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The role of group membership in active road user attention across different age groups

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ABSTRACT

This study aimed to explore how travelling in different group constellations (alone, with known or with unknown people) affects children's and adults' visual behaviour in traffic when cycling or walking. Additionally, mobile phone/earphone usage was considered, too. A follow-along study (n = 43) and an observation study (n = 898) were conducted to observe travellers in a natural setting. In the follow-along study, eye-tracking was used to investigate children's glances behaviour on their way to school and how well they manage to fulfil attentional requirements. The observational study focused on children's and adults' visual behaviour at several intersections. The main result of the study was that group membership appears to have a large influence on individuals' visual sampling strategy. In formal groups reliance on each other was found to be stronger than in informal groups. People with a natural responsibility in the group, such as parents or other adults, take a more active role in visual monitoring. Reliance on others is found to a greater extent among pedestrians than cyclists. Regarding communication devices, the use of earphones did not significantly affect glance behaviour towards relevant areas. In naturalistic situations, group constellation, age and phone/earphone usage are interlinked, which needs to be considered when studying these factors.

1. Introduction

Age and its effect on attention and safe behaviour in traffic is a well discussed topic in road safety research (Ayllón, Moyano, Aibar-Solana, Salamanca, & Bañares, 2021; Barton & Schwebel, 2007; Faulkner, Richichi, Buliung, Fusco, & Moola, 2010; Johansson, 2006). The research field ranges from studies using virtual reality where children travel with a virtual "risky peer" to determine the influence of risky behavioural norms (Babu et al., 2011), to using eye-tracking to explore adults' and children's visual field-of-view in various crossing scenarios (Biassoni, Bina, Confalonieri, & Ciceri, 2018). Self-assessment questionnaires on children's risk-taking behaviour in traffic have also been administered (Chinn, Elliott, Sentinella, & Williams, 2004; Meir, Parmet, & Oron-Gilad, 2013; Morrongiello, Seasons, McAuley, & Koutsoulianos, 2019).

However, to our knowledge, only few studies have assessed age and its effect on children's visual behaviour in different traffic situations when walking and cycling. Using photographs and video presentations, Whitebread and Neilson (2000) investigated the glance behaviour of children aged 4–11 and how well they detected potentially dangerous traffic situations. They found that children reaching age 10–11 were most likely to perform well on the tasks, but assumed that younger children could reach this competence, too, if more time was spent on teaching them traffic skills. Zeedyk, Wallace, and Spry (2002) studied 5–6-year-olds' visual behaviour in

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traffic by observing them crossing roads at a T-junction with a confederate moving car, as well as crossing between parked cars, as a part of a treasure trail organised by the school. The children's behaviour was described as "generally poor" (p. 47), including their glance behaviour, where around 60 % did not look at the moving confederate car. Also, the children commonly did not look first into the direction where approaching traffic was closer. Comparing the effect of children's age in different staged crossing conditions, Barton and Schwebel (2007) found that children aged 5–6 were significantly less attentive and showed more "risky" behaviour than 7–8-year-olds. Notably, adult behaviour often fell between the two groups and did not significantly differ from either. In a study conducted in a laboratory setting, Tapiro, Oron-Gilad, and Parmet (2020) found that adults missed more crossing opportunities than children (9–10 and 11–13 years old), and that children's visual gaze dispersion differed from that of adults in highly cluttered environments. None of the studies mentioned above were conducted in a natural setting without pre-defined tasks or experimental conditions, resulting in a limited ecological validity of the studies.

de Geus, Vlakveld, and Twisk (2020) conducted one of the few studies on visual behaviour in young cyclists. They compared adolescent and adult cyclists for the effect of distraction on hazard perception skills. The results showed a difference in hazard identification where adults more frequently assessed a situation as being hazardous, but no age differences for visual search and hazard localisation were shown. We are not aware of any research on visual information sampling for younger children using bicycles as mode of transport, except for one study conducted in a park away from motorised traffic (van Paridon, Leivers, Robertson, & Timmis, 2019). Here, children were found to adapt their glance behaviour to the circumstances.

To sum up, age seems to play a role in children's behaviour and information sampling, but few real-world studies in naturalistic situations have been conducted to validate this. To address this, we conducted a field study in an environment context that was familiar to the participants. They walked or cycled in the same way as usual, including potential company. The aim was to investigate whether age and mode of transport affected how children of different ages responded to attentional requirements in traffic (Kircher & Ahlstrom, 2017). First results showed that the presence of others influenced information sampling, and that this was confounded with the children's age (Odéen, 2022). Noticing this, we extended the scope of the study and included the group aspect more systematically with the goal not to sacrifice ecological validity. We included the hypothesis that it might be group behaviour rather than age which affects information sampling in traffic.

There is some evidence that being in a group influences the behaviour of individuals. Pedestrians who do not know each other but end up in the same cluster when they cross a road rely on others in the group to pay attention to traffic (Chinn et al., 2004; Simmons, Caird, Ta, Sterzer, & Hagel, 2020). Chinn et al. (2004) found that the number of safety checks performed by children crossing a road in a group varies, depending on whether they walked at the front, in the middle, or last. The children walking at the front checked the most times and those in the middle checked the fewest times. Children who walked with a younger friend or sibling were shown to take responsibility and look out for the younger child. Lanzer and Baumann (2020) observed that pedestrians aged 11–20 gaze towards traffic more often than older pedestrians. The young group was rarely observed walking alone. Still, similar to Chinn et al. (2004), Lanzer and Baumann (2020) showed that with increasing group size, the odds of gazing towards traffic decreased compared to pedestrians walking alone of whom almost all gazed towards traffic. When walking in pairs, at least one group member gazed towards traffic, and in groups of three to five there was at least one group member who did not glance at traffic. Pešić, Antić, Glavić, and Milenković (2016) showed that for every extra pedestrian added to a group, the probability not to check for traffic before or during crossing a road increased by 3.2 times. Similar behaviour has also been observed by Harrell (1991) and Aghabayk, Esmailpour, Jafari, and Shiwakoti (2021) who showed that pedestrians paid less attention to traffic if they crossed the road when more people were crossing at the same time.

