Exploratory Study on the use of Augmentation for Behavioural Control in Shared Spaces

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Abstract. Shared spaces are regulation free, mixed traffic environments supporting social interactions between pedestrian, cyclist and vehicles. Even when these spaces are designed to foster safety supported by reduced traffic speeds, unforeseen collisions and priority conflicts are always an open question. While AR can be used to realise virtual pedestrian lanes and traffic signals, the change in pedestrian motion dynamics using such approaches needs to be understood. This work highlights an exploratory study to evaluate how speed and path of pedestrians are impacted when using an augmented reality based virtual traffic light interface to control collisions in pedestrian motion. To achieve this objective we analyse the motion information from controlled experiments, replicating pedestrian motion on a lane supported by a stop and go interface and including scenarios such as confronting a crossing pedestrian. Our statistical and quantitative analysis gives some early insights on pedestrian control using body worn AR systems

Keywords: augmented control · pedestrian safety · shared spaces

1 Introduction

Shared space design [5] has drawn significant attention recently as an alternative to conventional regulated traffic designs. In shared spaces, heterogeneous road users such as pedestrians, cars and cyclists share the same space. The idea is that unclear situations and a mix of all traffic participants leads to reductions in speed and this results in everybody being more cautious. While the safety behind such designs has always been under debate due to fewer or no road signs, signals and lane marking [6], such spaces have continued to gain acceptance. There are a growing number of such spaces, e.g. in London, Bohmte, Norrköping, and Drachten.

Shared spaces however have also been a subject for criticism and debate for many reasons. Among traffic participants, many pedestrians feel less safe, due to the lack of vertical separation between pedestrian and vehicle movement regions. They also are vulnerable from cyclist attributed from the lack of separate cyclist lanes and the increased possibility of cyclist collision with walking pedestrians. While collisions are essentially a safety issue, priority confusion in such unregulated spaces are equally dangerous. This, for example, can prove fatal to a tourist with little or no knowledge of the local traffic rules while navigating such spaces with vehicular drivers who would continue to react to interactions based on priority.

Pedestrian infrastructure can reduce pedestrian exposure to vehicular traffic and reduce vehicle speeds ([10], [11], [12], [13], [14]). Specific engineering measures that reduce traffic volumes and pedestrian exposure to vehicular traffic include approaches that support sidewalks and footpaths, marked crossings, overpasses and underpasses, and mass transport routes [9]. Including the existing knowledge from conventional traffic designing to complement shared spaces with virtual pedestrian infrastructure would bundle the benefits of both street design approaches while reducing costs and improving safety.

Augmented Reality (AR) with its power of visualisation can be used to visualize virtual lanes and control traffic participants using traffic signals in mixed traffic [15]. Such large AR deployments will help pedestrians safety move in outdoor spaces [16], while avoiding collisions and also mediate participants to avoid priority confusion. This could enable behavioural change interventions in traffic using AR.

While walking in virtual lanes spaces people usually cross paths with other traffic participants. Existing research around pedestrian motion in free space considering collisions avoidance relates to the adjustment of the path and speed of motion as two of the most important parameters. In scenarios considered for motion towards a goal or target destination, adjusting the speed is more favourable amongst both. This is supported based on findings that speed adjustments help with keeping the intended path avoiding re-planning of the motion trajectory. Braking on the other hand seems to be favored when the field of view is restricted [1], in small areas, or crowded places [2], and when the environment or the obstacle's behavior is uncertain [3]. However when a pedestrian motion happens in a spatially constrained and temporally restricted setting like for example a pedestrian walking in an AR guided virtual lane, signaled to stop by a virtual traffic signal at an intersection, braking is the expected and favoured option [4].

The situational factors and environmental factors can also affect the motion dynamics. Situational factors (in other words, those that characterise the particular context in which a pedestrian finds himself or herself, but which are not 'fixed' from one outing to the next) may also help explain differences in recorded walking speeds between studies. It is well known, for example, that the prevailing density of other pedestrians has a significant effect on individuals' walking speeds: indeed, the speed flow relationship of pedestrian movement patterns is well documented (for example, [18]). Early reports have suggested that people prefer to maintain a buffer zone of around 0.45 m between themselves and the edges of buildings ([18]), a smaller distance (approximately 0.1 m) to stationary items of street furniture ([19]) and a larger distance (around 0.8 to 0.9 m) between themselves and other pedestrians ([20]). One report also suggested that people like to maintain a distance of around 0.75 m between themselves and their companion(s) when walking ([21]). When a pedestrian motion happens in a virtual infrastructure controlled with a virtual traffic signal, these factors could still be accountable.

