuscher, 2004). Tourist sites often make counts of the number of visitors by counting the number of cars and the number of people per car. For example, the average number of visitors per car to El Morro National Monument national parks during the period 1962 to 1966, based on 52,972 visitors in 12,551 cars, was 4.22 (Berger, cited in Cohen, 1971).

In addition to observing cars, we also interviewed fans both at tailgate parties and just before they entered the stadium. In particular, we asked fans whether they were alone or with others.

Method

Observations of Cars. In our study, three coders conducted observations at various parking lots and parking decks around campus several hours prior to the start of each game. As cars entered the parking area, the observer recorded the time and the number of people in the vehicle. On football Saturdays, streets near the stadium are either closed entirely or turned into one way streets with signs that read “Football Traffic Only” posted to ease traffic flow toward the stadium. For this reason, two coders observed the flow of traffic toward the stadium and counted the number of people in each car using the same procedure that was used at the parking lots and parking decks. At all locations, every vehicle was recorded, with the exception of commercial vehicles (e.g., Office of Physical Plant, Pepsi-Cola truck). Observations of vehicles were recorded at one noon game and two afternoon games (3:30 and 4:30 p.m., respectively).

Interviews With Tailgaters. Interviewers interviewed tailgaters, groups of picnickers who set up food and refreshments by their vehicles in the parking lots, at three of the seven home games during the 2008 football season. These included two noon games and an 8:00 p.m. game. These interviews were conducted with tailgaters in various lots around the stadium. Three interviewers conducted research on tailgaters by approaching the individuals in every 5th parking spot. If there were no people in the 5th spot, the interviewer went on to the next consecutive parking spot. In the case of rejection, the next consecutive tailgate was approached for an interview.

The 157 respondents who participated in the research (response rate = 99%; only two groups of tailgaters declined to participate) were asked a variety of questions about how they attended the game. First, the respondent was asked whether they attended the tailgate alone or with others. Respondents who attended the event with others were then asked how many others they were with and how many of these others were friends, family, male, female, came together, or arrived separately.

Next, respondents were asked a series of questions about whether and how they planned to attend the football game. First, the interviewer asked how many of the tailgate group members were planning to attend the game. Follow-up questions included how many games the individual planned to attend during the season, the location of his or her seat in the stadium, and which gates the individual planned to enter and exit.

Interviews With Fans About to Enter the Stadium. Entrance interviews were more complicated than tailgater interviews for three reasons. First, there are five major gates into Beaver Stadium. The two most heavily trafficked gates (A and B) were the focus of our interviews. Second, Gate A (the general admission entrance to the student section) opened 2 hr prior to kickoff, whereas Gate B (the gate for ticket holders with assigned seating) opened 90 min prior to kickoff. Interviewers arrived approximately 30 min before the gates opened at each location. Third, there are multiple corrals at each entrance, so there is no central line of attendees waiting to enter the stadium. Thus, interviewers stood in a central location and approached every 5th person passing in the direction of the entrance. In the case of rejection, the next individual was approached for an interview.

Entrance interviews were conducted prior to the spring scrimmage (2:00 p.m.) and three regular season games (noon, 4:30, and 8:00 p.m.). The response rate was low (60%), particularly as kickoff time grew closer. The 338 individuals who agreed to participate in the research were asked whether they were attending the game alone or with others.

Results

We present the results for each of the methodologies we used to obtain the data.

Observations of Cars. We observed a total of 1,663 cars at four different locations (two parking decks, one parking lot, and one major intersection of “football traffic only” heading toward the parking areas) over three football games (Game 1: 102 observations; 253 people; Game 2: 591 observations;

1,412 people; Game 3: 970 observations; 2,435 people). In total, there were 4,100 people who were observed, an average of 2.47 people per car (Median = 2). The distribution by group size was as follows: (a) alone—11%, (b) two people—56%, (c) three people—14%, (d) four people—15%, and (e) five or more people—4%. There was no significant difference by game in terms of the number of people per car. There were significantly more people in cars in the parking lots ($M = 2.53$) than in the parking decks ($M = 2.27$), $F(1, 1661) = 18.46, p < .001$, consistent with the idea that people who are tailgating in parking lots are likely to be in larger groups.

The same parking lot was observed over two games, one of which was against a team that had a mediocre record and the other of which was against a nationally ranked team. As might be expected, the number of people per car was significantly larger for the more important game against the nationally ranked opponent ($M = 2.65$) than against the mediocre team ($M = 2.39$), $F(1, 1271) = 20.87, p < .001$.

Interviews With Tailgaters

Across two games, we conducted 157 interviews of people who were tailgating before the game. These interviews covered the behavior of 1,888 people, an average of 12.2 people per tailgate site (Median = 8). There was no significant difference by game in terms of the number of people at the tailgate parties. The distribution by group size was as follows: (a) 2 to 4 people—30%, (b) 5 to 10 people—35%, (c) 11 to 20 people—19%, and (d) more than 20 people—17%. Alcohol was visibly present at 27% of the tailgate parties. Groups where alcohol was present ($M = 13.7$) were somewhat, but not significantly, larger than groups where alcohol was not present ($M = 8.9$).