Chinn et al. (2004) believe that this behaviour can be linked to the group members "just following the herd", while other authors believe that this behaviour indicates that diffusion of responsibility has taken place (Harrell, 1991; Lanzer & Baumann, 2020). As a part of this, trust could be a reason as to why the task of checking for traffic is given to other group members. Rosenbloom, Ben-Eliyahu, and Nemrodov (2008) and Deluka-Tibljaš, Šurdonja, Otković, and Campisi (2022) showed that children accompanied by parents checked for traffic to a lower extent compared to children of similar age walking alone. This could be explained by the children trusting their parents in taking the lead when travelling together. Similarly, in a naturalistic observational study by Wang, Tan, Schwebel, Shi, and Miao (2018) children were observed outside their school when crossing roads and walking on pavements. Younger children performed less rule conforming than older pupils, but as they either were accompanied by their parents or traffic police was present, it is possible that the children felt they were acting in a safe environment, because at least one adult was monitoring the traffic situation.

Similar to the findings by Chinn et al. (2004) concerning pedestrians watching out for each other, such strategies have also been seen for cyclists in a peloton. As shown in the review by Heeremans, Rubie, King, and Oviedo-Trespalacios (2022) cyclists in the front of the group take responsibility to watch out for obstacles and adjust the speed of the group, while cyclists in the back watch out for cars catching up, and indicate when it is safe to change lanes. In such a formal group, these strategies are defined in advance and jointly agreed upon, while the group behaviour described for pedestrians tends to happen spontaneously. A study of elderly couples showed that when driving, the passenger actively helps the driver with information sampling (Mårdh, 2016). No studies have been found investigating this type of shared attention for formal or informal groups of people who use the bicycle in everyday life.

To summarise, regardless of whether pedestrians know each other from before or not, they tend to adapt their attentional behaviour towards traffic when in a formal or an informal group. Cyclists in pelotons also show group specific behaviour. In addition, car drivers have been shown to change their driving behaviour when approaching a group of pedestrians about to cross the road (Lanzer & Baumann, 2020; Sucha, Dostal, & Risser, 2017). Car drivers give way to a greater extent to pedestrians who intend to cross in groups of three or more at an unsignalized crossing, and they give way more often to adults than children (Ābele, Haustein, & Møller, 2018). This could explain why young people feel safer when they walk in a group or with adults than when walking alone (Chinn et al., 2004). Cyclists have also expressed that they prefer to cycle in groups as they perceive it to be safer (Heeremans et al., 2022; López, Pérez-

Zuriaga, Moll, & García, 2020).

Most research on behaviour in groups is directed at changes on the individual level, with some studies touching upon the potential benefits of collective attention, like when parents or older children take care of younger ones, or in a cycling peloton situation. To unconfound age and group membership and to obtain information sampling data from all group members, we added an observation study to the follow-along study where only one person at a time was observed. The observation study was conducted in a natural context, where people crossing various intersections either by bike or on foot were observed. As mentioned, plenty of studies have been conducted on children's risk-taking behaviours in traffic, where risk-taking is often mixed with attention (e.g., Babu et al., 2010; Chinn et al., 2004; Meir et al., 2013; Morrongiello et al., 2019). However, there is a step between attention and risk-taking behaviour as the behaviour can be modulated by intention or intervention of others. Thus, taking risks in traffic is not necessarily caused by inattention. Therefore, the present study focuses solely on visual information sampling – looking around to take in relevant information – and how this is affected by age, mode of transport, and the type of company.

An observation study will inevitably imply that some of the observed people use mobile communication devices like telephones and earphones. A body of previous research discusses the role of active road users' usage of mobile devices in traffic. A *meta*-analysis indicates that hand-held phone usage is associated with a decreased probability to look left and right before or while crossing a street, while earphone usage did not have that effect (Simmons et al., 2020). Also, as shown in observational studies, texting pedestrians have been observed as less likely to look around before entering a crosswalk than pedestrians not using a phone (Horberry, Osborne, & Young, 2019; Thompson, Rivara, Ayyagari, & Ebel, 2013). People engaged in a phone conversation were least likely to look around or exhibit cautious behaviour (Aghabayk et al., 2021; Gillette, Fitzpatrick, Chrysler, & Avelar, 2016; Gitelman, Levi, Carmel, Korchatov, & Hakkert, 2019). There is no direct evidence, though, that this has any implications for pedestrian safety, and there are indications that compensation strategies are employed. Horberry et al. (2019) found that pedestrians who used their phones were less likely to cross the road on red than pedestrians not using phones. Ralph and Girardeau (2020) discuss the importance of not jumping to unjustified conclusions about possible risks only based on the observation that pedestrians use mobile phones. In the present study the main purpose of registering the use of communication devices was to set it in relation to the other investigated factors in a real-world setting.

The original research question for the study, to investigate how age influences children's capability of meeting the attentional demands put on children in their familiar environment, was expanded to also include how this is modified by being in a group. This also included an evaluation of the performance of the group as a whole compared to individuals in the group. With this shift in research focus, the character of the study became more explorative.

2. Method

Both the follow-along study and the observation study were approved by the Swedish Ethical Review Authority (Dnr 2020–05663). The difference between the two studies was that in the follow-along study, the children were aware of being observed as they used eye-tracking devices for capturing their visual information. Also, one of the researchers followed them on their way to school and recorded them and the surrounding traffic. In the observation study, a researcher discreetly observed and recorded all people crossing intersections without their knowledge of being observed.

