Effect of Virtual Human Gaze Behaviour During an Orthogonal Collision Avoidance Walking Task

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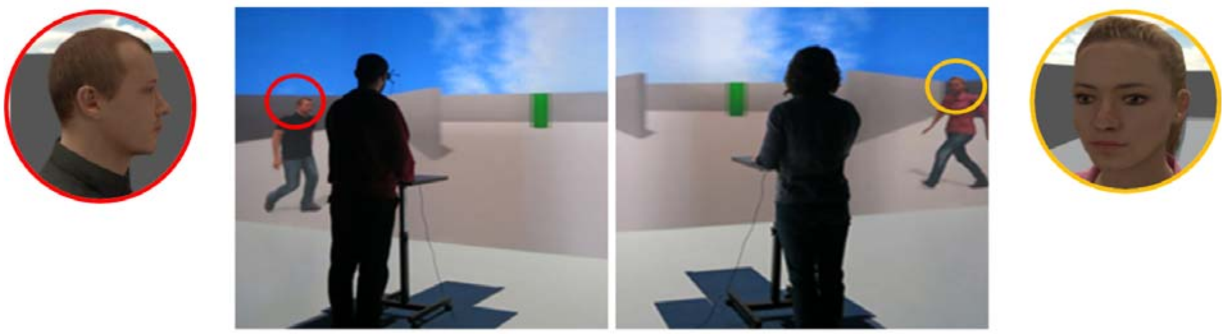

Figure 1: Third person perspective of participants navigating through a virtual environment; male participant interacting without gaze (left, red circle) and female participant interacting with gaze (right, orange circle).

Abstract

This paper presents a study performed in virtual reality on the effect of gaze interception during collision avoidance between two walkers. In such a situation, mutual gaze can be considered as a form of nonverbal communication. Additionally, gaze is believed to detail future path intentions and to be part of the nonverbal negotiation to achieve avoidance collaboratively. We considered an avoidance task between a real subject and a virtual human character and studied the influence of the character's gaze direction on the avoidance behaviour of the participant. Virtual reality provided an accurate control of the situation: seventeen participants were immersed in a virtual environment, instructed to navigate across a virtual space using a joystick and to avoid a virtual character that would appear from either side. The character would either gaze or not towards the participant. Further, the character would either perform or not a reciprocal adaptation of its trajectory to avoid a potential collision with the participant. The findings of this paper were that during an orthogonal collision avoidance task, gaze behaviour did not influence the collision avoidance behaviour of the participants. Further, the addition of reciprocal collision avoidance with gaze did not modify the collision behaviour of participants. These results suggest that for the duration of interaction in such a task, body motion cues were sufficient for coordination and regulation. We discuss the possible exploitation of these results to improve the design of virtual characters for populated virtual environments and user interaction.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, Augmented, and Virtual Realities; I.3.7 [Computer Graphics]: Three-Dimensional Graphics and Realism—Virtual Reality J.4 [Social and behavioural Sciences]: Psychology

1 Introduction

Navigation in populated environments is a fundamental requirement in many Virtual Reality (VR) applications. In this context, social interactions between a user and virtual human characters moving in the same environment is an important point to consider to improve the realism of the interactions as well as users' experience. During social interactions, gaze can be interpreted as one of several core processes: mutual and averted gaze, gaze following to joint attention and shared attention (see [26] for a social-cognitive review). In our daily experience of walking among other people, we generally accept that gaze plays an important role in the negotiation of collision avoidance. For example, mutual gaze between two walkers forms a mutual awareness, however, if one walker does not gaze at the other but rather is concerned with their direction or distracted with their personal device, it is the gazing walker whom is aware of the interaction and thus avoids the other. In this paper, we explore the effect of the presence or absence of virtual character gaze towards the user on the collision avoidance behaviour of the subject.

