Cross-Cultural Behavior Analysis of Street-Crossing Pedestrians in Japan and Germany

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***Abstract*— Software solutions for advanced driver assistant systems should be culturally fair, in particular when perceiving and reacting to pedestrians. To ensure the generation of suitable training and testing scenarios, a detailed understanding of pedestrian behavior and cultural differences in behavior must be established. However, direct comparisons between the populations in different countries are scarce and complicated to conduct in real environments. In this work, we present the first cross-cultural pedestrian behavior study analyzing and comparing pedestrian behavior between Japanese and German pedestrians. For this purpose, a new and large-scale virtual reality (VR) environment was created and the same experiment was conducted in Germany and in Japan. We identified new insights in gap selection, choice of velocity, following behavior, and route choice. Particularly for the route choice adjacent to zebra crossings, the differences between Japanese and German pedestrians are more complex than past studies might suggest. In addition, the data captured in the VR environment can be directly utilized to train and test algorithms used in intelligent vehicles in a digital domain.**

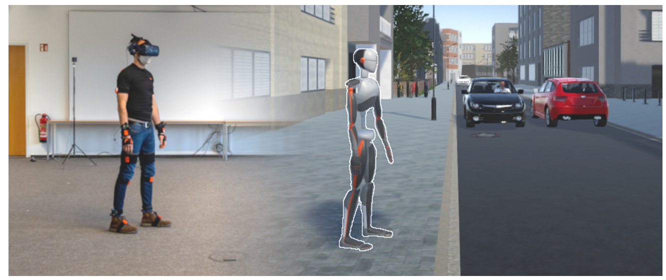

Fig. 1. Exemplary visualization of the experimental setup comparing the real environment (left) and the virtual environment (right)

I. Introduction

The next generation of intelligent vehicles will require robust and safe interaction with pedestrians. Long-horizon predictions of pedestrian intention and trajectory are required to allow an early adjustment of the ego-vehicle movement and to prevent emergency braking as much as possible. Solutions to perceive and interact with pedestrians need to be developed and tested in a safe environment, without endangering real pedestrians. In addition, these solutions should be able to operate in different countries. For example, solutions developed in Germany should be fully operational in Japan and vice-versa. Specifically for these two countries, we are not aware of any direct experimental comparison of pedestrian behavior. However, past studies conducted in each country separately suggest differences in rule compliance [1], [2], uncertainty [3], [4], gap acceptance [5], [6], or self-selected velocity for crossing [7], [8]. As such, assumptions made for pedestrian intention and path prediction can be violated or training data might be mismatched for one of the countries if these differences are not properly considered.

Conducting pedestrian experiments in virtual environments enables a direct comparison of cultural groups, while simultaneously enabling a very accurate recording of the state, posture, and gaze of participants. There have been multiple virtual reality (VR) studies using multi-screen environments [9], cave-systems [10] and head-mounted VR scenes [11]. Existing simulators do not offer enough walkable space to allow free movement of participants, especially when considering reeving behavior of turning into the traffic. However, improvements in head-mounted VR systems have enabled larger experimental areas and at the same time are easy to transport between different experimental sites.

In this work, we are presenting the results of an experimental cross-cultural study analyzing the pedestrian behavior of 120 participants in Germany and Japan. For this purpose, a new simulation environment was developed, in which participants can move freely at a self-selected route with a self-selected velocity and style of locomotion. An untethered, head-mounted VR display with external tracking was used for visualization. Participants were asked to cross the virtual street in different scenarios based on our research hypotheses, which were defined after consolidating existing research conducted in both countries separately. In particular, we could identify new insights for the gap selection, choice of velocity, following behavior, and route choice of pedestrians and present evidence for previously unknown cultural differences. Our findings are already relevant for the cultural adaptation of advanced driver assistant systems (ADAS) which interact with pedestrians, for example, path-prediction algorithms. In addition, the captured data can be directly utilized to generate and validate digital test environments for self-driving cars.