In the following we use the term "(visual) information sampling" for looking around to collect information. We differentiate that from "being attentive", which requires having sampled all relevant information with correct timing (Kircher & Ahlstrom, 2017). Active road users collect information in more ways than via foveal glances, including auditory and haptic signals (Erdei, Steinmann, &

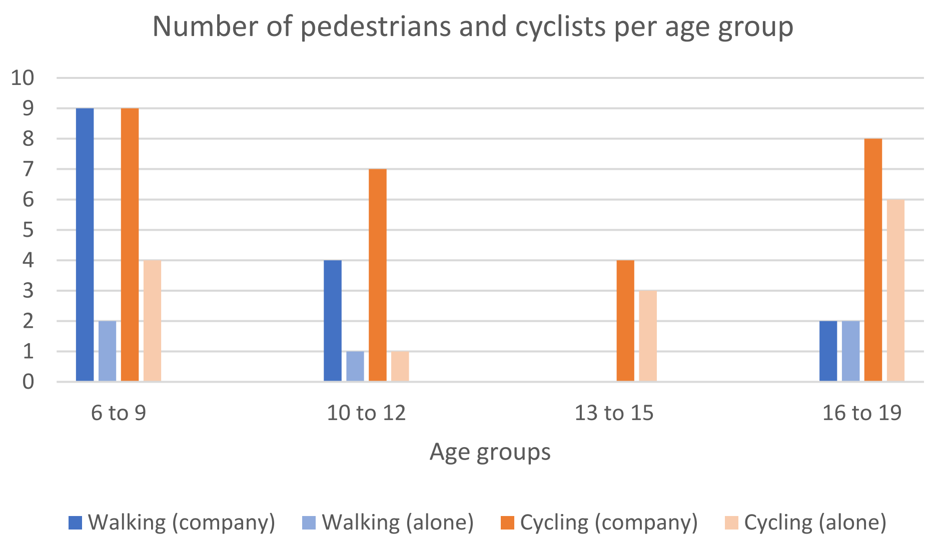


Fig. 1. Number of pedestrians and cyclists per age group traveling alone or with company.

Hagemeister, 2020). Peripheral vision is an important source of information in traffic for drivers, cyclists, and pedestrians (Belden et al., 2019; Wolfe, Dobres, Rosenholtz, & Reimer, 2017; Wolfe, Sawyer, & Rosenholtz, 2020). The use of eye trackers does not provide direct access to the peripheral visual information acquired, but ignoring it also creates validity issues, which necessitates the employment of a pragmatic solution.

2.1. Follow-along study

The follow-along study was conducted during the spring 2021. The original plan was to collect data for students from four different age groups (6–9, 10–12, 13–15, 16–19) walking or cycling to school. It proved to be difficult to recruit students in the older age groups, especially in the walking category, making the distribution of participants unequal across the age groups (see Fig. 1). This fact in combination with the emerging finding of the impact of group constellation on visual information sampling led to a decision to cover this age category in an observation study instead. Additionally, the two younger (6–9, 10–12) and the two older groups (13–15, 16–19) were later collapsed into young (up to 12 years) and teenagers (13 and above).

Participants were recruited via an online questionnaire advertised on Facebook and via flyers distributed around schools in Linköping, Sweden. Inclusion criteria were walking or cycling to school at least once a week, willingness to participate under the circumstances described, and informed (parental) consent. No compensation was offered.

The participants or their parents, depending on age, were contacted by phone prior to the study for detailed information. On the scheduled date, an experimenter arrived by bicycle at the participant's address ten minutes before the student would leave for school. The informed consent form was signed when all questions had been answered satisfactorily. The participant was equipped with a head-mounted eye tracker (Pupil Labs Invisible, Berlin, Germany). For cycling participants, an action camera (Sony FDR-X3000, Tokyo, Japan) was mounted on the handlebars pointing forward. The experimenter's bicycle was equipped with a camera of the same type. The participant then went to school as usual, in the typical company and along the typical route, with the instruction not to care about the experimenter. The experimenter followed at a distance of several metres, either cycling or walking the bicycle. Upon arrival at the school, the experimenter took care of the equipment and asked the student whether he or she wanted to comment upon anything regarding the trip or being part of the study. This was rarely the case. After saying goodbye, and if agreed beforehand, the experimenter got in touch with the parents to confirm that everything had gone well.

2.2. Data reduction in the follow-along study

Data reduction was done manually using the Observer XT16 (Noldus, Wageningen, NL). All recordings from a participant were synced. For each school way relevant areas for visual information sampling were identified together with the "zones" within which the sampling of information ideally should take place. This was done based on the theory of Minimum Required Attention (Kircher & Ahlstrom, 2017), which considers the layout of the infrastructure, regulations that apply, the mode of transportation, and the intended course of the road user. For example, upon approaching an intersection with a yield sign, a cyclist turning right would need to check for cross traffic from the left, but not for cross-traffic from the right, as their trajectories would not cross. This visual checking would have to occur within a critical window (the "zone") depending on the situational circumstances.

For each identified zone of visual information sampling, eye tracking and behavioural data were used to note whether the participant had sampled the target area (i) foveally, (ii) presumably peripherally, (iii) presumably not or (iv) highly likely not, as described in Table 1. This corresponds to the "purpose-based" data coding approach as described in Ahlström, Kircher, Nyström, and Wolfe (2021), as it is assessed whether a certain area is monitored for approaching traffic. Focus is not on the number or duration of glances to each target area, but whether the area was glanced at or not within the critical window.

2.3. Observation study

During spring 2022 observations were conducted at 14 different intersections on 18 occasions in Linköping, Sweden. To this end a researcher used a bicycle equipped with two inconspicuous action cameras filming the intersection from an angle that afforded a view of one leg and the side road(s). One camera was set to wide angle to provide information about potential surrounding traffic, one was set to a focal length that allowed a judgement of whether the pedestrians and cyclists on the observed road leg visually checked the side

Table 1
Coding description of visual behaviour. The upper two categories were defined as "sampled", the lower two as "not sampled".

Visual behaviour	description
foveal glance	at least one foveal glance to the target area in question was noted
presumably peripheral sampling	the target area lay within around 30 degrees of the foveated spot, possibly but not necessarily combined with behavioural indications that information that was present was noted (e. g. slowing down in the presence of traffic), or a glance on the trajectory towards a relevant target area that stops short of actually falling into the area (e. g. a cyclist looking over the shoulder upon approaching an intersection, clearly with the intention to check for motorised traffic turning right)
presumably not sampled	the target area lay outside of around 30 degrees of the foveated spot, no behavioural indication, however, peripheral sampling cannot be strictly excluded
highly likely not sampled	as for "presumably not", but with a strong indication that the target area was not visually sampled (e. g. counteracting behaviour, or target area clearly outside of field of vision)

road(s) or looked over their shoulder. For the researcher not to reveal herself observing the pedestrians and cyclists, she remained with the bicycle and pretended to be occupied with her mobile phone. Consequently, the pedestrians and cyclists were unaware of being observed, such that their natural behaviour was not influenced. The recordings were done in the morning before school started and lasted between 5 and 30 min.