When two individuals gaze towards each other, mutual eye contact between the two implicitly influences the perception each has of the other [16]. Further, mutual gaze has been characterized as a main factor for social interaction [14]. The social interaction of mutual gaze is considered as a form of nonverbal communication, through emotional arousal from previous experiences or communicative intention [27]. For example, Caruana et al. [5] used virtual faces and

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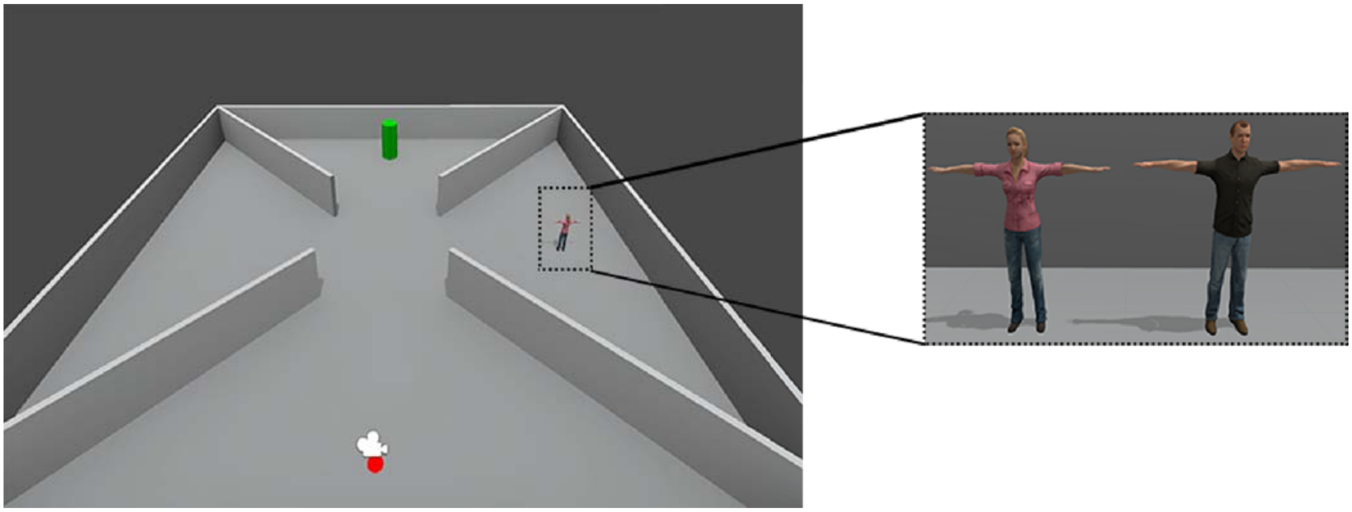

Figure 2: Participants navigated from the red circle to the green cylinder using a joystick, avoiding gender matched virtual characters.

gaze direction to form joint attention towards a goal. Bailenson et al. [1] highlighted the positive aspects of mutual gaze during interaction in terms of coordination-regulation and immediacy-arousal. The effect of mutual gaze has been demonstrated considering both real-real humans, humans and objects, and real humans-virtual characters social interactions [2, 16, 30]. Indeed, authors reported an increase of activity in the superior temporal sulcus, a region of the brain involved in the perception of gaze in a mutual gaze task with a virtual character [25]. Even if gaze is fundamental in social communication, it is also closely linked to associated body motions and orientation. For example, Marschner et al. [18] reported that emotion was evoked through the sum of mutual gaze and body orientation. Participants did not feel gazed upon if the character was gazing whilst orientated away from the agent.

The influence of gaze and eye contact during walking tasks have predominantly been investigated through face-to-face interactions; direct gaze, towards the participant or averted gaze, looking away from the participant. For example, in walking tasks, Bailenson et al. [2] reported that walkers gave more personal space to virtual characters who engaged in mutual gaze. During head-on collision avoidance, gaze direction of an oncoming walker is an important determinant cue for future path intention. Nummenmaa et al. [21] reported that participants used gaze as a cue to avoid collision: they orientated their path to the opposite side of the character's gaze. In this study, they did not report the effect of mutual gaze. Additionally, Narang et al. [20] reported the presence of a character's gaze towards a human walker improved sense of immersion in a crowded simulation. Finally, preliminary work has been completed during a collision avoidance task for crowd simulation [11]. The authors reported the subjective feedback of participants after crossing paths with a virtual character with or without gazing behaviour. The initial findings of this preliminary work are promising, with participants reporting a sense of being acknowledged and further self-reporting that they adjusted their responsive behaviour as a result.