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II. Related Work

Traffic regulations. The Japanese and German traffic regulations are similar, most of all when it comes to pedestrians, and thus present an ideal opportunity for direct comparisons. In both countries, pedestrians are allowed to cross the street without crossing facilities (e.g. zebra crossings) but are supposed to utilize facilities, if they are in the vicinity.[1] Vehicles must yield to pedestrians at zebra crossings, even before they are on the street[2]. Improper crossing (e.g. crossing right next to a zebra crossing), can still be fined depending on the situation. There are minor differences though, which must be considered during experimental design to establish comparable environments. For example, while cars in Japan are driving in the left lane (left-hand traffic), right-hand traffic is mandatory in Germany. For a more in-depth comparison of traffic regulations, we refer to review articles [12], [13].

General cultural differences. Considering internal factors of both cultural groups, [14] showed a higher uncertainty avoidance and lower individualism in Japan compared to Germany. It is usually assumed, that in western societies, including Germany, an independent construal of self can be assumed [15], in which the primary cause of action is attributed to personal preferences, internal thoughts, and feelings. People with an interdependent construal of self, on the other hand, rely more on the social context, maintaining interdependence and harmony among the members of society [16]. Although Japan's orientation towards collectivism has gradually declined in the past, it is still a fundamental part of its culture [17]. However, the extent to which general differences in uncertainty and collectivism of the peoples of both countries affect the concrete behavior of their pedestrians remains unclear.

Pedestrian behavior differences. There are only a few studies that directly investigated the cultural differences in pedestrian behavior (e.g. [5], [18]). To the best of our knowledge, none of them specifically address differences between Japanese and German pedestrians. Different pedestrian studies have been conducted in each country separately, allowing not a direct comparison but information about potential differences. In these separate studies, Japanese pedestrians show a slightly lower violation of traffic regulations (2% - 7%) [1], [5] compared to German pedestrians ($5.8\% - 39\%$) [2], [19]. They displayed a larger range of selected velocities (1.4m/s - 3m/s) [7], [20] than German pedestrians (1.57 - 1.72m/s) [8] and are observed to change their velocity, unlike German pedestrians [7], [8]. When crossing streets, Japanese pedestrians are observed to utilize larger gaps (16s) [5] compared to German pedestrians (5-6s) [6], [8]. For a more comprehensive overview in this regard, we refer the interested reader to [13]. However, these reported results are not definite but served as a starting ground for further cross-cultural investigation of other aspects of street-crossing behavior of pedestrians in both countries.

[1]JPN: Street Traffic Law no. 105 (1960) §12; GER: STVO §25
[2]JPN: Street Traffic Law no. 105 (1960) §38; GER: STVO §26

VR user studies. While observational studies usually result in the most realistic behavior [21], they involve many confounding events (e.g., other pedestrians and variation in traffic density) and the extraction of data is difficult. Experimental studies in virtual environments, on the other hand, allow easier data processing, higher safety for participants, and excellent comparability between cultures. When considering experimental studies using virtual environments, there are different techniques that can be employed. In multi-screen environments (e.g. [9]), multiple displays show the street environment and the participant can provide information via game controllers or indication of crossing intention. In cave-systems (e.g. [10]), multiple displays or projections are surrounding the participant, allowing for a 360-degree view. In addition, participants can move inside this environment, although the utilization of treadmills is common for longer distances [22]. Head-mounted displays (HMDs, e.g. [11]) allow for proper display of the ground in relation to the background and can result in a higher immersion and better perception of crossing affordances [23]. For further information on VR-simulator studies of pedestrian behavior we refer to respective review articles, such as [22]. However, regardless of the VR technology utilized in these studies, the physical space that a participant could enter was highly restricted. This restriction stretched from a few steps [24]–[26] up to a single lane crossing [27]. In addition, the scene complexity [21] and answer modality [10] are reported to influence the decision of pedestrians. Thus, free movement in all directions and across the whole street is required to improve the realism of the captured data. Unlike the above-mentioned studies, our newly developed environment offers this type of freedom.