All sites were near schools for different age groups. Each site had pedestrian pavements and four of the sites had either separate cycle paths or combined pedestrian and cycle paths. Seven of the sites were a four-way intersection and seven were a three-way intersection. In 63.4 per cent of the cases no motorised traffic was present in the vicinity, in 34.4 per cent of the cases, motorised traffic was present on one street leading up to the observed intersection, and in 2.2 per cent of the cases motorised traffic was present on more than one street.

2.4. Data reduction in the observation study

In total 898 road users were observed, the average number per occasion was 49.9 (std = 49.9). Twelve people were excluded from analyses, as they used a different means of transportation like e-scooters, mopeds or similar. Data coding was done manually using the Observer XT16 (Noldus, Wageningen, NL).

For each site an imaginary line was drawn at the curb of the pedestrian pavement where the pedestrian would step onto the road to cross it. A time marker was set for each active road user when reaching that line. In addition, a list of variables was coded for each road user (Table 2). Five different types of company were discerned. These are described in Table 3 and Table 4.

The images in Table 4 show examples of how the various group constellations were determined and what they could look like. In all photographs the imaginary time marker is represented by an orange dashed line. As soon as a pedestrian or cyclist crossed the dashed line, the time was counted until the next person behind crossed the same line to determine whether they belonged to the same group or not. Five seconds were used as cut-off, reflecting the approximate time needed to cross the intersection. The same classification method was used for cyclists. Groups were identified within the same mode of transportation, that is, cyclists and pedestrians never belonged to the same group.

If a formal group walked or cycled within five seconds of other people, the group was classified as mixed group. Thus, mixed groups always contain at least one formal group and at least one additional person.

2.5. Analysis

To allow for comparison between the two data sets, we focused the analyses on the percentage of occasions where no visual information sampling from any direction but forward occurred on the way leading up to the intersection. This was used here as a crude indicator for reduced attention compared to actively looking around and scanning relevant areas, as it simplifies comparisons across situations with different relevant areas.

In the follow-along study, all instances in which the participant had “presumably not” or “highly likely not” scanned a relevant target area were considered as “not sampled”. In the observation study all occasions where the person did not make any head turns

Table 2
The variables that were coded in the manual data reduction or computed afterwards, their levels and explanatory comments.

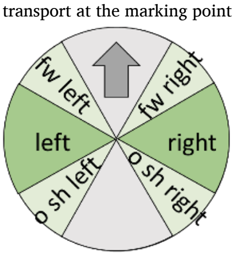
Variables	Levels	Comment
mode of transport	pedestrian cyclist (other)	people leading a bike were classified as pedestrian; “other” could be scooters etc.
age	young (up to 12 years, estimated) teenagers (13 to 19, estimated)	estimated age, based on the notion of “traffic maturity”
manoeuvre	left straight on right	direction of travel in the intersection, from road user’s point of view
communication device	no earphones hold in hand	some people wore headgear, which could hide in-ear earphones
member of formal group	yes (obvious social relationship) no	for yes: obviously belonging together socially, e. g. talking or holding hands
member of informal group	time interval to next person using the same mode of transport at the marking point is below 5 s	5 s was used as cut-off as it reflects the approximate time needed to cross the intersection
information sampling	 forward left (fw) left over shoulder left (o sh); analoguous to right	direction(s) of visual information sampling (except forward or rearward) from the road user’s point of view, if clearly visible; here categorised into not sampled or sampled

Table 3
Explanations of the five different types of company present in the data set, depending on formal and informal group membership.

type of company	observed person is member of		comment
	formal group	**informal group**	
alone	no	no	
strictly formal group	yes	yes	everybody in the group belongs to the same formal group and travels in physical proximity of each other
strictly informal group	no	yes	nobody in the group belongs to a formal group
mixed group	either	yes	everybody in the group belongs to the same informal group, with some people belonging to (a) formal group(s), too
distanced from company	yes	no	travelling with a physical distance, but obviously belonging together (e. g. a child travelling ahead of a parent with another child)

indicating a glance towards a non-forward area were counted as "not sampled".

Analyses were carried out with SPSS 28.0 (IBM SPSS Statistics for Windows, Armonk, NY: IBM Corp.). The alpha-level was set to 0.05.

3. Results

Naturally in real traffic not all combinations of groupings, age category and communication device usage are equally likely. In the follow-along study, none of the participants was physically distanced from their company and the occasions in which the participants ended up with unknown people in informal or mixed groups were transient. Altogether this occurred for a duration of 18:56 min, of which 73 % were spent waiting at a traffic light, such that 1.1 % of the total time was spent in motion close to unknown people. This was neglected in the analyses, such that the follow-along study only contains data in the group types "alone" and "pure formal group". Two participants briefly checked their telephones (below 1 min in total). This was not considered separately. In the observation study, as evident from Table 5 and Table 6, young children rarely walked or cycled alone. Communication devices were normally not used when in formal groups, and pedestrians were more likely to hold the devices in their hand than cyclists (see Fig. 2 and Fig. 3). It was uncommon to keep a time gap of more than five seconds from one's formal company.

Crossing behaviour or interactions with other road users were not part of the investigation. However, neither in the follow-along nor in the observation study any incidents, near-crashes or crashes were observed.

The differences in the data collection procedure entail some differences in the data reduction. Table 7 shows how this may have affected the results. The observation study was conducted to complement with data that were difficult to obtain in the follow-along study setting, therefore comparisons could only be made for a subset of the data.

For most comparisons, the observation study returned slightly higher non-sampling rates than the follow-along study (Table 7). In both studies, walking alone is associated with more sampling than walking in a formal group. The effect is less pronounced for cycling. Cyclists had higher non-sampling rates than pedestrians (follow-along: chi-square(2) = 7.7, $p = 0.021$; observation: chi-square(2) = 35.7, $p < 0.001$; Table 7).

Initial analyses of the follow-along study indicated the importance of group membership for information sampling (Odéen, 2022), therefore this factor is treated first. Age and mobile device usage is then analysed holding group membership constant. It must be noted that here group cycling typically means riding behind each other, and when parents ride with children, the parent usually rides behind the child and in some cases side by side with the child. In contrast, pedestrians in groups usually walk side by side.