Interviewees reported that on average they came together in groups of about 4 ($M = 4.25$, Median = 3) and they met about 7 people who were already at the tailgate ($M = 7.19$, Median = 2). Of these tailgating fans, the number who said that they would be going to the game averaged 9.3 per tailgate party (Median = 6). Across the interviewed tailgates, 77% of these tailgaters reported that they were going to the game. These data are consistent with our hypothesis, based on Stokols and Shumaker (1981), that as people transition to a group-oriented place, the groups they are with become larger.

Interviews With Fans About to Enter the Stadium. We interviewed fans before four football games: the annual intrasquad game in April and three football games in the fall. Admission to the annual intrasquad game in April is free and attendance is usually high, especially by local families with

children who have the opportunity to get autographs from players before the game starts. For the April 2008 game, the estimated attendance was 73,000. Of the 78 fans we interviewed, the distribution by group size was as follows: (a) alone—5%, (b) two people—36%, (c) three people—15%, (d) four people—14%, (e) five people—13%, and (f) six or more people—17%.

For the three games in the fall, we conducted 354 interviews, which totaled 1,535 people. The average group size was 4.3 (Median = 3, Mode = 2). The distribution by group size was as follows: (a) alone—2%, (b) two people—43%, (c) three people—12%, (d) four people—18%, (e) five people—10%, and (f) six or more people—15%. There was a significant difference by game in terms of the number of people who entered the gate together, $F(3, 350) = 7.47$, $p < .001$. Groups were significantly larger at the game against Penn State's rival ($M = 7.92$) than at the other three games involving mediocre opponents that were not rivals ($M = 4.36$, $M = 2.75$, $M = 4.36$), which did not differ significantly from each other. There was also a significant difference in terms of the gate where the fans entered. Fans who entered through the gate for students were in significantly larger groups ($M = 4.96$) than were fans who entered through a admission gate for nonstudents ($M = 3.64$), $t(322) = 2.37$, $p < .02$. This pattern makes sense, in that the student section is general admission, so that students would need to enter together if they wanted to sit together, whereas in the nonstudent section, seats are assigned by the tickets, and people could meet inside.

Discussion

Our use of two traditional social science methods, observation and surveys, provided support for both of our hypotheses. First, we found, as we expected, that groups going to tailgates at football games and about to enter the football stadium were larger than the groups James (1951) and Bakeman and Beck (1974) observed. Their average group size, about 2.5 people per group, was what we observed in terms of the average number of people per vehicle. Second, we found that the average group size was larger (about four) at the football stadium than when people arrived in vehicles, consistent with Desportes and Lemaine's (1988) argument that environments conducive to social interaction are likely to have larger groups.

A problem with relying on observational and survey methodologies is that they are labor intensive, requiring several hours of researchers' involvement, plus additional costs such as training and transportation. Moreover, the involvement of people in the research can lead to error and nonconscious bias. To address these problems, we have developed an automated procedure

involving computer vision tracking, which can automatically detect pedestrians and estimate whether these individuals are in groups. We used this method in a second study to identify and track small groups.

Study 2

Recent developments in the field of computer vision suggest that computers can be used to analyze video to measure crowd size, composition, and dynamics (Zhan, Monekosso, Remagnino, Velastin, & Xu, 2008). For example, there has been work in vision on detecting a crowd and estimating its size (e.g., Arandjelovic, 2008; Chan, Liang, & Vasconcelos, 2008). Other research has addressed the measurement of the flow of a crowd (e.g., Ali & Shah, 2008; Kratz & Nishino, 2010). Although these techniques are sufficient to generate size estimates and predictive macro models of crowd motion, they do not address the problem of identifying and tracking groups of individuals traveling together.

Our program is a hierarchical clustering algorithm that automatically discovers the small groups in a crowd. A pairwise distance measure that combines proximity and velocity cues is extended to form a robust measure of intergroup closeness (the distance between groups or clusters of people) using a generalized, symmetric Hausdorff distance (Huttenlocher, Klanderma, & Rucklidge, 1993). A Hausdorff distance determines the largest minimum distance between any point in one set and all the points in the other. Thus, two sets are considered “close” only if every point in one set is close to some point in the other. This measure’s robustness means that outliers have little impact on the results. Agglomeration of clusters is further constrained by intragroup tightness, a type of group compactness measure, and the number of groups in the scene is determined automatically by the clustering procedure. We used this method, described in more detail below, as an independent method of identifying small groups near the football stadium.

Aside from whether groups going to a football game might be larger than informal groups in other locations, we wondered how the size of informal groups approaching the stadium would be related to the amount of space the group occupied. The guidelines that city planners use for sidewalks relate to pedestrians walking abreast: for one pedestrian, a sidewalk should be 3 feet; for two pedestrians walking side by side, the sidewalk should be 5’6””; for three pedestrians 7’6””; for four 9’6””; for five 11’6””; and for six people 13’ (Nelessen, 1994). For children walking to school, the recommended width of sidewalks is five to six feet (University of North Carolina Highway Safety Research Center Safe Routes to School Online Guide Development Committee,

n.d.). For a wheelchair, the Americans with Disabilities Act suggests 36" wide sidewalks for a wheelchair, 44" wide sidewalks for a wheelchair and a pedestrian, and 60" wide sidewalks for two wheelchairs (Gibbons, 1999).