Fig. 1: Stop and go interface for pedestrian motion control

The goal of this study is to explore how an AR guided collision control interface affects the dynamics of interaction between pedestrians whose paths cross with each other. For a fair comparison, we have used the existing knowledge and understanding in research on crossing collision avoidance to evaluate the AR guidance approach. We compare the impact in terms control, safety and user feedback while using the interface with both a crossing and non crossing constellations of pedestrian motion. We focus on the diversity of the interactions captured and map them to scenarios when these interactions are mediated with an AR based virtual pedestrian traffic control system.

2 Experimental Setup and Procedure

2.1 Participants

Six participants (2 females and 4 males) with a mean age of 25.5 took part in the study. All the participants had normal mobility, normal vision or corrected to normal vision. Two confederates taking turns volunteered in the experiment.

2.2 Interface Design

A traffic light based 3D AR interface was designed using Unity (Figure 1) with a Stop and Go (S&GI) trigger activating the corresponding transitions in control. The S&GI was positioned at a fixed height from the ground and tested with the Hololens. An external trigger was developed which communicated to the Hololens AR signalling interface over WiFi network. This S&GI transition trigger was controlled by a volunteer who observed interactions in the experiment.

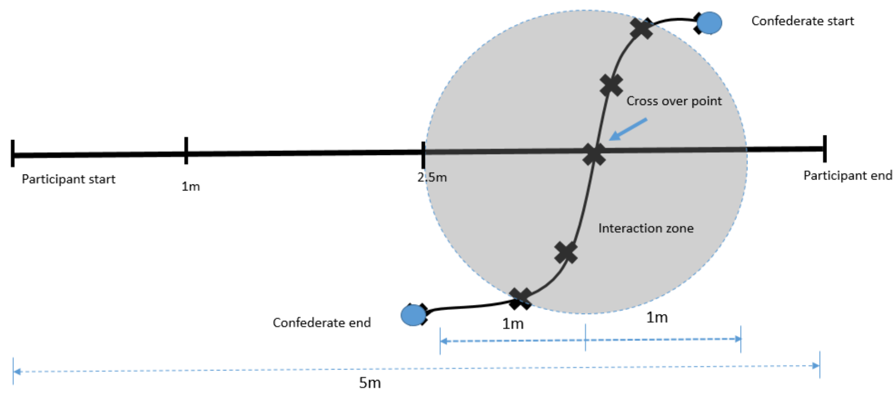

Fig. 2: Experimental scene: The pedestrian start and stop positions are marked with standardised crossing marking for confederate

2.3 Experimental Setup

Floor markings were made to support a visual path of motion (Figure 2) for both the participant and confederate. While the participant markings were directed to propel him to walk on a straight line from the start to the end, the markings for the confederate were designed to intersect the participant starting with a motion at an obtuse angle (180°) and later intersecting at right angles at the cross over point. We have defined the cross over point as the point where the confederate crosses the path with the participant and is positioned at the center of the interaction zone. This is also the point where the collision would happen if the participant would not react to the motion of confederate. This path was chosen to account for complete visibility of the confederate and to enable complex interaction and have been detailed in the paper. The experiment was conducted with a static camera overlooking the scene, capturing video frames at 30 frames per second. The tracked scene was 6x3 meter in a well lit indoor lab setting for clear augmented visualisation. The camera was focused to cover foot movements. A local WIFI network connection was set up in the experimental arena for remote control of AR interfaces.

Before the start of the experiment, the participants were explained the procedure and introduced to the HoloLens device. The participants had to walk a total distance of 5 meters, with clear start and end marking. They were also informed that during their walk, another pedestrian (confederate) would possibly cross paths without reacting to them. However this information was not disclosed to avoid any learning bias in the expected behaviour and this accounted in the total 4 conditions that were tested (herein called scenarios). Each participant also completed two practise trails until they demonstrated that they understood the task.

Confederates were trained prior to the experiment to standardise their motion. Each confederate was provided a headset which played metronome beats at

70 beats per second. They were instructed to walk along the confederate path, where each cross mark on the path corresponded to foot positions for every beat. The confederate estimated the onset of interaction (point in time where they had to start motion) based on the position of the participant in the initial 1m and the entry of the participant to the interaction zone and was expected to walk not reacting to the participant motion even in the event of near collision. The behaviour of the confederate changed in a few scenarios as detailed:

Scenario I - No interface - No interaction (No interaction Motion Baseline) The participant moved from the start to the end position wearing the Hololens but with no S&GI control. The confederate was expected to remain stationary at the confederate start position during the experiment.