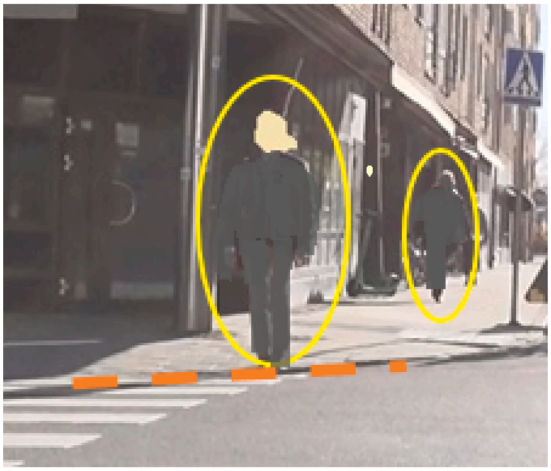
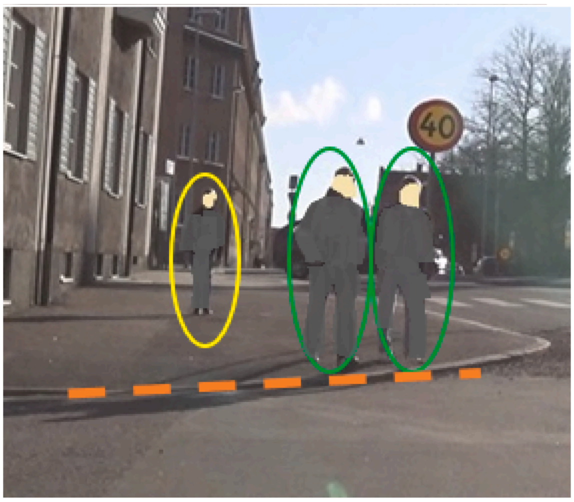
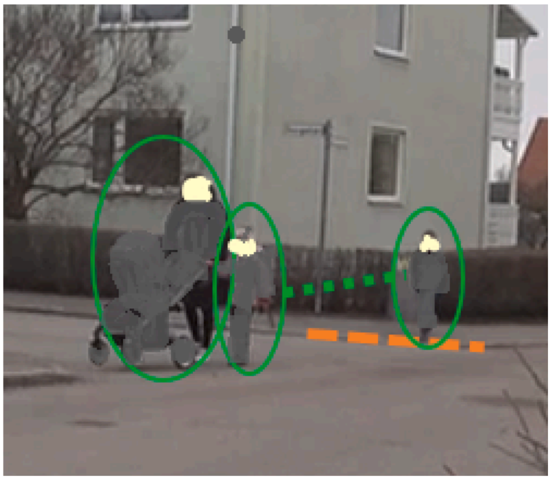
3.1. Group

In the observation study, group membership determined significantly to which extent each individual person would not look at any target area other than forward (walking: chi-square(4) = 20.6, $p < .001$; cycling: chi-square(4) = 16.3, $p = .003$). Of the people walking alone 94.1 per cent sampled information. All ten people distanced from their company sampled some information. The percentage for cycling alone was 24.0 %. The individual non-sampling percentages for the other group types can be found in Table 8.

In the follow-along study, the percentage of non-sampled target areas did not differ significantly between being alone or in a group (walking: chi-square(1) = 2.4, $p = 0.121$; cycling: chi-square(1) = 0.35, $p = .554$). For walking participants, the type of company played a significant role. In the company of friends 4.9 % of the target zones were not sampled by the main participant, whereas in the company of parents 19.2 % of the target zones were not sampled (chi-square(1) = 12.1, $p < .001$). In this study, no information about the sampling of other group members was available, as only the main participant used an eye tracker.

For the observation study it was possible to investigate the sampling of all group members and therefore also the sampling of the group as a unit. Naturally, the percentage of whole groups not sampling is lower than the percentage of individuals in those groups. However, groups as a unit also exhibit lower non-sampling rates than people travelling alone using the same mode of transportation.

Table 4
Illustrations and descriptions of different group constellations.

	The time gap between the first and second person marked in yellow was larger than 5 s. Therefore, they were classified as walking alone and not belonging to the same group.
	The two pedestrians marked in green, walking side by side were classified as belonging to the same formal group due to their evident interaction with each other. The person behind, marked in yellow, was more than 5 s behind and was therefore classified as walking alone and not as part of the group.
	There was a time gap of more than five seconds between the pedestrians in the front and the third pedestrian walking behind them. They were still classified as a formal group as they belonged to the same family, even though the child in the back lagged behind.

(*continued on next page*)

Table 4 (*continued*)

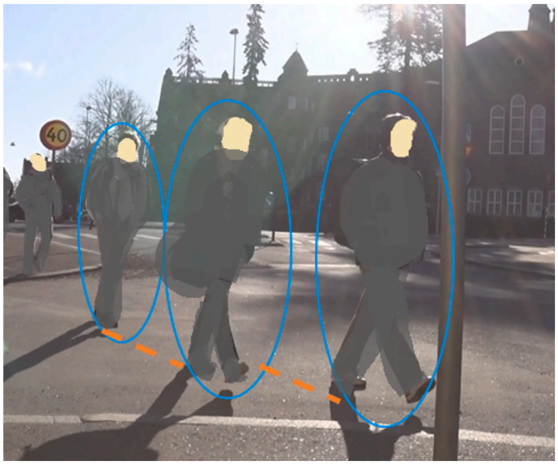
	Here, three pedestrians are walking within a five second gap of each other, meaning they were classified as a group. However, since they were not interacting with each other, they were classified as an informal group. All of them were wearing headphones.

Table 5
Number and percentage of pedestrians per group type and age group in the observation study and follow-along study.

Pedestrians per age group presented in number and percentage (%) for each group type				
Group type	Observation study (# and %)		Follow-along study (# and %)	
	Teenagers	Young	Teenagers	Young
alone	206 (93.2 %)	15 (6.8 %)	86 (48.3 %)	92 (51.7 %)
formal group	100 (73.5 %)	36 (26.5 %)		281 (100 %)
informal group	114 (99.1 %)	1 (0.9 %)		
mixed group	124 (95.4 %)	6 (4.6 %)		
distanced from company	6 (85.7 %)	1 (14.3 %)		
total	550 (90.3 %)	59 (9.7 %)	86 (18.7 %)	373 (81.3 %)

Table 6
Number and percentage of cyclists per group type and age group in the observation study and follow-along study.