Other studies have considered collision avoidance, but did not consider gaze information. They showed that collision avoidance behaviour responses during walking incorporate adaptations to the path of a walker, where further speed adaptations are reported at oblique angles of interaction [12]. Linear extrapolation of the instantaneous speed and orientation of two walkers during an orthogonal intersection predicts a future distance of closest approach, if no further adaptation of speed or orientation occurs [24]. This minimal predicted distance (*MPD*) quantifies the risk of collision, since initial values below 1m reveal a risk of future collisions and adaptations are observed. The threshold for adaptation [24] is in accordance with the notion of personal space, an elliptical area predominantly located in front of an individual. This personal space has been evidenced in reality and further it is preserved whilst immersed in virtual reality [9]. Temporal evolution of *MPD* showed that collision avoidance presents three successive phases: an observation phase (constant *MPD*), a reaction phase (MPD is increased to an acceptable value) and a regulation phase (the acceptable value is maintained). Moreover, it was reported that two walkers with a specified crossing order at the instant the two can observe each other kept their crossing order throughout the trial [23]. They associated this consistency of crossing order to nonverbal communication between walkers. This communication should be based on the global cues (the body trajectory more than limb trajectory) conveyed by the motion of the walker [17]. Moreover, crossing order and avoidance behaviours were shown to be influenced by situation specific characteristics of the task rather than personal appearance and traits of walkers, such as height and personality [15].

Finally, we can refer to the study of Croft et al. [7] who included gaze analysis in a collision avoidance task. They sought to identify locomotor strategies whilst crossing an interferer with two different velocities and two participants' path constraints. Their findings suggested that an early gaze at the interferer and longer fixations increased the likelihood that participants would cross second, and not gazing at the interferer increased the likelihood to cross first. However, they only evaluate the gaze behaviour of the walker but not the effect of this gaze on the other walker since it was an interferer with a predefined trajectory.

Objectives and contributions

In this paper, we investigated the influence of gaze behaviour on a collision avoidance task between a real human and a virtual human character. In contrast with previous works, we focused on the effect of gaze on the kinematics of interactions with two questions in mind. Would the presence or absence of gaze interception change the kinematics of collision avoidance between two walkers? And by extension, as Virtual Reality is today used to study locomotion and interactions [4, 17], is it important to correctly control virtual characters' gaze behaviours so as to not bias the experimental data acquired this way?

To answer these questions, we asked participants to perform a trajectory in a virtual environment and controlled a virtual character to cross their path. Among trials, the character would present a varying risk of collision with the subject, the character would gaze or not at subjects, and the character would perform or not avoidance maneuvers.

We assumed that the presence or the absence of gaze interception during the negotiation of collision avoidance will have an effect on the trajectories performed by a participant to avoid a virtual character. Our first hypothesis **(H1)** is that the absence of gaze interception (i.e., due to the character not gazing at the subject) may result into larger avoidance maneuvers by the participant, who does not expect collaboration to solve the task. However, the absence of gaze can be compensated by the presence of avoidance maneuvers perceived in the motion of the character. Which of these two visual cues plays the greatest role? Our second hypothesis **(H2)** is that if the gaze-related visual cue plays no important role in the interaction, the distance of crossing will not be impacted by the gaze factor (the subject controls their trajectory according to the relative motion of the character, whatever the gaze behaviour). A final hypothesis **(H3)** is that, when some incongruent stimulus is displayed, i.e., when the character looks at the participant but does not avoid them, we may observe a lack of avoidance by the participant who should expect collaboration (and thus, potential collision or abnormally low crossing distances).

Our contribution is to demonstrate that, in the simple kind of situation we considered, the locomotion of virtual characters provided sufficient information for participants to control their own motion. The presence or absence of gaze interception did not affect their motion. This result is detailed in the next sections.

2 METHOD

Participants. Seventeen healthy participants (12 males, 5 females), aged 24.6±2.9 years (mean±SD) volunteered for this study. Written informed consent forms were obtained prior to the experimentation and the study standards were in accordance to the Declaration of Helsinki.