We expected that the amount of space would not be linearly related to group size. Knowles (1980) suggested that when interactions are desired, approach tendencies increase with distance. That is, people want to be physically closer to friends than to strangers. And, interactive individuals sit closer together than do independent individuals (Batchelor, & Goethals, 1972). Moreover, we would expect larger groups to use proportionately less space per individual because spatial cohesion serves as a way of preventing invasion from outsiders, particularly those walking in the opposite direction (Knowles, 1972; Knowles & Brickner, 1981; Knowles, Kreuser, Haas, Hyde, & Schuchart, 1976). Our hypothesis was also based on the work of Burgess (1984), who took photographs of groups at shopping malls. He then measured the distances between persons in groups of up to four and found that in larger groups, people tended to be closer to each other. Thus, based on the prior research, we expected an exponential relationship between group size and the area taken up by the group.

Method

We videotaped people entering the football stadium at the two most heavily trafficked gates, the same two gates that were used in Study 1. At one gate, the general admission entrance to the student section, we began videotaping 2 hr prior to kickoff. At the second gate, the busiest gate for ticket holders with assigned seating, we began videotaping 90 min prior to kickoff. We also videotaped pedestrians on the street next to the stadium, using a camera located between the two gates about 100 feet above the street. It is this video that we analyzed in Study 2 using the computer vision program.

The computer vision program first detects pedestrians in each video frame, analyzes and tracks their movements by connecting detections in successive frames, and then identifies small groups based on similar patterns of movement among pedestrians near one another. Each of the three steps is described in detail in the following section.

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Detection of individual people in each frame. The computer system performs motion analysis to create a foreground mask that is a binary labeling of pixels in each video frame as belonging to either a moving foreground object or to the stationary scene background (see Figure 1). The first step of detection is to calibrate the camera viewpoint because the camera was mounted at different places for different games. As we know that pedestrians will be oriented

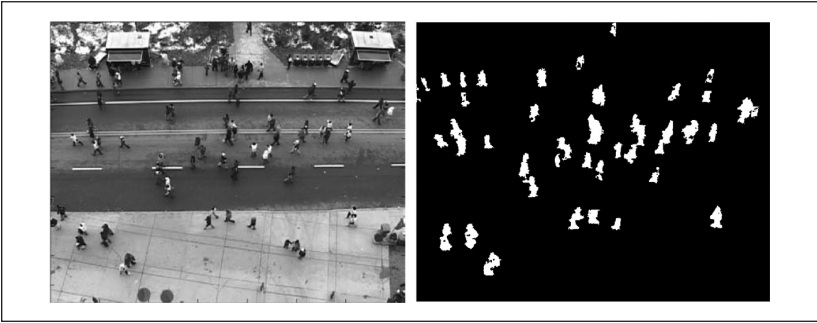


Figure 1. An image frame and the corresponding binary foreground mask
Note: The white regions in the mask represent moving blobs, which are considered to be foreground objects (pedestrians) by our program.

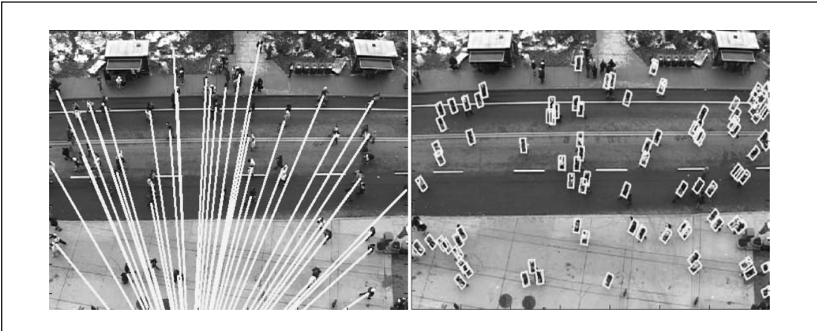


Figure 2. Determination of the vertical vanishing point
Note: The vertical vanishing point is determined automatically by watching people walk through the scene, thus determining the image orientation of upright people at any location in the image. Left—lines connecting blob centroids to the computed vertical vanishing point. Right—estimated mean orientation and scale of pedestrians at different locations in the frame, displayed as overlaid rectangles.

vertically, it suffices to determine the vertical vanishing point of the scene, which completely determines the 2D image orientation of a vertical object at any image location. Conversely, we can estimate the vertical vanishing point by intersecting the measured major axes of elliptical blobs extracted from foreground masks of walking people. Because the automatically generated foreground masks are noisy, a robust estimation technique is required. We used Random Sample Consensus (Fischler & Bolles, 1981) to find the intersection point voted for by the most axes. As demonstrated in Figure 2, the computed vanishing point correctly captures the change in image orientation of

people at different parts of this scene. The orientation of a blob centered at any pixel in the image can now be computed and stored in a lookup table representing the mean of a normal distribution on orientation. Similar estimation methods were used to create lookup tables to store the average height and width of a person blob viewed at each location in the image.