Cyclists per age group presented in number and percentage (%) for each group type				
Group type	Observation study (# and %)		Follow-along study (# and %)	
	Teenagers	Young	Teenagers	Young
alone	159 (95.2 %)	8 (4.8 %)	803 (82.6 %)	169 (17.4 %)
formal group	28 (75.7 %)	9 (24.3 %)	181 (29.8 %)	427 (70.2 %)
informal group	54 (96.4 %)	2 (3.6 %)		
mixed group	14 (100 %)			
distanced from company		3 (100 %)		
total	255 (92.1 %)	22 (7.9 %)	984 (62.7 %)	596 (37.3 %)

3.2. Age

To prevent a confounding of age and group membership, age was analysed only when there were enough individuals per age category within the same type of group. This was the case for travelling alone in the follow-along study. Neither for cyclists nor for pedestrians, significant differences in non-sampling were found (Table 9). In the observation study, the number of young individuals travelling alone was too low for a meaningful comparison. In the follow-along study, no teenager students walked in groups, so only cycling was investigated. Teenager students cycling with friends of a similar age had significantly higher non-sampling rates than young students cycling with friends of their age. The friends' sampling behaviour was not logged in the follow-along study, so the sampling behaviour of the group cannot be determined.

In the observation study, the only possible comparison was for walking groups consisting of either young children or teenagers (Table 9). Non-sampling was not significantly different between individuals in those two groups. At group level, two out of the twelve young groups did not sample any direction but forward. For the 33 groups with only teenager students, this happened once.

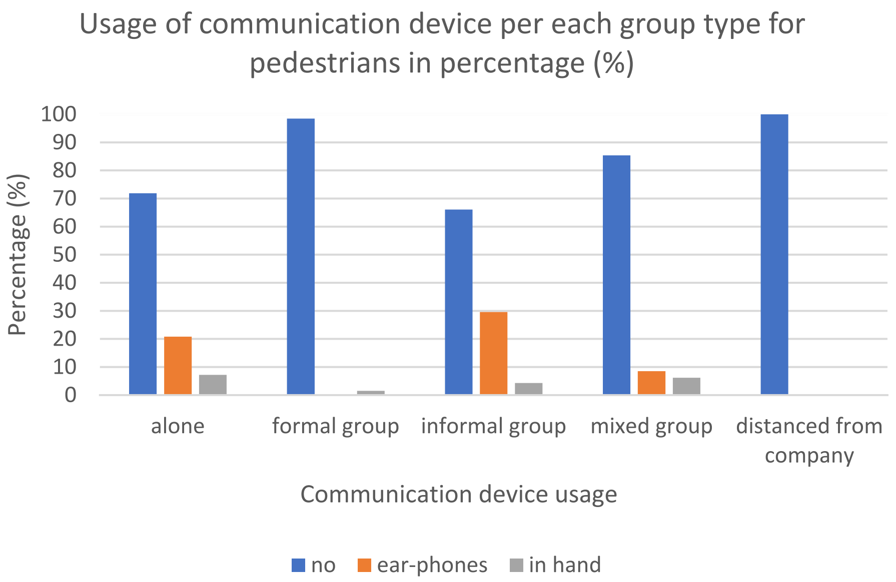


Fig. 2. The usage of communication device for each group type for pedestrians shown in percentage. Data from observation study.

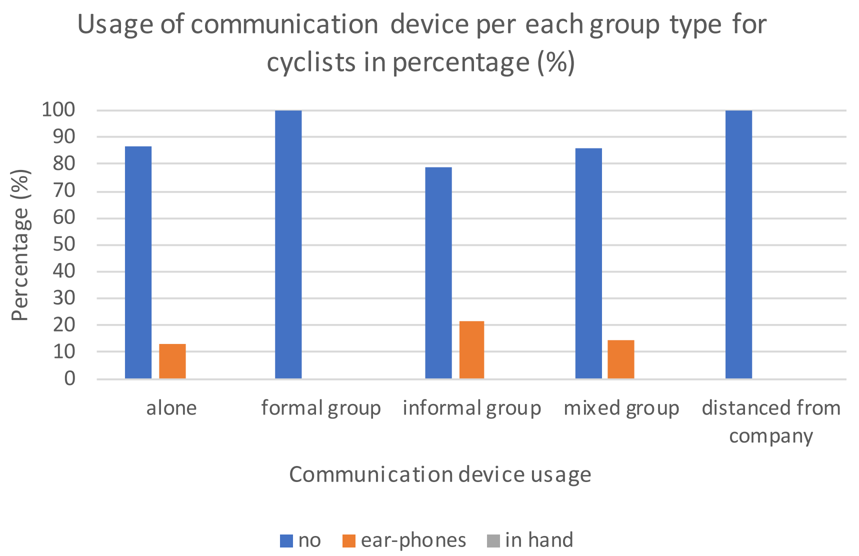


Fig. 3. The usage of communication device for each group type for pedestrians and cyclists shown in percentage. The data is collected from the observation study.

Table 7
Percentage of cases in the follow-along study and the observation study where no visual sampling except to forward occurred, split into comparable groups. For the follow-along study "certainly not" and "presumably not" are given in parentheses.

	Walking		Cycling	
	follow-along	observation	follow-along	observation
young	11.2 % (7.2 + 4.0) of 373	22 % of 59	13.7 % (9.2 + 4.5) of 596	18.2 % of 22
teenagers	8.2 % (3.5 + 4.7) of 86	11.1 % of 550	16.2 % (9.2 + 7.0) of 984	29.4 % of 255
alone	7.8 % (3.9 + 3.9) of 178	5.9 % of 221	15.8 % (10.1 + 5.7) of 972	24 % of 167
formal group (some bias due to the age combinations)	19.2 % (14.2 + 5.0) of 141 (only parents)	21.3 % (pure formal) of 136	16.5 % (8.6 + 7.9) of 152 (only parents)	35.1 % of 37 (pure formal)

Table 8
Group size range and number of groups per type, the non-sampling rate per individual for each group type, and the share of groups per type depending on whether all, some or no people in the group did any visual sampling other than from forward.