Task. Participants were immersed in a virtual environment (Figures 1 and 2) and asked to navigate from their initial position (red circle) to a goal position (green cylinder) using a joystick. The apparatus was the same as the one used in [17,22]; participants were immersed in a 20m^2 virtual room, using a 9m wide, 3m high and 3m deep Computer Assisted Virtual Environment (CAVE) equipped with 13 projectors with 15MPixels resolution in total. Character animation and the 3D environment was designed using Unity game engine, multi-surface rendering was performed by MiddleVR, and active stereoscopy was achieved using Volfony ActiveEyes Pro Radiofrequency wearable glasses that were tracked by a 16 camera ART tracking system. User starting position was located 9.5m from the centre of the room (Figure2, red circle). Participants were instructed to avoid potential collisions with a virtual character that would appear in their path whilst advancing towards their goal, located 19m opposite their starting position. To limit any gender effect in the interaction, female and male participants were interacting respectively with female and male virtual characters. The character moved along a trajectory perpendicular to participants' own trajectory. We set occlusion walls in the environment to control the moment at which participants can perceive the character (tsee). This allowed participants to reach a baseline steady state speed (1.4m$\cdot$s^{-1}), which resembles a typical normative human walking speed [3], before the interaction and before being able to adapt their speed and trajectory using the joystick. The longitudinal axis of the joystick controlled speed linearly from 0.8m$\cdot$s^{-1} to 2.0m$\cdot$s^{-1}, and the lateral axis controlled angular rotation speed linearly from -25deg$\cdot$s^{-1} to +25deg$\cdot$s^{-1} [4,17,22].

Experimental Design. Following our hypotheses, two main factors, namely gaze with head rotation behaviour and the reciprocal avoidance behaviour of the virtual character, were manipulated in our study. Each factor has two levels described below:

1) Gaze Behaviour: For the first level **No Gaze (*NG*)**, the virtual character does not look at the participant but straight ahead, as a stereotypical interferer that does not formulate social interactions with the agent. For the second level, **Gaze (*G*)**, the virtual character looks at the participant. More precisely, the character first looks ahead, then, 0.2s after MPD_{tsee}, it directs its gaze to the head of participants. During 1.5s, the character fixates on the participant before returning gaze to walking direction. Gaze behaviour is performed by animating eye, head and neck components (through head and shoulder rotation) of the virtual character, based on previous work of [10].

2) Avoidance Behaviour: For the first level **No Avoidance (*NA*)**, the virtual character maintained a straight path towards its goal at a constant speed. For the second level **Avoidance (*A*)**, the virtual character adapted its path to ensure a safe passage at the future predicted crossing point using the RVO algorithm [28].

We combined these two factors so that we had the following conditions: No Gaze + No Avoidance (*NGNA*), No Gaze + Avoidance (*NGA*), Gaze + No Avoidance (*GNA*), Gaze + Avoidance (*GA*).

In this study, the virtual character would advance from the agent's occluded right or left. We controlled the potential danger of the interaction to assess whether the gaze behaviour had an effect on the perception of the situation. The future risk of collision was computed using the Minimum Predicted Distance variable (MPD) as previously defined by [24]. It was set at the beginning of the interaction by controlling participant's baseline speed and heading until tsee, and further controlling the starting position of the character, which had the same baseline speed as the participant and a constant heading [24]. Both participant and virtual character were located 9.5m from the intersection point, at constant heading and velocity both arrive at the same instant. For our experimental conditions, we offset the starting position of the character, in place of offsetting the starting time. A total of 5 future crossing distances computed at tsee (MPD_{tsee}) were chosen, varying the initial risk of collision in the interaction; 2 high risk distances, where a collision would occur if no adaptation is implemented (0.1 and 0.3m), an intermediary distance (0.6m) that would require no adaptation, what is actually observed between two pedestrians, but an inversion is reported while interacting with robots and virtual characters [17,29], and finally 2 low risk distances, where no collision would occur if no adaptation is implemented (0.9 and 1.2m). Furthermore, we controlled the initial crossing order at tsee where the virtual character would pass the participant either in front ($MPD_{tsee} < 0$) or behind ($MPD_{tsee} > 0$) at these randomized risk of collision distances. Each participant performed 80 randomized trials (4 behaviour responses × 2 crossing sides (left-right) × 5 MPD × 2 crossing orders). At the end of the experiment, we asked participants to report which parameters they thought we evaluated during this study. We also collected self-reported feedback. The duration of the experiment per participant was one hour.

Data analysis. Post-processing of trajectories and the interaction response of the participant was performed using customized MATLAB scripts (Mathworks 2015b). The dependant variables were: final crossing distance, number of collisions, and number of inversions of initial crossing order. Where crossing distance was the shortest distance between the participant's and the character's centers, collision occurred when crossing distance was less than the sum of both participant's and character's radii, and crossing order was classified as the participant passing the character first or second and an inversion was a change from initial order (initial order is estimated by a linear extrapolation of trajectories based on the initial positions and velocities). *MPD* evolution over time was also computed and was normalized to the period of interaction, that is, from MPD_{tsee} to MPD_{tcross} (i.e. the instant when the crossing distance is minimal).