Detection of people in each frame is then posed as the problem of finding a rectangular covering that best explains the foreground mask. That is, the program estimates a set of rectangles that cover as many foreground pixels as possible while leaving uncovered as many background pixels as possible, based on the expected size, shape, and orientation of people at different locations in the image. The combinatorial solution space of rectangular coverings, which we refer as crowd configurations, is efficiently explored by an iterative hypothesis testing procedure called reversible jump Markov Chain Monte Carlo (RJCMCMC).

To generate configuration hypotheses, we use three types of RJCMCMC search proposals: birth, death, and update. In a birth proposal, a rectangle is added to the current configuration by sampling an image location according to the foreground mask. The rectangle's width and height are sampled from normal distributions indexed by that image location, centered at values stored in the lookup tables from the camera calibration procedure. A death proposal chooses one rectangle randomly from the current set of rectangles and removes it from the configuration. An update proposal generates a new configuration hypothesis by making a local adjustment to an existing detection. Specifically, a rectangle is randomly chosen from the current configuration and either its location or size is modified. Location update is performed as a random walk around the current object center, whereas modification of size is done by sampling from the corresponding normal distributions on width and height associated with the current location.

RJCMCMC's exploration of the space of configurations is guided by a likelihood function that measures how well the current configuration hypothesis explains the foreground mask. The likelihood function also contains an overlap penalty term to avoid excessive numbers of overlapping rectangles in areas where several people overlap. The final output of the program is a set of rectangles representing the bounding boxes of people in each frame.

Connecting detections into trajectories. Detected rectangles are linked together across multiple frames of video to trace out the path of each pedestrian's trajectory. Detected rectangles in a given frame are matched to a current list of evolving trajectories by solving a linear assignment problem. The affinity score for any given pairing between a rectangle in the current frame and the set of trajectories from the previous frame is based on spatial overlap between the

observed rectangle and the hypothetical rectangle predicted by the trajectory. The resulting assignment problem is solved in polynomial time using the Hungarian algorithm, which is a combinatorial optimization algorithm that efficiently solves the linear assignment problem of determining the best way to pair up N elements in one set with M elements in the other, given an associated cost of each pairing (Munkres, 1957). A motion model is used to extend an existing trajectory when it does not have any matched detection. A trajectory terminates when it cannot be matched for several frames. Over time, trajectories are automatically initiated and terminated as people enter or leave the scene.

Analyzing trajectories for detecting small groups. Small groups of people traveling together are identified by hierarchical clustering on trajectory features that are based on a group's "entitativity" (Campbell, 1958), defined in terms of criteria from Gestalt psychology: common fate (same or interrelated outcomes), similarity (in appearance or behaviors), proximity, and pregnance (patterning). More specifically, beginning with clusters consisting of single individuals, we gradually group people exhibiting collective locomotion by agglomerative hierarchical clustering. Each merging step is governed by intergroup closeness and intragroup tightness (compactness). Group membership is assumed to be transitive.

The agglomerative clustering procedure is inspired by McPhail and Wohlstein (1982), who considered two people to be members of a group if they are within 7 feet of each other and not separated by another individual, have the same speed to within 0.5 feet per second, and are traveling in the same direction to within 3 degrees. A group-expand procedure is also defined to test whether a new individual should be added to an existing group. To our knowledge, the McPhail and Wohlstein criterion is the only objective measure that has been put forth in the social science literature to determine which people are traveling together through the scene.

We extended McPhail and Wohlstein's (1982) frame-based grouping measures (such as 7 feet apart) to an aggregated pairwise distance measure between people's trajectories over time, which favors grouping people who walk close to each other with similar velocities for a long period of time. The aggregated measure also increases robustness to tracking errors, so that we are able to estimate stable groups from noisy, automatically extracted trajectories. Instead of considering the speed and direction differences separately, as McPhail and Wohlstein did, we computed the velocity difference, which is a distance in a two-dimensional space, considering speed and direction simultaneously, because it is more robust against noise in the estimated trajectories. Moreover, two people engaged in a conversation will have small speed if they are standing still, but can possibly have large random oscillations in orientation. The

velocity difference comparison is still stable in this case, and satisfies our expectation that people with coordinated behaviors are likely to be grouped together.

In previous work (Ge, Collins, & Ruback, 2009), we have validated our algorithm for detecting pedestrians and determining whether they are traveling alone or in a group. When tested on two indoor sequences of 9 and 15 min in length, for which human coders provided consensus ground truth groupings, our method had a raw agreement rate of 88% and 89%, respectively, and a Cohen's Kappa coefficient of agreement of .74 and .75. A subsequent evaluation (Ge, Collins, & Ruback, 2010) on 1 hr of video taken in a student union with pedestrian crowd densities similar to those observed in the present analyses compared rates of agreement of the computer algorithm, two real-time observers, and human coders labeling the video offline with no time pressure, with responses to interviews in which pedestrians were asked whether they were walking alone or with others. In determining whether a pedestrian was alone or in a group, the computer algorithm scored better than the two real-time human observers. Specifically, the Cohen's Kappa coefficients of agreement with the responses to the interviewers (the ground truth) were .29 for a real-time observer on the ground, .60 for a real-time observer viewing from an elevated position, .74 for the computer algorithm, and an average score of .86 for the offline human coders.