Scenario II - No interface - Interaction (No Interface Interaction Baseline) The participant moved from the start to the end position wearing the Hololens but with no S&GI control. The confederate moved along the confederate path with motion directed to create a conflict at the cross over point (Figure 2).

Scenario III - Interface - No interaction (AR Interface Guided Motion) The participant moved from the start to the end position wearing the Hololens but was motion controlled with S&GI control. A green indication was triggered by the external volunteer to signal the participant to "go" and the participant followed the control. The confederate was expected to remain stationary at the confederates start position during the experiment.

Scenario IV - Interface - Interaction (AR Interface Guided Interaction) The participant moved from the start to the end position wearing the Hololens but with motion controlled with S&GI control. The confederate moved along the confederate path with motion directed to create a conflict at the cross over point. A green indication was trigger by external volunteer to signal the participant to "go". As the participant approached the interaction zone and confederate motion approached the cross over point, the external volunteer trigger the interface transition from green to red signalling the participant to "stop". Once the confederate stepped away from the cross over point, the AR trigger was transitioned to green allowing the participant to continue motion.

Prior to each experiment, the first trail was used to familiarise the participant with the different scenarios. For each of the participant, the ordering of scenarios were randomised to avoid any learning bias. Once the experiment was completed, a questionnaire was handed over after each scenario for a user feedback of their experience.

3 Data Processing

3.1 Camera based position information

Location information of both the participant and confederate was extracted using the deep learning based image detection approach Yolo ([29]).The frames

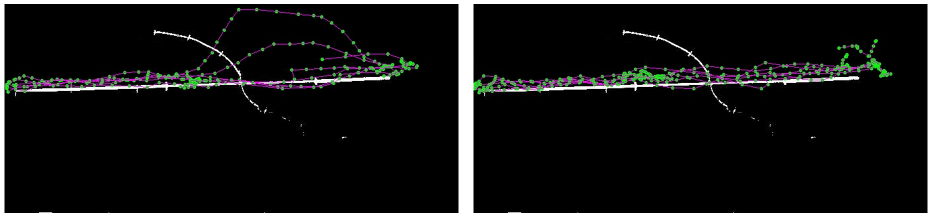

Fig. 3: The left shows the participant trajectories interacting in Scenario II (No Interface Interaction Baseline) while the picture on the right shows the interaction in Scenario IV (AR Interface Guided Interaction)

were processed at 30 fps and the pedestrians in each frame were tracked with DeepSORT [28] tracking to extract the individual trajectories. The foot of the pedestrian in each pedestrian frame was used to find the position of the participant.The position information from the image coordinate frame were transformed to world coordinate frame using the size of know landmarks in the images. A projective transformation was used to transform the location information to a birds eye view. The position information from the camera was further downsampled to 5 frames per second. The trajectory position was further smoothed with a sliding window with a filter size of three.

4 Results and Discussion

For all the 6 participants, the dynamics of the participant path and velocity profiles across different scenarios have been compared.

To account for the change in positional information of the participant, the instantaneous tangential velocity of the body was computed according to the formula

$$V(t) = \sqrt{\dot{x}(t)^2 + \dot{y}(t)^2}$$

In order to measure the variability of the velocity profile among the different participants and scenarios, we computed the mean speed and the corresponding SD and this information has been used give statistical insights on different scenarios.

The time to collision (TTC) was calculated using the position information of the participant when the confederate is at the cross over point

$$TTC = \frac{d}{V_f - V_l}$$

,

where d is distance between the participant and confederate and V_f and V_l correspond to the speed of the participant between consecutive frames.

As it can be shown by the results (Table 1), the stop and go interface has significantly improved the distance between the participant and confederate (GAP) and the TTC as opposed to the no interface scenarios.

Participant	Scenario	GAP (cm)	TTC (sec)
P1	No Interface	77.05	2.5
	AR Interface	106.01	3.5
P2	No Interface	111.01	3.7
	AR Interface	132.6	4.42
P3	No Interface	59	0.65
	AR Interface	104	3.4
P4	No Interface	32	0.36
	AR Interface	67	2.23
P5	No Interface	70.29	0.39
	AR Interface	95.18	3.17
P6	No Interface	72.11	0.48
	AR Interface	100.12	3.37

Table 1: Response comparing Scenario II (No Interface Interaction Baseline) with Scenario IV (AR Interface Guided Interaction)

To further evaluate the user acceptance of the interface, we analysed the questionnaire data. The acceptance was measured using the Van der Laan scale and the results for the responses for 5 participants are shown in Table 2.