III. Methodology

A. Research Hypotheses

Based on related work on pedestrian behavior, we investigated behavioral aspects according to the following new research hypotheses in our VR user studies in Japan and Germany. For 'direct street-crossing' scenarios without any crossing facility, Japanese participants are expected to cross the street with higher velocity (*H1.a.*) [7], [8] while requiring longer gaps to directly cross the street (*H1.b.*) [5], [6]. When crossing together with virtual pedestrians ('group crossings'), it is expected that the virtual pedestrians influence the gap choice of participants (*H2.a.*). Furthermore, we hypothesize that Japanese participants, unlike German participants, are influenced by the number of other crossing pedestrians (*H2.b.*), based on a difference in construal of self [15], [16]. Finally, for zebra-crossing scenarios ('zebra crossings'), Japanese participants are expected to have higher rule compliance [1], [2] and thus utilize the zebra crossings more often (*H3.a.*). In addition, Japanese are expected to wait longer in front of the zebra crossing before crossing (*H3.b.*) due to a higher uncertainty [14].

TABLE I

DESCRIPTIVE STATISTIC OF ALL PARTICIPANTS

	GER	JPN
Participants	60	60
Female	30	30
Age ($years$)*	25.42 (5.93)[a]	35.70 (8.68)
Height (cm)*	176.09 (8.66)	168.83 (8.90)
BMI (kg/m^2)*	23.02 (3.77)	21.04 (2.20)
Driving experience ($years$)	6.80 (6.10)	12.03 (10.34)

*Significant differences with a Bonferroni-corrected level of 0.00625

[a]mean values, standard deviations in brackets

B. User Studies in Japan and Germany

Participants. In each country, 60 participants between the age of 20 and 50 years were recruited. The experiments took place in Saarbrücken, Germany, and Tokyo, Japan. Participants had to be within a normal range of BMI (body-mass index), without any known physical or mental disabilities, and normal or corrected to normal vision. The study was reviewed and approved by the local ethical review boards in each country in advance (registration numbers in Japan: H2022-1166-B; and in Germany: 21-08-06).

The descriptive statistics of all participants can be found in Table I. As expected, Japanese participants were significantly smaller in both height and weight (BMI) compared to German participants. The German participant group was significantly younger compared to the Japanese age group due to differences in recruiting. While participants were recruited from the local university in Germany, a recruiting company selected participants from the general population of the Kantō area. Within this age group, however, past research does not suggest an influence on the analyzed behavior.

Experimental procedure. After preparation, participants started with a short initial familiarization and training period inside the virtual reality environment. During the actual experiment, three different types of crossing scenarios were performed for the above-mentioned hypotheses. In ‘direct crossing’ (15 trials), participants had to cross the street alone. In ‘zebra crossing’ (15 trials), there was a zebra crossing 6.25m away from the starting position, which participants were not required but allowed to use. In ‘group crossings’ (30 trials), there were additional virtual pedestrians crossing alongside the participant. Fig. 3 shows the experimental setup for all different scenarios and an example frame from an ego-perspective of a pedestrian can be found in Fig. 2.

The ‘direct’ and ‘zebra crossing’ trials were grouped together in one block and shown separately from the ‘group crossings’. The order of blocks was balanced over all participants. After every 20 trials, participants were offered a break. On average, participants required 11.63min for 20 trials.