A Kolomogorov-Smirnov test determined whether data followed a normal distribution. In congruence with the aim of this study, *NA* and *A* behaviours were considered separately, focusing on an effect of gaze behaviours. Since data were not normally distributed, we evaluated this effect using Wilcoxon's signed-rank non-parametric test. We performed this comparison considering all the trials for each condition of gaze/avoidance but also separately with respect to MPD_{tsee} values, defining the initial risk of collision in the interaction. We set the level of significance to $\alpha = 0.05$ and we reported median values. Finally, we compared the evolution of *MPD* using statistical parametric mapping (SPM, [8]).

3 RESULTS

3.1 Collisions

Table 1: Total percentage of collisions observed for each MPD_{tsee} values (in meters) with respect to the conditions of gaze and avoidance.

	% of Collisons			
mpd tsee	*GNA*	*NGNA*	*GA*	*NGA*
-1.2	0	0	0	0
-0.9	0	0	0	0
-0.6	0	2.94	0	0
-0.3	2.94	0	0	0
-0.1	5.88	2.94	0	0
0.1	2.94	11.76	0	0
0.3	5.88	5.88	0	0
0.6	0	0	0	0
0.9	0	0	0	0
1.2	0	0	0	0

First, we inspected the presence of collisions between the participants and the virtual character. Among all of the 1360 trials performed by all participants, the collision avoidance task was successfully performed: there was a total of 14 collisions between the character and the participant, meaning that only 1% of the trials performed presented a collision. Figure 1 illustrates the percentage of collisions observed depending on the MPD_{tsee} values as well as the conditions of gaze and avoidance. Obviously, no collision was observed in the avoidance condition since the RVO navigation algorithm prevented the character from colliding with the user. Collisions were observed only in the No Avoidance trials where MPD_{tsee} ranged from -0.6m to 0.3m.

There was no significant effect of the virtual character gaze behaviour ($p>0.05$) neither in *NA* nor in *A* conditions when considering the number of collisions per participant for all trials (median value: *GNA*=0% and *NGNA*=0%, *GA*=0% and *NGA*=0%) or separately for each MPD_{tsee} conditions (i.e., defining the initial risk of collision).

These results are not in accordance with hypothesis **(H3)**. Indeed, in the *GNA* condition, we hypothesized that the virtual character gaze would let participants expect collaboration in the avoidance task while there is not. Assuming collaboration, the participant would not adapt the trajectory enough to avoid the character, resulting into more collisions. Comparisons between gaze and no gaze conditions (resp. *GNA* and *NGNA*) show no significant difference in the number of collisions. Therefore, there was almost no ambiguity in the interpretation of the virtual character trajectory whatever the gaze conditions, allowing safe crossings even in most situations without avoidance strategy being implemented by the virtual character where the initial risk of collision was high ($-0.3\text{m} < MPD_{tsee} < 0.3\text{m}$).

3.2 Inversions of Crossing Order

Second, we explored inversions of the crossing order between the participant and the virtual character. Among all of the 1360 trials, 165 trials presented an inversion of the crossing order (i.e., 12% in total). The percentage of inversions depending on MPD_{tsee} values with respect to the conditions of gaze and avoidance is illustrated on figure 2. Inversions were observed for MPD_{tsee} values ranging from -0.6m to 0.6m. Especially, we found a high percentage of inversions in the -0.1m condition with half of those trials recording an inversion of the crossing order.

Table 2: Total percentage of inversions of crossing order observed for each MPD_{tsee} (in meters) values with respect to the conditions of gaze and avoidance.

	% of Inversions			
mpd tsee	*GNA*	*NGNA*	*GA*	*NGA*
-1.2	0	0	0	0
-0.9	0	0	0	0
-0.6	20.59	17.65	8.82	11.76
-0.3	32.35	17.65	38.24	29.41
-0.1	47.06	55.88	50	50
0.1	8.82	20.59	17.65	20.59
0.3	8.82	11.76	2.94	8.82
0.6	0	0	2.94	2.94
0.9	0	0	0	0
1.2	0	0	0	0