Results

Computer Vision Tracking. The grouping algorithm was run on four different sequences at four different games, each of 9000 frames, about the length of a 5-min clip. Sample frames from each of the four sequences are shown in Figure 3. Each sequence was recorded using a Sony DCR VX2000 digital video camcorder mounted on the upper observation deck of the stadium, approximately 80 feet above the ground. Groups were automatically detected and sampled as they traveled through the regions of interest denoted on each frame. On average, a group was sampled about 40 times. Thus, the number of unique groups is less than the number that is generated by the computer algorithm. In addition to identifying the groups of individuals, we also computed the radius (in pixels) of a circle comprising the individuals in the group.

On average, across the four games, about 24% of the individuals who were walking on the street by the stadium roughly 2 hr before game time were alone (range = 0.20-0.27). In terms of just the three quarters of the individuals who were in groups, the average group size was 3.89 across the four games that were video recorded (range = 3.75-4.05). A detailed breakdown of percentages

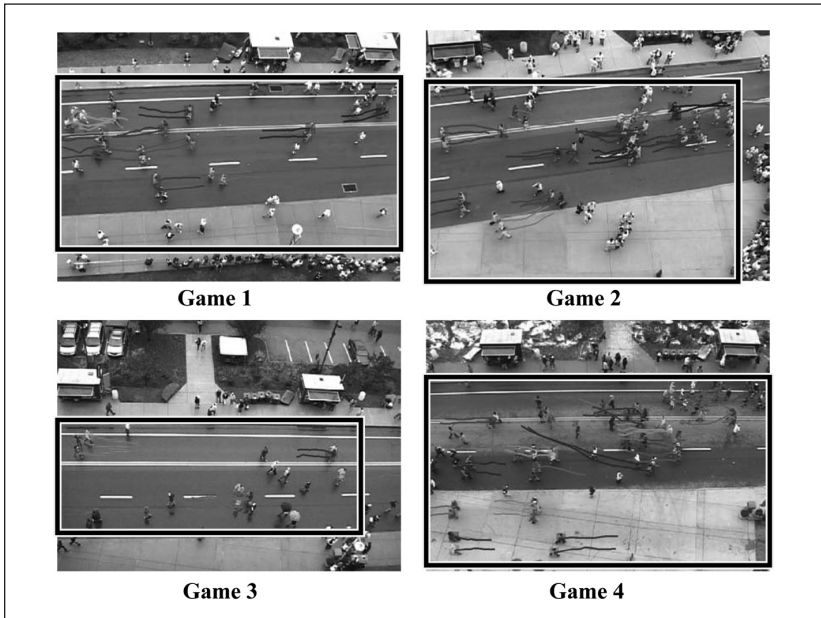


Figure 3. Sample frames with overlaid regions of interest, from the four observed games

Table 1. Percentage Composition of Groups by Numbers of Members

Game observed	Group size					
	1 (%)	2 (%)	3 (%)	4 (%)	5 (%)	6 or more (%)
Game 1	20	27	16	16	8	12
Game 2	27	27	16	16	7	8
Game 3	24	24	19	11	8	14
Game 4	24	32	19	15	4	7

of individuals estimated to be traveling alone versus traveling in groups of varying sizes is shown in Table 1.

In comparison with James (1951) and Bakeman and Beck (1974), the percentage of individuals who were alone was about the same and the size of the groups excluding solitary individuals was as much as 61% larger. Specifically, Bakeman and Beck reported that the percentage of people who were alone ranged from 11% (at a swimming pool) to 50% (at the library). Averaged

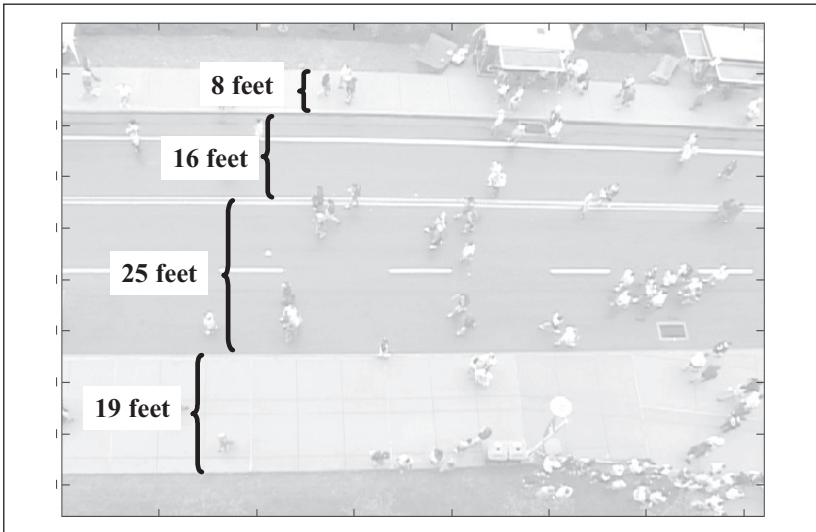


Figure 4. Dimensions of sidewalks and roadway where pedestrians were observed

across five locations, the average percentage of individuals who were alone was about 25%.