C. Technical Set-Up

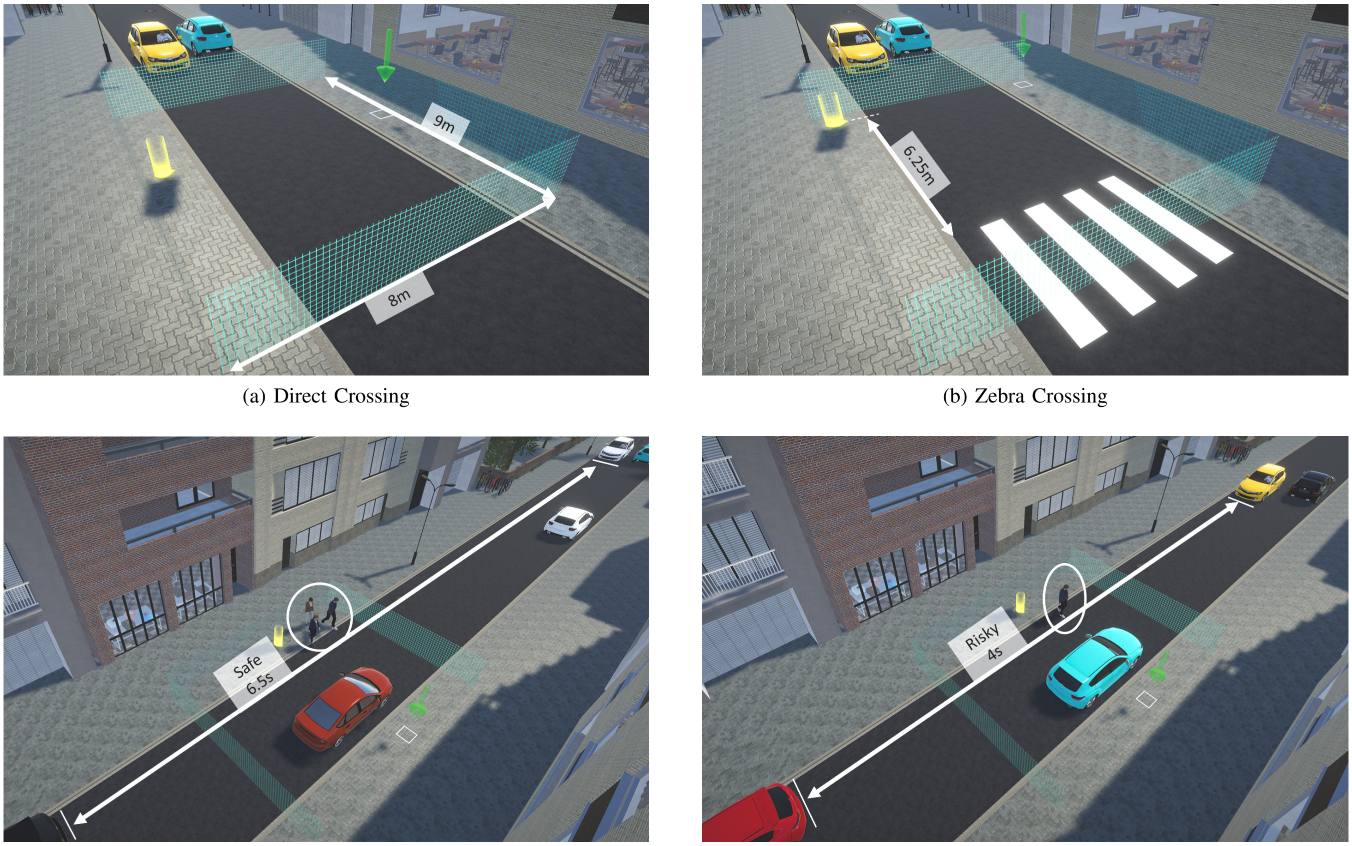
As mentioned above, we developed a simulation environment to capture pedestrian behavior and movement. In particular, this virtual 3D environment was specifically designed to represent a street scene in both countries, requiring only minor cultural adaptations. The proposed system allows the participants to walk and run freely in a 9m by 8m area with head-mounted VR headset and an IMU-based motion-capturing system.