Considering the influence of our experimental parameters, mutual gaze had no significant effect ($p>0.05$) on these percentages neither in *NA* nor in *A* conditions either considering all the trials together (*GNA*=10% and *NGNA*=10%, *GA*=10% and *NGA*=15%) or when performing the statistics separately for each MPD_{tsee} values. These results are in contradiction with our expectations, i.e., in the No Gaze conditions, the participant would not expect collaboration and would more readily give way, even when likely to pass first. While [23] reported no inversion within unconstrained collision avoidance between two real walkers, Vassallo et al. [29] reported inversions between a walker and a robot when MPD_{tsee} values ranged between 0 and 0.8m. Similarly, Lynch et al. [17] reported inversions between a user and a passive virtual obstacle but did not detail their results with respect to MPD_{tsee} values. Olivier et al. [23] attributed the task resolution as a nonverbal communication between two walkers, where [17, 29] presented subjects with non-communicative partners, a passive robot and passive virtual obstacles respectively. While, Vassallo et al. [29] suggested a level of perceived danger, a lack of experience of interacting with robots as well as the passive nature of the robot as causes of inversion, Lynch et al. [17] attributed inversions to a lack of nonverbal communication and behaviour uncertainty. Here we studied the effect of gaze behaviour and reciprocal avoidance behaviour during a collision avoidance task with a virtual character. Similarly to collisions, the gaze behaviour had no effect. Few inversions were reported when considering all the trials but a large number were reported for the -0.1m condition. This result can be linked to the one previously observed in [22] involving the interaction between a participant and a non reactive and neutral virtual character. In their perceptual study, authors showed that participants were not accurate to predict the future crossing order when MPD_{tsee} was equal to -0.1m. They interpreted this inaccuracy as a forward shift in space of the perceived body envelope in virtual reality. We can then hypothesize that in our set-up, the perception of the relative motion of the virtual character with respect to the participant perceived position was more important than the gaze to define the interaction.

3.3 Crossing Distance

Crossing distances for all trials considered together are illustrated in Figure 3 (the large variability is explained by the fact that we plot the values for all the MPD_{tsee} conditions).

Gaze behaviour of the virtual character had no significant effect ($p>0.05$) on the final crossing distance, neither in *NA* nor in *A* conditions (*GNA*=1.22m and *NGNA*=1.20m, *GA*=1.20m and

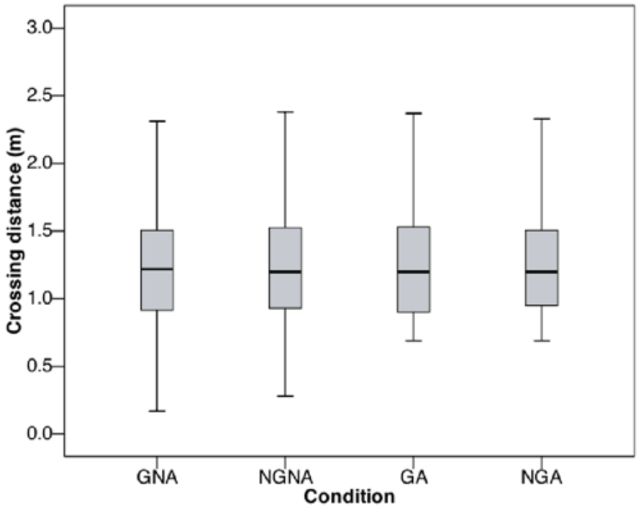

Figure 3: Boxplot of crossing distance (median, 1st-3rd quartiles, min-max values) depending on gaze and avoidance behaviour.

NGA=1.20m) when considering all the trials performed by participants. This is also true when considering the trials with respect to the initial risk of collision (MPD_{tsee}). These results validate our hypothesis **(H2)**. The final crossing distances reported here are similar to those of [17, 22], which are larger than those observed in reality [24, 29]. The increased crossing distance in VR may have been caused through immersive depth perception that was mainly reported in previous studies. Gerin-Lajoie et al. [9] compared behavioural differences and personal space preservation between reality and VR during an obstacle circumvention task, it was reported that the personal space elliptical shape was similar to reality although the size increased within VR. Furthermore, the fidelity of the environment or the perceived agency of the the virtual characters may have affected the behavioural responses. Where, considering the effect of gaze with virtual characters, behaviour is significantly altered if an individual is in belief of interacting with a virtual avatar or a virtual agent [2]. Which was in agreement to the sense of being gazed upon, with decelerated heart rate, skin conductive responses, and positive frontal P3 cortex response [19]. Considering these previous findings, participants may have adapted their behaviour to the belief of interacting with an avatar as opposed to a reciprocal agent. Therefore, participants may have directed their attention to perceptual variables, such as bearing angle and optic expansion of full body motion, which are sufficient for collision avoidance from full body motion cues [17].