Walking			Individuals sampling information (percentage)	How many per group sampled information?		
	# people in group	# groups per type		all group members	some group members	none
informal	2–5	36	88.7 %	25 (69.4 %)	11 (30.6 %)	
mixed	2–16	25	85.4 %	15 (60.0 %)	10 (40.0 %)	
formal	2–7	55	78.7 %	35 (63.6 %)	17 (30.9 %)	3 (5.5 %)
total	**2–16**	**116**	**84.0** %	**75 (64.6** %)	**38 (32.8** %)	**3 (2.6** %)
cycling						
	# people in group	# groups per type		all group members	some group members	none
informal	2–5	23	71.4 %	12 (52.2 %)	8 (34.7 %)	3 (13.1 %)
mixed	2–5	4	28.6 %	1 (25.0 %)	1 (25.0 %)	2 (50.0 %)
formal	2–4	17	64.9 %	9 (52.9 %)	4 (23.5 %)	4 (23.5 %)
total	**2–5**	**44**	**63.6** %	**22 (50.0** %)	**13 (29.5** %)	**9 (20.5** %)

Table 9
Comparison of non-sampling rates for age within the same group constellation.

	young	**teenagers**	**study**	**chi-square(1)**	**p-value**
walking alone	7.6 % (of 92)	8.1 % (of 86)	follow-along	0.02	0.895
cycling alone	17.2 % (of 169)	15.4 % (of 803)	follow-along	0.31	0.577
cycling, formal group of similar age	10.4 % (of 164)	19.9 % (of 181)	follow-along	6.00	0.014
walking, formal group of similar age	26.9 % (of 26)	20.1 % (of 154)	observation	0.62	0.432

Table 10
Comparison of non-sampling rates for young students, depending on the age of the company in formal groups.

Travel mode	Young students accompanied by		Study	chi-square(1)	p-value
	friends similar age	parents			
walking	4.9 % (of 122)	19.1 % (of 141)	follow-along	12.07	<0.001
cycling	15.4 % (of 345)	16.4 % (of 152)	follow-along	0.094	0.759
	similar age	with adult company			
walking	26.9 % (of 26)	14.3 % (of 14)	observation	0.833	0.361

Finally, the behaviour of young students in formal groups was investigated with respect to the age of their company (Table 10). When cycling, non-sampling rates were equal for students accompanied by friends or by parents. For pedestrians, the results from the follow-along and observation study potentially contradict each other. In the follow-along study, non-sampling was significantly more frequent when accompanied by a parent than when with same-aged friends. In the observation the opposite is the case, even though the difference is not significant, and the absolute numbers are low.

As mentioned above, two of the twelve all-young groups did not sample at all. For all ten formal groups of mixed age, at least one group member performed some sampling. Three of these groups contained members that did not sample. In all three occasions, these were young people, with adult people doing the sampling.

3.3. Communication device

Effects of communication device usage on sampling are only investigated for the observation study, given the low frequency of device usage in the follow-along study. For pedestrians walking alone, there was a tendency for more non-sampling when interacting with a hand-held device (18.8 % non-sampling) than when not using any device (5.0 %) or using earphones (4.3 %; chi-square(2) = 5.19, p =.075). Non-sampling was not significantly more frequent when walking with earphones in an informal or mixed group (11.1 %) than when walking alone (4.3 %; chi-square(1) = 1.47, p =.226). When holding a device in an informal or mixed group, there was a trend for increased non-sampling (46.7 %) compared to when walking alone with a hand-held device (18.8 %, chi-square = 2.76, p =.097).

The observed cyclists did not use any hand-held devices. Non-sampling was not significantly different between cyclists with earphones (18.2 %) and without (24.8 %; chi-square(1) = 0.46, p =.496). Non-sampling among cyclists with earphones in informal or mixed groups (28.6 %) was not significantly more frequent than among cyclists travelling alone (18.2 %; chi-square = 0.53, p =.465).

4. Discussion

The main finding of the study is the large influence of group membership on individuals' visual sampling strategy. The common denominator seems to be that people rely on each other more in formal than in informal groups, that people with a natural responsibility in the group (e. g. grown-ups/parents) take a more active role in information sampling, and that mutual reliance is more prominent among pedestrians than cyclists. Thus, group behaviour is fundamentally different from the average behaviour of individual group members. How paying attention is delegated within the group seems to follow rational, albeit possibly not conscious choices. When accounting for the group effect, age does not seem to play a big role in non-sampling of relevant information.

While individuals in groups are less likely to sample relevant visual information than individuals travelling alone, the likelihood that nobody in a group would sample any information was lower than for individuals travelling alone. The number of observations made was too small to draw any conclusions about how group size affects information sampling, but results from Pešić et al. (2016) and Lanzer and Baumann (2020) indicate that an increasing group size reduces the likelihood of individuals to scan for traffic. It seems that the social connection between people provides a stronger cue for relying on each other than mere physical proximity, as the effect for informal groups is weaker than for formal groups.

In general, with respect to information sampling people seem to behave in a rational manner that can be described as "efficient" in that the effort is shared. They take responsibility for their visual information intake when necessary and share the task depending on the situational circumstances and the relationship of the group. This can even be extended to reliance on external support – Thompson et al. (2013) found that pedestrians obeying the traffic signals were 2.8 times more likely not to look both ways than those who did not. This behaviour can be related to the common human behaviour termed "satisficing", after the notion that a satisfactory outcome may often be most cost-effective (Simon, 1955).

In line with previous studies (Chinn et al., 2004; Deluka-Tibljaš et al., 2022; Rosenbloom et al., 2008), when walking, parents take the main responsibility for information sampling. When children walk with a parent, the parent's physical position is very close to the child's, such that the parent can sample in lieu of the child. Additionally, the parent can make the child stop almost instantaneously. The data from the follow-along study indicate that children are more prone to rely on their parents than on friends of their own age. This is not confirmed in the observation study, but here the number of observations was smaller. Cyclists seem to have less opportunity to benefit from being in a group, which can be linked to the fact that they ride behind each other and that they move at a faster speed. This situation requires more own responsibility, which is reflected in the information sampling behaviour. This relates to the finding of Chinn et al. (2004) that the position in the group affects the likelihood to check for relevant information.