Fig. 2. View from the perspective of a participant during the experiment

Virtual environment. Using the Unity 3D game engine, a virtual 3D scene displaying a single-lane bi-directional street was constructed. Each lane has a width of 2.25m and the street a total width of 4.8m (including the gutter), a curb of 5cm height and 10cm width, and a 4.5m wide sidewalk. The lanes are not separated by a center line. Participants are able to walk within 1.5m of the sidewalk until a visual wall indicates the bounds of the physical experimental space. The virtual street consists of a straight segment of 200m after which a curve follows. The participant space is positioned in the center of the straight segment, allowing for a visual distance of up to 140m. Additional houses prevent participants from perceiving the horizon in all directions. Several virtual small-sized sedans of different colors are displayed, driving along the predefined curve of the street. Cars are spawned outside of the visual space of the participants, are driving at a constant 30km/h, and a virtual driver is placed inside each vehicle in a driving position. A visualization of the environment can be seen in Fig. 3.

In some trials, unsignalized zebra crossings with a width of 3m are displayed, and the start is moved to the corner of the walkable space to a distance of 6.25m of the zebra crossing (see Fig. 3b). When participants are within the vicinity of the zebra crossing, vehicles stop at the zebra crossing until the participant leaves the vicinity of the crossing again. Outside of the zebra crossing, vehicles do not stop for pedestrians and in case of a collision, the trial is stopped and an according message is displayed to the participant. Some trials also contained other virtual pedestrians in the scene. Two male and two female characters were created for each cultural environment and dressed in the same clothing. Virtual pedestrians crossed the street either in a ‘safe gap’ (6.5s) or a ‘risky gap’ (4s). A visualization of the ‘risky gap’ can be seen in Fig. 3d.

Cultural adaptations. To conduct a pedestrian study in different countries, minor cultural adaptations of the traffic scenes were required. Besides mirroring the street from right- (Germany) to left-handed (Japan) traffic, the UI elements were translated and the body size and facial features of the virtual pedestrians were adjusted. No participant complained



(a) Direct Crossing

(b) Zebra Crossing

(c) Group Crossing (Safe)

(d) Group Crossing (Risky)

Fig. 3. Experimental setup showing all types of trials. Start and goal positions were mirrored in every other trial to prevent street crossings outside the experiment. The example images here display right-handed (German) traffic. In all trials, the start position was in the middle of the walkable space, except for zebra crossings (b), where the start and goal were shifted to one side of the space. In group crossing scenarios ((c) and (d)), different combinations of pedestrians were shown. Pedestrian geometry models were randomized.

about the authenticity of the environment or visualization of characters.

Hardware. The Vive Pro Eye head-mounted VR goggles were utilized using the wireless adapter to allow uninhibited movement of participants. Since the Vive wireless adapter was not certified in Japan at the time of the experiment, permission to use the device was obtained from the Ministry of Internal Affairs and Communications (Registration number: 01-20220524-03-997372). Using four SteamVR Basestations, a lighthouse environment of 9m by 8m was created. The IMU-based motion-capturing solution "MVN Awinda" by Xsens using 17 IMU sensors was utilized to track the kinematic movements of all participants. The sensors are strapped to the body of participants with the provided straps and t-shirts on top of their usual clothing. Additional Vive trackers were used for better spatial alignment [28].

Dataset. The recorded raw data contains only minimal information required to exactly replay the whole experiment, including state information, duration information, positional information, and motion capture synchronization for every frame. During replay, more computationally expensive and acausal operations can be performed, like image extraction or the identification of false starts. The only difference between the actual experiment and the replay was the stochastic noise inherent to the render pipeline. The statistical evaluation presented in the results is performed on data, computed in the replay functionality.

IV. Results

Non-parametric tests were utilized for statistical comparisons, if the assumption of normal distribution was violated. If multiple tests were computed for the same construct, significance levels were adjusted using the Bonferroni correction. The statistical evaluation was computed using R [29] version 4.2.1.

A. Direct Street Crossing

From the recorded data of all 'direct crossing' trials, the velocity was computed using the differences of position in a sliding window of one second. While on the pavement of the street, Japanese participants moved with a mean velocity of 1.51 m/s (SD=0.18), while German participants moved with a velocity of 1.43m/s (SD=0.19). This difference was significant ($t(117.92)$=-2.444; p=.008), thus confirming our hypothesis of Japanese participants using a faster pace when crossing the street *H1.a*.