Scenarios	Satisfaction		Usefulness	
	Mean	SD	Mean	SD
Scenario I	-0.7	0.65	-0.84	0.512
Scenario II	-0.3	1.19	-0.56	1.29
Scenario III	0.9	0.64	1.28	0.51
Scenario IV	0.95	0.748	1.4	0.619

Table 2: User satisfaction user feedback

To measure how exhaustive the speed regulation effort was, participant rated their experience over a SMEQ scale [31] with a value of 220 corresponding to extremely demanding. The participants rated to have felt the need for more effort using the interface (Table 3) than scenarios without the interface. However more experiments need to be done to verify the same. Future designs for AR based interaction support systems should take this into account.

Iteration	**Mean**	**Variance**
Scenario I	39.33	70.67
Scenario 2	43.3	69.76
Scenario 3	49.2	44.9
Scenario 4	50.67	41.31

Table 3: Scale measurement based on SMEQ

The exploratory study focused on evaluating the impact of the AR based control on both motion path and speed dynamics. Furthermore we have focused on the following research questions to better understand the change in behaviours enabled with the interface.

Q1. How does the general walking speed of the participant change using a body worn control system?

From the speed profile information of the participants while comparing (Table 4) the participant motion in Scenario I (No Interaction Motion Baseline) with Scenario III (AR Interface Guided Motion) gives a fair comparison. While most of the participants maintained more controlled pedestrian motion exhibiting lower average speeds and lower speed variations (low SD), one in six participants exhibited increased average speed supported with low speed variations during walking reflecting in more confidence in using AR controlled interface. This has been reflected in the speed for the participant for other scenarios too, throughout the experiment.

Participant	Scenario I		Scenario III	
	Mean Speed (m/s)	SD	Mean Speed (m/s)	SD
P1	0.79	0.46	0.53	0.277
P2	0.85	0.56	0.50	0.37
P3	0.60	0.30	0.43	0.21
P4	0.57	0.23	0.62	0.18
P5	0.53	0.37	0.55	0.25
P6	0.56	0.23	0.47	0.202

Table 4: Walking speed variations for different participants comparing motion based scenarios

All participants showed controlled speed motion dynamics (low SD in speed) when using the interface. This however is in contrary to the observations made in vehicular traffic studies for virtual traffic interface [26] where the drivers have shown to exhibit only lower speeds at traffic intersections. The low speeds for pedestrians could be attributed to the level of attention given continuously as exemplified from the speed information while using AR based navigation applications [27].

Q2. How does the behaviour of the participant change with the interface to strategies to adjust walking path to accommodate for static confederate in the scene?

During human locomotion in goal-oriented tasks, they pursue a planning and /or control strategy for the spatially oriented task [23]. These strategies also include steering, obstacle avoidance and route selection and depends on the appearance of the obstacle [24].

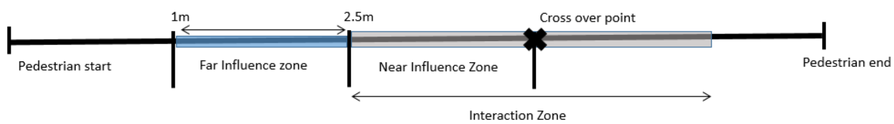

Fig. 4: Spatial zones identified to account for the influence of confederate on participant motion.

Recent pedestrian simulation models have also accounted for it at a microscopic level. In these models, the collision avoidance pattern stems automatically from a combination of the velocity vector of the other pedestrians and the density parameter. An individual tries to keep a minimum distance from the others ("territorial effect"). In the social force model for example, this pattern is described by repulsive social forces.