A practical implication of these results might be that parents systematically underestimate children's capacity of information sampling in traffic because parents only see their children when their behaviour is modified by the presence of the parent. In line with this, Rosenbloom and colleagues found that children accompanied by grown-ups exhibit less "safe" crossing behaviour than children walking alone (Rosenbloom et al., 2008; Rosenbloom, Sapir-Lavid, & Hadari-Carmi, 2009).

The finding that cyclists generally appear to sample less relevant information than pedestrians can have several explanations. Cyclists move faster, such that they have less time available to obtain the necessary information. Therefore, they might use more peripheral vision (Schepers & den Brinker, 2011; Schepers et al., 2013), which can be sufficient to confirm the absence of obstacles or other road users. Pedestrians who, due to their slower speed, have more time available can take the liberty to make more head movements that might be redundant. Another explanation could be that, at least in mixed traffic, cyclists move on the road while pedestrians are on the pavement. This usually means that cyclists are farther away from objects that may block the line of sight, like houses or hedges. This provides a more beneficial position for seeing into side roads in time, which further enhances the possibility to use peripheral vision. Still, the option cannot be ruled out that cyclists in fact sample less information than pedestrians. Kircher and Ahlström (2020) found evidence that attentional requirements on cyclists are higher than on car drivers in the same situation, which may have made it more difficult for cyclists to fulfil all requirements. If there is a systematic bias in how different road user groups are treated in the transport system, this should be addressed at a legislative level.

There are indications that the usage of communication devices follows a similar pattern in that appropriate adaptation occurs. In a semi-controlled study cyclists employed a range of compensatory strategies when texting (Ahlstrom, Kircher, Thorslund, & Adell, 2015), and findings by Nygårdhs, Ahlström, Ihlström, and Kircher (2018) indicate that attention to traffic remains largely intact. Earphone-usage does usually not lead to decreased sampling (Walker, Lanthier, Risko, & Kingstone, 2012), whereas texting or browsing does (Simmons et al., 2020). The present studies replicated those results. Whether decreased sampling was compensated for by increased attention to auditory information could not be investigated with the employed method.

Future studies should look systematically into group size and composition for pedestrians and cyclists in a naturalistic setting. This can be combined with systematically investigating drivers' information sampling and behaviour with special focus on interactions with active road users. A complete picture of how the infrastructure, traffic regulations and group constellations affect the likelihood of obtaining all relevant information can serve as base for a transportation system that supports sustainable travel by considering the needs of active travellers.

Limitations.

The data from real-world studies of the type used here are bound to be "messy" and imbalanced. This necessitated a somewhat crude approach to classify information sampling. Also, a further subdivision of the data, for example according to whether any relevant traffic was present, or on which side of the road the pedestrians walked, would have decreased the sample size in each category, making analyses difficult. Even as it is, certain constellations are much less common than others in a natural setting, such that some comparisons can be difficult to make in real traffic settings. While they still could be investigated in a controlled setting, the ecological validity would be uncertain, as participants may be unfamiliar with the situation.

In the observation study age was estimated, formal group membership and the usage of communication devices was judged by observable behaviour, which may have caused inaccuracies in the data. In the follow-along study, the presence of the experimenter may have influenced the participants' behaviour. This is difficult to control for or assess, but we speculate that glance behaviour would be less affected than tactical behaviour such as how a road is crossed.

The slightly higher non-sampling rates in the observation study could stem from an experimenter effect in the follow-along study, but can also be due to the fact that the eye trackers used in the follow-along study also informed about information sampling via eye movements without head movements. This also implies that non-sampling as defined here does not necessarily mean inattention. A person may use peripheral vision, auditory information, or eye movements without moving the head. The relevant information can also have been sampled earlier or in another way that could not be detected with the methods used. An indication for this is the finding of Pfeffer, Fagbemi, and Stennet (2010) that 23.6 per cent of the adults accompanying children on their way to school were not sampling information by looking left or right before crossing a street. As discussed above, parents naturally take the responsibility of watching out for their children, therefore non-sampling should not be seen as confirmation of inattention. Absolute values for visual non-sampling rates can be location-dependent, as traffic volumes, speed, the possibility to use other sensory modalities and other factors may vary. Therefore, rather than focusing on absolute values as representing cases of inattention, the relative values can be seen as indicators for the influence of different factors in the same environment.

The data reduction method, especially the inclusion of assumptions on peripheral vision, can be criticised for being subjective. However, as detailed in Ahlström et al. (2021), subjective components are always included in the reduction and analysis of eye-tracking data. As shown above, excluding peripheral information would inevitably lead to biased results. The development of a method to assess peripheral information sampling systematically and reliably would be an important tool to advance gaze-based research.

5. Conclusions

This study focused on the attention of pedestrians and cyclists of different ages travelling alone or in groups, with or without communication devices, in their natural environment. When it comes to information sampling, groups – especially when group members have a social connection – are qualitatively different from the average of the individual group members. A group can be collectively attentive, even though not each single individual in the group has sampled all relevant information. However, by watching out for each other and by having an understanding that this process is taking place, the individuals in the group are taken care of. Examples are parents watching over their children, and the first cyclists in a peloton considering the whole group. This group behaviour also implies that parents may underestimate the competence of their children, while children may lay their trust on their parents to look out for them. This is supported by the fact that children who are walking on their own have shown to be more attentive than when walking with an adult.

Using children's age as the only reference for their expected competence in traffic appears limited in the light of the present findings. The explicit and especially the implicit sharing of responsibility in groups in naturalistic situations is a topic that must be explored further when assessing competence in the traffic system of today. While this has been an implicit assumption in the present research – investigating tactical behaviour on an individual level in a given context – this need not be the end of the story. Instead, future research should also focus on how to make the public space more accessible for children by planning according to their competence.

CRediT authorship contribution statement

Katja Kircher: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Project administration, Funding acquisition. **Martina Odéen:** Methodology, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization.

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.

Data availability

The authors do not have permission to share data.

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