As to our hypothesis *H1.b.*, the gap in traffic was computed as the smallest time-gap between both cars on the opposing lanes. The gaps were computed over all 'direct crossing' trials. In this study, German participants accepted a mean gap of 5.94s (SD=0.43) and Japanese participants a mean gap of 6.11s (SD=0.44). Although the numerical difference between the average gap is only small (0.17s), the difference was significant (t(117.95)=-2.152; p=.017). Thus it confirms our hypothesis, that Japanese participants require larger gaps in traffic to cross. Before crossing, Japanese participants waited significantly longer (Mdn=14.09s), than German participants (Mdn=10.23s) to select a suitable gap (U(N=60)=816, p<.001) and rejected larger gaps (4.8s, SD=0.85) than German participants (4.07s, SD=0.81; t(117.65)=-4.44, p<.001). In addition, twenty-three Japanese participants were not able to complete crossings in time (60s), in contrast to only one German participant in this respect.

In general, these results suggest that Japanese pedestrians may have a higher desire for safety than German pedestrians, as they waited longer to accept a larger gap and then walked faster to cross the street. In addition, in all trials 119 Japanese participants (56 German participants) aborted their crossing attempt, which indicates an additional higher uncertainty before crossing.

B. Following Behavior

To test the influence of other pedestrians on the gap choice, direct crossing trials without virtual pedestrians (agents) were contrasted with trials in which these agents took either risky or safe gaps. The experiments revealed that the general following behavior of all participants concerning accepted gaps is significantly influenced by the presence of virtual pedestrians (ANOVA $X^2(2)$=18.43, p<.001), which confirms our hypothesis *H2.a*. Pairwise comparisons revealed that the presence of an agent that safely crosses the street resulted in significantly larger accepted gaps (Mdn=6.50s) by the participant than in the presence of a risky agent (Mdn=6.12s, p<.001). Furthermore, a safe agent led the participants to more conservative gap choices (Mdn=6.50s) compared to trials in which participants crossed alone (Mdn=6.10, p<.001), whereas a risky agent did not evoke riskier gap choices by the participants compared to crossing solo (p=1.00).

In order to test whether the number of crossing pedestrians influenced gap choices differently for both countries, we only selected scenes in which several other agents were present and contrasted trials in which either the minority or the majority of them crossed the street with risky or safe gaps. Consistent with the previous analyses, there was a significant effect of safety (Q=21.64, p<.001), showing again that safely behaving agents led to larger accepted gaps than risky agents. However, there was neither an effect of the actual number of agents crossing (Q=0.72, p=.396) nor of culture (Q=0.27, p=.603). Importantly, there also was no significant interaction (Q=0.18, p=.670). When the virtual pedestrians utilized a larger gap, participants utilized a larger gap as well. However, virtual pedestrians using very short gaps had no significant effect on the gap selection of participants. We did neither find results supporting a cultural difference, nor supporting an influence of the actual number of virtual pedestrians. To summarize, the experimental results revealed that the number of other street-crossing pedestrians did not influence Japanese participants more than Germans, which falsifies our hypothesis *H2.b*.

TABLE II

TRIALS PER CLUSTER AND COUNTRY

	Germany	Japan
Clst1	**136** trials	69 trials
Clst2	**210** trials	173 trials
Clst3	**350** trials	231 trials
Clst4	116 trials	**285** trials
Clst5	32 trials	**116** trials

C. Use of Zebra Crossings

In total, 16 Japanese (7 German) participants utilized the zebra crossing always, while 12 Japanese (7 German) participants never did. During the post-questionnaire, participants confirmed their behavior to be representative of their real zebra crossing utilization. There was no significant difference in this respect between German and Japanese participants on average, which is against our hypothesis *H3.a.*. However, when utilizing the zebra crossings in the scenes, Japanese participants waited significantly longer (4.55s, SD=1.06) than German participants (2.95s, SD=1.19) before stepping on the street. These results confirmed our hypothesis *H3.b*.