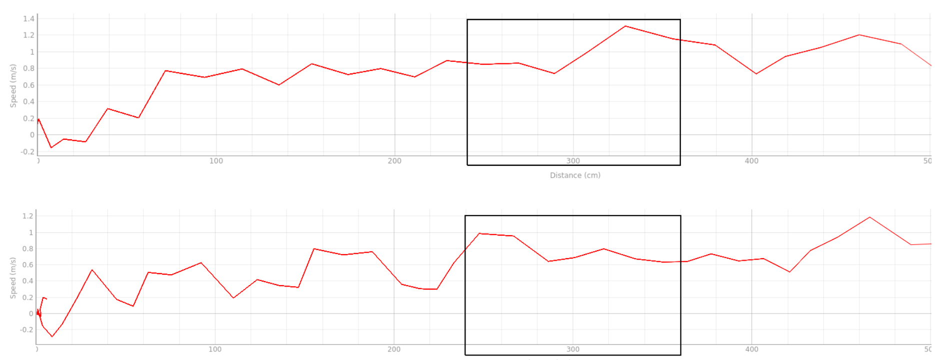

Fig. 5: The figure on the top shows the participant speed vs distance variation for near influence zone (Figure 4) for Scenario I (No Interface Motion Baseline) while the bottom shows no speed adjustments accounted by the participant in Scenario III (AR Interface Guided Motion)

To evaluate the impact of the static confederate in the scene, we identified spatially separated Far Influence Zone and Near Influence Zone and observed the speed variations in Scenario I (No Interface Motion Baseline) and Scenario III (AR Interface Guided Motion) for the participants in these zones. Two (P3 and P4) in six participants approached the intersection cautiously without an interface and later increased the pace of motion once no interactions were predicted.

All participants reacted equally in Scenario III (AR Interface Guided Motion) showing significant impact of the interface to counter the effects of external forces. Figure 5 shows how P4 speed variation in the near influence zone.

Q4. How abrupt is the stopping motion for participants using the interface?

The motion data pointed that P3 participant reacted cautiously by reducing speed in the near influence zone, as the confederate approached closer to the cross over point. P3 continued to show significant speed variations and exhibited backward motion (Figure 6) while stopping in the interaction zone when encountering the crossing pedestrian at the cross point in Scenario II (No Interface Interaction Baseline).

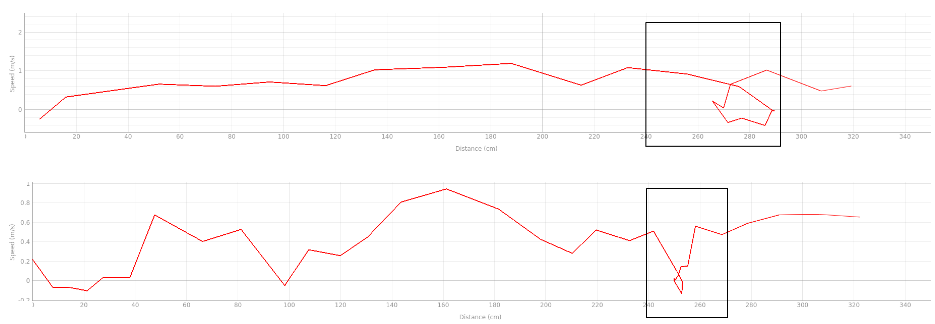

Fig. 6: The figure above shows the response of participant P3 stopping abruptly while the figure below shows same participant reacting to interface instructions more smoothly when mediating the interaction.

When using the interface in Scenario IV (AR Interface Guided Interaction) participant P3 continued to react cautiously in the near influence zone coupled with lower speeds of motion and backward motion. Thus the cautious pedestrian reacted with less backward motion and lower window of reaction while using the interface.

Q5.How are the collision avoidance strategies mapping when mediated with a stop and go interface?

While most of the participants in the experiment preferred to brake giving the right of way to the crossing confederate, two participants P4 and P5 reacted to the interaction by path and speed adjustment (Figure 7) in Scenario II (No Interface Interaction Baseline). These adjustment strategies are highly depended on the crossing angle as accounted in the finding [25] wherein it can be concluded that acute crossing angles (45°and 90°) account for more complex collision avoidance strategies. While other angles support speed adjustment, really small angles (45°) support the adjustment of the path while maintaining the desired speed. However in these interactions pedestrians can optimise the smoothness of trajectories by implementing braking, thereby avoiding big changes in walking paths.

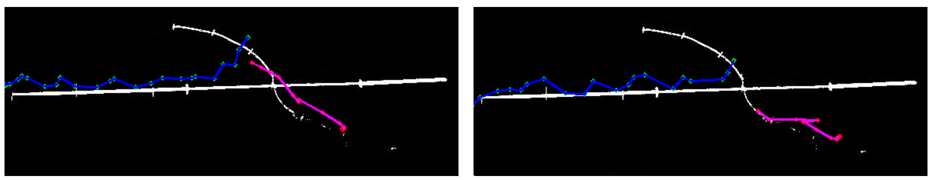

Fig. 7: The left shows participant P4 exhibits path adjustment as the collision avoidance strategy while encountering the confederate, while P5 exhibits a combination of both path and speed adjustment to counter the crossing confederate.