Over the four games, the computer algorithm identified 89,768 groups of two or more individuals who were in the region of interest captured by the video recording, which is roughly 2,240 unique groups. To compute the width of a group, we first found the largest distance, in pixels, between any person in the group and the center of mass of the group, doubled this distance measure, and took the average of this measure over the sequence of frames in which the group was tracked. To convert these pixel distances to a measure of ground distance, we determined a scale factor for converting pixel units in the image to inches on the ground based on multiple scene measurements of ground regions shown in the frame (e.g., in Figures 1-3, the width of the street and the size of the squares in the sidewalk). A sketch of some of the relevant distances for sidewalk and roadway widths is shown in Figure 4. Because the camera views in the four games were not exactly the same, this scale factor varied slightly across games (Game 1: 1.98, Game 2: 1.82, Game 3: 2.10, and Game 4: 2.11). We also computed the area of the smallest circle encompassing the group by squaring half the width (essentially the radius of the circle) and then multiplying by pi. As the two measures yielded similar findings, we report only the width measure because it is simpler. Moreover, as noted earlier, standards for sidewalks are given in terms of width.

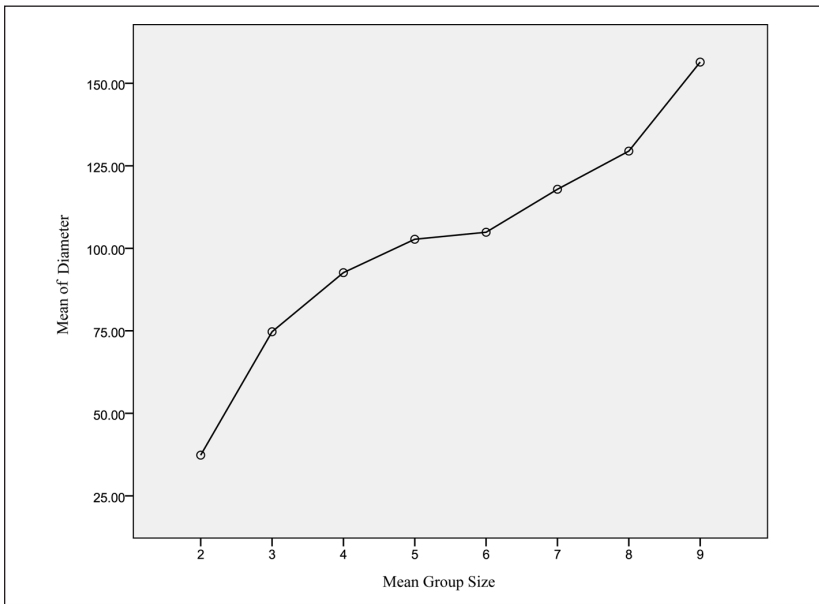


Figure 5. Plot of mean widths by group size

Because there were small numbers of groups of size eight and nine at some of the games, we analyzed the measure of the width of groups using two separate one-way analyses of variance, one for game and one for group size. There was a significant effect for game, $F(3, 89764) = 476.23, p < .001$. Groups took up the most space in Game 2 (Illinois; $M = 69.90$ in.), next most in Game 1 (Oregon State; $M = 58.52$ in.), third most in Game 4 (Michigan State; $M = 57.44$ in.), and least in Game 3 (Indiana; $M = 47.19$ in.). All differences were significant, based on a post hoc Newman–Keuls test ($p < .05$). Although we have too few data points to conduct an analysis, it is interesting to note that groups took up more space when the weather was warmer (see Table 1).

There was also a significant effect for group size, $F(7, 89760) = 4579.20, p < .001$. Not surprisingly, larger groups had larger widths: two–37.34 in., three–74.72 in., four–92.62 in., five–102.74 in., six–104.87 in., seven–117.89 in., eight–129.45 in., and nine–156.41 in. All differences except between group sizes 5 and 6 were significant. A power function ($y = x^{1.272}$) best explained the pattern of group widths, $F(1, 89766) = 74179.76, p < .001, R^2 = .452$ (see Figure 5).

Discussion

One purpose of the second study was to develop a computer procedure that could identify individuals and small groups. Our technique, which has been validated in other studies, proved to be useful in this context as well. This technique could be used in other situations investigated by environmental psychologists, such as monitoring park usage or evaluating the effects of changes in the environment (e.g., bike paths, bus stops) on pedestrian flow. Such uses would be similar to the work of Whyte (1988), except that our procedure would not require the huge investment in human coders who would have to count individuals. In our work in validating the computer algorithm, human coders took about 1.5 hr to code 15 min of video.