Interestingly, our experiments also showed that Japanese participants seem to cross the street even further away from the zebra-crossing compared to the German participants. This route choice behavior was analyzed by considering the full trajectories of all participants in 'zebra crossing' trials. Principle component analysis was performed and a hierarchical cluster analysis was computed on the first 21 components explaining 99% of variance. Clusters Clst1, Clst2, and Clst3 were primarily composed out of trials of German participants, while clusters Clst4 and Clst5 contained mostly trials of Japanese participants (see Table II). The statistical significance of the differences was confirmed (X^2(4, N=1718)=168.27, p<.01). As seen in Fig. 4, clusters primarily composed of trials of Japanese participants show a clear distinction between either waiting and directly crossing (Clst5) or utilizing the zebra crossing (Clst4). Clusters primarily composed of trials of German participants (Clst1, Clst2, Clst3) show a clear influence of the zebra crossing, partially visible in a 'short-cutting' behavior or tendency to veer towards the zebra crossing.

Analyzing the average durations (see Fig. 5) shows another important difference. Clst3 has a shorter duration than Clst1 and Clst2, hence there is a strong indication that a direct crossing was chosen as it enabled faster crossing. However, Clst5 has a longer duration than any other crossing, indicating the motivation to reduce the path length rather than the path duration. This temporal effect is highlighted in Fig. 4 where a star is denoting the position at the half-time of the crossing duration.

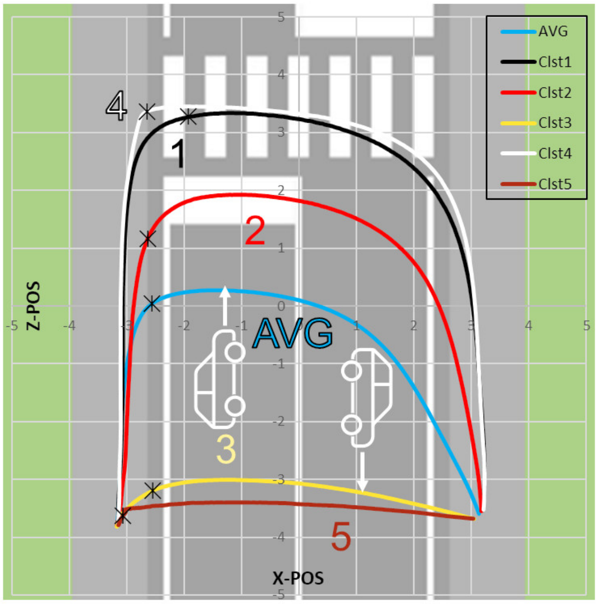


Fig. 4. Reconstructed trajectories of the hierarchical cluster analysis. The German data was mirrored to the left-handed traffic for analysis. Stars [*] denote 50% of the crossing duration.

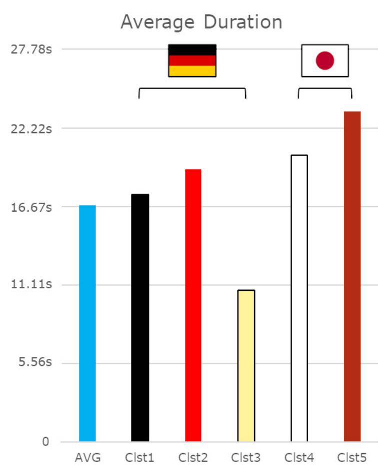


Fig. 5. Average duration (time) of the trajectories of each cluster.

D. Discussion

Using the virtual reality setup, it is possible to capture and compare pedestrian behavior between participants in Germany and Japan.