The participant P4 for instance applied a path adjustment in Scenario II (No Interface Interaction Baseline) but still failed to avoid collision with the confederate. The participant also rotated the body during the encounter exhibiting step-and-slide movement. This movement [22] occurs mostly between members of the same gender and conveys that interacting pedestrians do not take a total detour or attempt to avoid physical contact at all cost. Rather, there is a slight angling of the body, a shoulder turning, and an almost imperceptible side step. Neither of the pedestrians will move enough to guarantee contact avoidance or bumping into each other, unless the other pedestrian cooperates. However in Scenario IV (AR Interface Guided Interaction) the participant P4 accounted for more controlled interaction when augmented with the stop and go interface and this is reflected in the results from the calculated time to collision.

A combination of both speed adjustment and path adjustment strategy for P5 help steer pass the crossing confederate, where the speed of motion was increased. P5 however exhibited controlled motion in the interaction in Scenario IV (AR Interface Guided Interaction).

The current study investigated the influence of AR virtual traffic interface with respect to walking and interaction dynamics of pedestrians. The results indicate body worn control systems are successful in averting collisions and influencing motion. When we take the mean speed and its SD in No Interaction Motion Baseline, it is observed that participants move at their desired speed but are also influenced by the presence of other pedestrians in the environment. It also seems that this influence is based on the distance of the crossing pedestrian. When the participants are augmented with virtual control for motion, we observed that they preferred to walk at lower speeds with lower speed variations and were less impacted by the influence of nearby pedestrians.

We urge that the increase in TTC in interaction involving AR interfaces might be due to a combination of factors. While the standardised trigger to stop is significant, other factors like the increased attention of the participant to the control interfaces in the event of a conflict is equally significant. However we are unable to back this claim with technical data but urge that the user acceptance ratings evaluating it as a useful system as a strong indicate of this.

While significant efforts have been made to standardize the motions in our work. It should also be noted that the experiments did not simulate a real shared space, since the simulated setting was unable to mimic the motion dynamics of all other agents in a mixed traffic scene. In addition visual clues to indicate the confederate foot positions were visible to all the participants during the experiment. Understanding how the participants would behave while moving in virtual lanes with virtual traffic interfaces would be equally interesting.

To give a summary of the findings: We investigated on how AR can mediate collision avoidance along the pedestrian path. By introducing AR, we reduce the impact of other participants by instructing them to stop or go whenever they are hesitant on whether they should keep going, reducing the more diverse and less predictive behaviours which might include stopping and moving back, changing trajectory or speeding up. This will also make shared spaces more predictable and reduce the impact of other pedestrians or other traffic participants on the walking behaviour of subjects. We also observe that the control element introduces the fear of not obeying rules recommended to them (eg : stop when a red signal is shown). This is an indicative of how these interfaces can resolve conflicts.

The results of the study give some insights on the dynamics involved in human interface controlled motion. Several domains could benefit from the findings. Firstly it contributes to how people would walk in virtual infrastructure junctions and this could be useful traffic planners and traffic designers. On the other hand the learning's could also be valuable to transportation engineers on understanding how interactions would differ between pedestrians and other agents like autonomous vehicles when using AR based interfaces to avoid collisions in shared spaces. Finally it could also be interesting to researchers on how pedestrians would be accommodated as traffic agents in lane-free vehicular traffic [30].

5 Conclusion

We have investigated how different free space collision avoidance interactions in pedestrians differ when the interactions are supported by a central collision avoidance traffic infrastructure for pedestrians. On this basis we conclude that spatiotemporal restrictions imposed via augmented reality can enable collision avoidance by braking and enable controlled motion dynamics in pedestrians.

Furthermore we compare how pedestrians with different levels of tolerance to safety react to virtual safety systems. We conclude that AR based pedestrian control systems are effective in increasing the Time to Collision (TTC) and resolving conflicts.

While the first results of this proof-of-concept experiments have been promising, there is still room for improvement. The study currently has focused only on a small number of participants with limited scenarios and hence the conclusions are more biased along the observations on this small group. As a shared space would include more traffic participants and a wider interaction landscape, user studies including more participants and open spaces would give more insights and is a direction for future works. While safety of pedestrians is important factor being considered, the scalabilty of such systems when considering cyclist and vehicles still remains an open question which needs to be addressed.

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