A second purpose of this study was to look at the amount of space that groups occupied as they walked by the stadium. Our expectation was there would be a positive gradient for group cohesion as a function of group size, such that the amount of space per person would be less in larger groups than in smaller groups. Our finding that the amount of space per person decreases with larger group sizes is consistent with this hypothesis and with Latane's (1981) social impact theory, which suggests that the marginal impact of additional individuals is less than that of the initial individuals. Moreover, this finding is consistent with research on territoriality showing that the amount of space claimed on a beach was about the same whether the group was one, two, three, four, or five people (Edney & Jordan-Edney, 1974). Work by Edney and Grundmann (1979), showing that group space boundaries increased when the group members were strangers but not when the group members were friends, suggests that our finding is generalizable only to groups, like ours, that involve acquaintances traveling together to a goal (Knowles, 1989). In addition, this finding is consistent with the idea that spatial cohesion serves as a way of preventing invasion from outsiders, especially from those who are walking in the opposite direction (Knowles, 1972). This notion of group protection probably explains the "banded structure" of pedestrian flow in crowds (Yamori, 1998).

General Discussion

The notion that places can be characterized in terms of whether they are primarily occupied by individuals, aggregates, and groups (Stokols & Shumaker, 1981) proved helpful in understanding the transitions people make as they go to a football game. Our suggestion that there is a fourth type of place, one occupied by groups nested within aggregates, proved helpful for understanding attendees at football games. Thinking about crowds at football games as

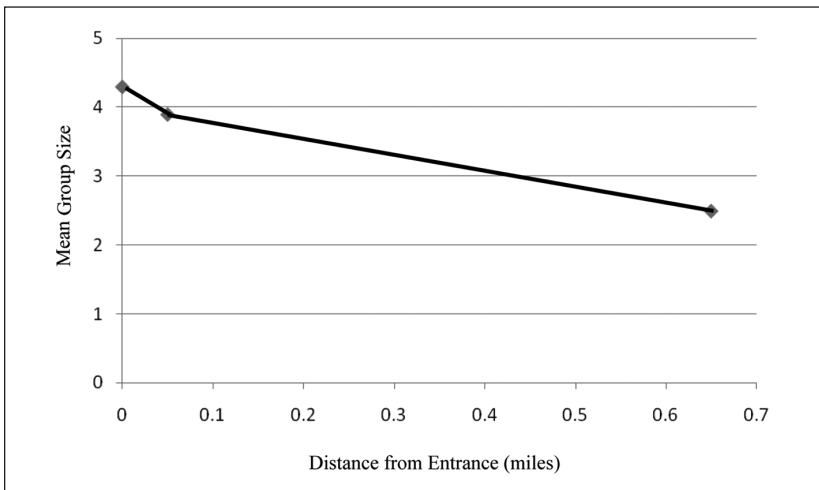


Figure 6. Plot of group size as a function of distance from the stadium entrance

consisting of small groups, rather than individuals, makes sense because sporting events are highly social and almost all people go to games with relatives or friends. This idea has both theoretical and practical implications. After summarizing our findings in the two studies, we discuss the results in terms of these implications.

Summary of Results

As others have reported, we found that most people go to football games in small groups. However, by using a multimethod approach, we have evidence that the size of those informal groups likely varies across time and across location. From our indirect evidence, it appears that people initially come in small groups (about 2.5 per car at a distance of 0.65 miles from the stadium), that they may join others on the way to the stadium (small groups walking by the stadium that averaged about four at a distance of about 0.05 miles from the entrance), and that they likely enter the stadium in groups of just more than size four, a group size that research suggests people like (Hackman & Vidmar, 1970).

This pattern, which resembles an approach gradient, is presented in Figure 6. An approach gradient refers to the “pulling power” of an incentive as a function of the distance between the organism and the incentive (Underwood, 1949). Knowingly going to a football game with more than 100,000 people is a situation where the avoidance gradient (the “repelling power” of the incentive as

a function of distance) is likely zero or close to zero. Thus, for football games, the questions regarding group size and group space concern whether the approach gradient near the goal is positively accelerating or negatively accelerating, that is, whether people are more motivated or less motivated the closer they are to the goal. Knowles (1980, 1989) suggested that with goals that can be consumed only when the goal is reached (e.g., food), the approach gradient increases with nearness to the goal. For example, rats that have learned a maze run faster the nearer they get to the goal, a pattern described by Hull (1932, 1934) as a positively accelerated gradient. In contrast, there are other goals, like being warmed by a wood stove, by which some satisfaction can be gained being closer to the goal, and that actually reaching the goal (i.e., touching the stove) would be uncomfortable. In such a case, the approach gradient decreases with nearness to the goal.

Knowles (1980, 1989) suggested that many affiliative situations are analogous to a stove, in that the presence of a physically distant friend draws a person closer to that friend, until the person stops to respect intimate personal space norms. Thus, being closer to another person can bring satisfaction up to a point, meaning that the approach gradient would be negative beyond that point. We believe that going to a football game more closely resembles food in a maze than warmth from a stove, as shown by the pattern in Figure 6. That is, going to a football game means the more the merrier, up to a point, such that group size increases as proximity increases.