Implications for intelligent vehicles. In line with our hypotheses, our experimental results suggest a higher desire for safety on direct crossings for Japanese pedestrians, indicated by a higher crossing velocity and by requiring larger gaps in traffic. As hypothesized, we found indications for a higher uncertainty in the Japanese group, as Japanese participants aborted a crossing attempt more frequently than German participants. In addition, Japanese participants waited longer in front of a zebra crossing before stepping onto the pavement.

There are several implications of these cultural differences for intelligent vehicles. The indication of the yielding of a vehicle (e.g., by reducing the velocity, optical signals), should be performed earlier in Japan than in Germany to account for their higher gap requirement and uncertainty. At zebra crossings, this is even more important. On the other hand, pedestrians should not wait at the zebra crossing until the approaching car stops, as this would inhibit a smooth flow of traffic but autonomous vehicles should obey traffic rules and yield to pedestrians. Hence, pedestrians should be enabled to start their crossing before the vehicles come to a complete stop.

Regarding 'group crossings', a clear influence of the presence of virtual people on the selection of gaps in traffic was shown. More specifically, a virtual pedestrian selecting a safe gap would lead to the selection of a safer gap by participants. However, we could not identify a cultural difference in this behavior. As a result, ADAS should always consider all pedestrians together when predicting the intention of an individual pedestrian in a group.

The cultural differences in the route choice behavior at zebra crossings were opposite to our expectations: while we did expect Japanese pedestrians to utilize the zebra crossing more often, a more diverse behavior was observed. German participants tended to cross the street on an arch, short-cutting the entrance and exit of the crossing. Japanese participants, however, either utilized the zebra crossing and waited before entering it or ignored the crossing completely and crossed the street on a direct route. This behavior was chosen, even if waiting for a suitable gap would take longer than taking the path with a longer distance utilizing the zebra crossing. Multiple Japanese participants confirmed their strategy of either using the zebra always or never in the post-questionnaire.

To the best of our knowledge, this behavior was not yet reported in the literature and contradicts the often-stated hypothesis of Japanese being more cautious. As this points towards a systematic difference in trajectory between Japanese and German pedestrians, it is highly important for pedestrian path prediction solutions for highly-automated driving and must be considered when training and testing these systems.

Limitations. There are some limitations of our study: First, the influence of height difference between the sample groups as well as the influence of past accident experiences were not further investigated and could, potentially, influence the gap acceptance. Second, gap duration was uniformly sampled between 2.5s and 8.5s and between cars approaching from both or only a single lane. This could result in sequences of very short gaps or sequences of very long gaps.

Future work. Large-scale VR experiments are a useful tool to investigate complex pedestrian behavior. The data captured can be utilized to develop pedestrian software agents for the simulation of test scenarios in a digital reality [30]. Specifically, when including the motion capture data, pedestrian agents can be built that not only behave as their natural counterparts but move their bodies accordingly, enabling a more realistic simulation for image- and posture-based prediction algorithms. Further analysis of the gaze, body postures, and movement dynamics is required to support more information in that regard. The presented experimental setup seems to be especially useful for capturing and analyzing risky scenarios in the future (e.g. near misses) which cannot be created in real environments, as well as experiments with high-risk groups.

V. Conclusions

We reported on the first cross-cultural behavior analysis of Japanese and German pedestrians in a VR environment. The experimental results of our respective user studies in Tokyo, Japan, and Saarbrücken, Germany, support our hypotheses on cultural differences in direct street crossing, but not on the following behavior. Most importantly, however, the usage of zebra crossings appears to contradict established assumptions on cultural differences. The behavioral difference between Japanese and German pedestrians cannot be simply summarized as 'Japanese behave more cautiously than Germans', since their utilization of zebra crossings suggests otherwise. We encourage to take the findings of our cross-cultural studies into account for the configuration and testing of intelligent vehicles, possibly interacting with pedestrians in Japan and Germany. In general, to ensure cultural fairness, more direct comparison studies of pedestrians in different countries, as presented here, are required.

Acknowledgment

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