3.4 MPD Evolution over Time

Finally, we investigated the collision avoidance behaviour during the interaction by considering *MPD* evolution over time. For each condition of gaze and avoidance, the behaviour conformed to those previously reported in real and virtual conditions [17,22,24]. Indeed, as illustrated in Figure 4 for all the trials, we can describe for each condition of the present study the three distinct phases of interaction: observation (*MPD* value is constant), reaction (*MPD* is increased), and regulation (*MPD* is maintained constant at a comfortable distance). The anticipation previously reported during interactions between real walkers is preserved since we observed the regulation phase that showed that the task is solved before the end of the interaction.

Quantitatively, the SPM analysis showed that there was no significant effect of gaze behaviour on *MPD(t)* values or duration of each phase, neither in *NA* nor in *A* conditions ($p>0.05$) when considering all the trials together (considering the absolute value of *MPD*) as illustrated in Figure 4 or separately with respect to initial MPD_{tsee} values. These findings are not in accordance with Hypothesis **(H1)** and thus further corroborates Hypothesis **(H2)**. There were no reported differences throughout the evolution of *MPD*, independent of our experimental parameters. Interestingly, the evolution of *MPD* in both *NA* and in *A* conditions were similar. This similarity was observed for all initial MPD_{tsee} with no reported significant differences ($p>0.05$), suggesting that participants may have directed their attention to perceptual variables related to the trajectory [17] rather than to the gaze behaviour of the character to avoid.

3.5 Gaze Behaviour and Collision Avoidance

From these results, our first **(H1)** and third **(H3)** hypotheses were not validated and our second hypothesis **(H2)** was, since the presence of virtual character gaze activity towards the participants did not modify collision avoidance behaviour neither whilst interacting with a passive nor a reactive virtual character. Indeed, as suggested by [13, 18], we would have expected that interaction is influenced by both mutual gaze and body motion cues.

Considering our results, we can conclude that within this current experimental set up, body motion cues conveyed by the virtual character were enough for the collision avoidance task. We reiterate that our set up considered a pairwise interaction within a simple environment, without challenging conditions requiring adaptation in a small amount of time, or within a restricted space. Therefore, when designing a simple situation of interaction where a user has to avoid a collision with a virtual character, it is important to focus on the generation of a relevant walking trajectory rather than focusing on the gaze behaviour of the character.

However, we can hypothesize that stronger spatial and temporal constraints of the virtual environment would have increased the importance of mutual gaze in the decision-making process of avoiding a collision. In particular, the effect of gaze during a collision avoidance task within a crowd should be considered as future work. The increased immersion that subjects experience from a crowded environment and the increased complexity as opposed to a single virtual character could increase the role of mutual gaze between walkers, which may produce significant differences of avoidance behaviour.

3.6 Limitations

One can wonder whether these results can be explained by the fact that users did not perceive the gaze behaviour of the virtual character. However, we validated that the gaze behaviour was perceived by the participants and thus forming a mutual gaze between walkers, through their subjective questionnaire post immersion. Each participant responded to the question "In your opinion, what were the parameters being investigated today", to which several example responses were: "The movement of the head", "The orientation of the head and eyes", "Orientation of the eyes and head during collision avoidance", and "The trajectory and function of position, speed and gaze of the virtual character". These subjective reports confirm that participants noticed the gaze and body motion cues of the character, however, there were no differences on avoidance behaviour. In our study a social presence questionnaire was not included due to the randomized experimental design. However, it would have been interesting to evaluate this potential effect of the mutual gaze since it was previously shown that mutual gaze can increase the sense of immersion [20]. Additionally, being an interaction through virtual reality and joystick, one can wonder whether the ecological validity of the interaction is preserved and therefore whether the gaze behaviour is the same as in real conditions. Nevertheless, the apparatus we used was previously validated for goal directed locomotion trajectories [6] as well as interaction involving collision avoidance between walkers [22]. Especially, during collision avoidance tasks, it was shown that the trajectory performed by the user qualitatively matched the