Contrary to the conclusion of James (1951), our research suggests that group size varies by activity, consistent with Desportes and Lemaine's (1988) notion that the size of small groups will be larger in inherently social situations, like attending a football game. Our research adds to this literature by suggesting that group size varies by proximity to the event. Future research might continue this investigation by examining the size of small groups moving away from a football game. For example, the possibility that groups might get smaller after the event is over is suggested by Aveni's (1977) finding that groups of Ohio State fans engaged in a celebratory riot after a football game averaged 2.37, with 26% of the individuals being alone, 40% in dyads, and 34% being in groups of three or more.

Theoretical Implications

Our notion that there are places that can be characterized as being primarily composed of groups within aggregates needs to be elaborated in future work. Aside from audience environments, like football games, there are also other *groups nested within aggregate-oriented* locations where most people are in

small groups. For example, most people at the beach are in groups of two or more (Edney & Jordan-Edney, 1974), and there is some evidence that groups at the beach are slightly larger in Europe than in the United States (Smith, 1981). Similarly, at amusement parks about 90% of patrons are in groups of two or larger (Burgess, 1984). In his observations of restaurant visitors, Cohen (1971) found that more than 99% of the patrons were in groups, and the average group was composed of about four people.

This last example of restaurants also illustrates the design implications of the *groups nested within aggregate-oriented* locations idea. Although most restaurant patrons dine in groups, some may arrive as individuals. For them, it is important to accommodate them until their group arrives. A sociofugally designed bar can be used by a single individual waiting for a dinner companion, whereas the actual dinner occurs in a sociopetally designed setting that permits groups to sit around tables.

Design and Policy Implications

The size of informal groups coming to the game has implications for traffic and traffic control. Two thirds of the cars we observed had only one or two people in them. Aside from the environmental costs of having such small numbers of people coming in each car, there is also the fact that even though Penn State and other universities make money by parking, there is a limited number of parking spaces available. Thus, Penn State, with about 28,000 parking spaces still needs to use these spaces more efficiently. One way to do so would be to raise parking rates (which Penn State did the year following our observations) to encourage more people to ride together.

A second implication of this research on informal groups concerns people waiting for their groups. At venues like football stadiums, this waiting can occur at two points: (a) outside the gate, roughly 100 feet from the entrance and (b) after people have entered the stadium. Although people enter the stadium through a turnstile one at a time, once they are through, they wait for the entire group to get through before proceeding. In both cases, there are potential bottlenecks as these small groups block the flow of traffic. That is, football stadiums are designed for individual entry when the reality is that people want to enter as groups. The problem with trying to limit these effects of small groups through environmental constraints is that it is likely to make people uncomfortable. In college residential settings, for example, architectural manipulations that inhibit group development lead to negative affect and subjective feelings of crowding (Baum & Valins, 1977). It may be that limits on groups in settings like football stadiums may similarly produce negative effect. Thus,

it may be useful for designers of such public places to include spaces for groups to reconnect, out of the flow of main traffic but with high visibility so that group members could see one another.

A third implication relates to the width of sidewalks. Our findings regarding the width of groups suggests that, at least at events like football games, the standards for the width of sidewalks are adequate. As compared with the national standards (Nelessen, 1994), our data showed smaller widths: two people—37" (ours) versus 66" (Nelessen, 1994), three people—75" (ours) versus 78" (Nelessen, 1994), four people—93" (ours) versus 114" (Nelessen, 1994). However, because the national standards must accommodate strangers walking in opposite directions, whereas our data refer to nonstrangers walking in the same direction, the extra distance makes sense in terms of a personal space buffer. Based on our data, the 8-foot (96") sidewalks around the Penn State football stadium are smaller than are needed for groups larger than three people, a finding that supports the need for closing streets prior to the game.

A final implication concerns evacuation from the stadium. Research indicates that people generally leave from the same entrances that they entered and that they usually leave with the people with whom they arrived (Cornwell, 2003). For instance, at basketball games, McPhail (2009) found that 94% of those who came with others left with those same individuals. These two factors can be problematic in emergencies like fires, as people might be waiting longer than they should before leaving to be with family and friends. Trying to leave through the same exit that they entered can be problematic if the exit is blocked.

Conclusion

How pedestrians negotiate the environment depends on both the configuration of the built environment and the nature of their social environment. In particular, our research suggests that environmental design needs to take into account the fact that in social situations, people are likely to be in informal social groups and that the size of these informal groups varies as a function of time and distance from the focal event. In addition, our computer programs that can automatically detect the small group structure of a crowd are likely to have important practical applications for measuring crowds and observing their behavior, and to have potential applications for providing real-time situation awareness during emergencies.

Acknowledgment

The authors thank Clark McPhail and Barbara Brown for their helpful comments.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This research was supported by the National Science Foundation's Human and Social Dynamics Program, Grant No. 0729363.

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