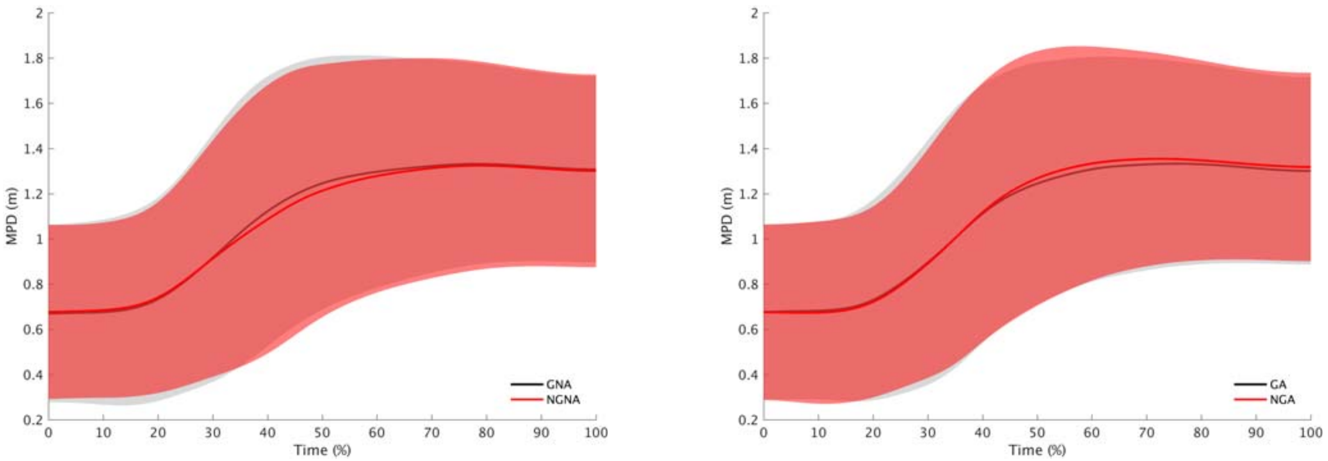

Figure 4: SPM analysis of *MPD* evolution, comparing effect of gaze within trials of No Avoidance (*NA*, left) and Avoidance (*A*, right) conditions. Each plot shows mean *MPD* evolution with gaze (black line) and without gaze (red line), with respective standard deviation clouds.

ones performed in real conditions even if quantitatively some differences exist (e.g., over-adaptation to avoid the collision). Therefore, the quantitative differences that exist between virtual and real conditions in such a situation may have hidden the influence of gaze if this influence is subtle. It should of course be interesting to design new experiments which include other locomotion metaphors to be more accurate in the quantification of the avoidance behaviour and its link with gaze behaviour. Finally, we can question the gaze behaviour model we used in this study [10]. While, the model is efficient and easily introduced to our experimental set up, it is based on joint rotational timing laws and a fixed point of interest, in this case the participants position. It is generally accepted that participants gaze at their confederates and reported to influence avoidance behaviour depending on number of fixations and duration [7]. However, to our knowledge, there have been no report specifying limits for fixation location, duration and, head and eye rotational limits for a similar paradigm of occluded walkers intersecting paths. Therefore, future work should consider the capture and analysis of the gaze behaviour between two unconstrained participants to experimentally assess that there is indeed a gazing behaviour and furthermore a mutual gaze during the interaction.

4 Conclusion

The results of this study showed that mutual gaze had no effect on pairwise avoidance behaviour, neither whilst interacting with a passive nor a reactive virtual character. We still believe that gaze plays an important role in collision avoidance, but our experiment was not able to reveal an effect on avoidance behaviour. The influence of gaze may be dependent of the characteristics of this task, such as the duration of interaction and its complexity. Alternatively, body motion cues conveyed enough information to solve this task. Future work should then consider more complex situations and the use of eye tracking, which allows specification of cues derived for future collision prediction. For example, we can immerse a user within a crowd with some virtual walkers gazing and others not gazing at the user. This situation would allow to investigate whether the selection of the interactions within the users' neighbourhood as well as their trajectory is influenced by the gaze of the virtual walkers. Finally, even though we do not report a significant effect of gaze on avoidance behaviour within our experimental set up we would still conclude that a gaze behaviour should be included in the animation of virtual characters. Where the inclusion of gaze has been previously reported to increase immersion [20] and within our experiment, even though no presence questionnaire was included, participants acknowledged the change in the virtual characters behaviour.

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