Pedestrian Behavior in Japan and Germany: A Review

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***Abstract*— The prediction of pedestrian behavior remains a major objective for the development of autonomous vehicles. Pedestrians do not merely represent the most vulnerable traffic participants, but are also a challenge in the prediction process, since their behavior entails a large number of options for possible paths, velocities, and motions. In addition, autonomous vehicles should be able to operate safely in different countries, and thus the incorporation of cultural differences in the training and evaluation of the relevant AI systems is required. This paper provides the first review of Japanese and German pedestrians' behavior in urban traffic. In particular, cultural behavior differences of pedestrians in risk avoidance, compliance, gap acceptance, and walking velocity together with different environmental factors like pedestrian facilities in both countries are addressed.**

I. Introduction

Despite tremendous advances in the area of autonomous driving, collision-free navigation and interaction with pedestrians in urban traffic remain a challenge for self-driving cars [1]. Current methods for multi-pedestrian intention estimation [2], [3] make use of various features of pedestrian dynamics such as pedestrian position, moving direction, velocity, scene context (e.g. distance to curb, traffic light state, crosswalks) and social context (e.g. distance to others and social interaction) [4]. Though the majority of them relies on pedestrian dynamics for mere data-driven pedestrian behavior prediction [5], the current trend in pedestrian perception models appears to increasingly include more high-level features of psychology-informed models instead of pure kinematic or random velocity walk models [6], [7].

Pedestrian behavior in urban traffic scenarios can significantly differ throughout the world, partially due to different rule sets, partially due to social, cultural, and anthropometric [8] differences. As traffic law is less specific for pedestrians rather than vehicles, analyzing the cultural difference between pedestrians becomes more important. Pedestrians in urban environments have a high degree of freedom in their movement capabilities, tend to violate rules, and are vulnerable to accidents and harm. While city planners usually consider pedestrian behavior on a local (city or countrywide) scale, differences in the behavior of pedestrians in different cultural regions, such as Europe and Asia, should be taken into account by researchers and engineers of self-driving cars. This goes beyond regulatory differences, such as rules for left- or right-handed traffic. In fact, there may not only be cultural differences in the chosen path and velocity of pedestrians but in their higher-order behavior, like general rule compliance, following behavior, and gap acceptance, as well. Knowledge about culture-based behavioral differences may serve as an additional input to the development of advanced methods of pedestrian intention estimation for collision-free navigation in different cultural regions of the world.

In the area of traffic psychology, there are numerous experimental and observational studies highlighting pedestrian behavior in very fine granularity, and some studies are setting the findings in perspective. For example, the VDA (German Association of the Automotive Industry) analyzed the difference in velocity and gait (walking, running, etc.) for different age and gender groups in the pedestrian context [9], [10]. The in-depth accident databases, like GIDAS [11] for Germany and ITARDA [12] for Japan, focus on a biased subset of pedestrian behaviors, namely accidents, with a very coarse level of granularity like the side of the street and estimated velocity. The requirements for safe navigation in a street context are analyzed in [13], highlighting the deficiency occurring with increasing age. A three-stage model for pedestrian simulation, considering a strategic, tactical, and operational level of behavior, is proposed in [14]. Alternatively, [15] analyze the effect of age, gender, delay, crossing type, gap acceptance, and compliance on pedestrian velocity in street crossing environments, and provide a comprehensive review of pedestrian simulation techniques. However, none of these works analyze culture-based behavioral differences of pedestrians in urban traffic scenarios. In fact, there exist only a few studies on cultural differences in pedestrian behavior, and none specifically addressing differences between Japanese and German pedestrians.

To this end, we provide the first literature review on behavioral differences between pedestrians in Germany and Japan. Drawing from the available literature on the research of general cultural differences, as well as studies of pedestrian behaviors in both countries respectively, we identify and discuss the behavioral differences and similarities between both groups. In particular, general differences in traffic rules and pedestrian facilities are summarized in Section II, while general cultural differences that can affect pedestrian behavior are highlighted in Section III. Differences in specific aspects of pedestrian behavior, namely compliance, acciden-

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tal risk and risk perception, gap acceptance, and pedestrian velocity are highlighted in Section IV. Finally, we discuss the findings of this review in Section V and provide examplary implications on the design of intelligent vehicles in Section VI before we conclude in Section VII.

II. Traffic Regulations and Infrastructure

The traffic rules in Japan and Germany are comparable in many instances. For example, in both countries, typical speed limits in urban areas are between 30 and 50 km/h and there are usually no traffic signals in areas with a 30 km/h speed limit or restricted residential zones [16], [17]. Left- and right-handed traffic is usually generalized by considering only the near and far lane with respect to the pedestrian and, to our knowledge, should not influence pedestrian behavior further. In both countries, crossing on a red light, as well as crossing the street without using a crossing facility, can be fined (§ 25 StVO and § 121 (1) Road Traffic Act). However, the fine in Germany is significantly lower (5-10 €, up to 1 demerit point) [18] than in Japan (ca. 160 € / 20.000 ¥ and potential criminal charges) [19].

The overall signalized crossing intersection rate in Germany is about one intersection per 1000 inhabitants [16] and thus lower than 1.35 intersections per 1000 inhabitants in Japan [20]. In Germany, the rate is larger in mid-sized cities (250-500 thousand inhabitants) and smaller in densely populated and rural areas [16].

Although the position of vehicular traffic lights differs, with lights before the crossing in Germany and after the crossing in Japan, it is always after the crossing for pedestrian signals with a vertical orientation and the red light at the top. The green light in Japan is often referred to as "blue", as it has a slightly more pronounced blue tint than in Germany [21]. Additionally, both lights are displaying figurines in standing and walking poses. In Germany, most of the pedestrian signals are operating in an actuated or timed mode [16], while in Japan, 43% of signals are in an adaptive control loop, 48% in fixed-time control and only 8% are operating in an isolated control [20]. Actuated controls in Japan are used mostly in low pedestrian demand zones and can include elderly-actuated controls [20]. While countdown devices are only rarely implemented in Germany, they are common in Japan [20]. On the other hand, acoustic devices are mandatory and widely available in Germany [16]. In both countries, the minimal green time is chosen to allow pedestrians to cross half the distance [16]. In Japan, the expected number of waiting pedestrians, the flow rate and the width of the crosswalk are considered as well [20]. The major difference, however, is that Japanese traffic lights have a constant green mode and a flashing green mode *(PFG - pedestrian flashing green)*, on which a crossing should not be started anymore, but finished as soon as possible. German pedestrian lights do not consider such a phase. In Germany, pedestrians receive a head-start compared to turning traffic in many cases [16], but isolated and exclusive phases for pedestrians are rarely found apart from mid-block crossings. An example of the signal phases can be found in Fig. 1.

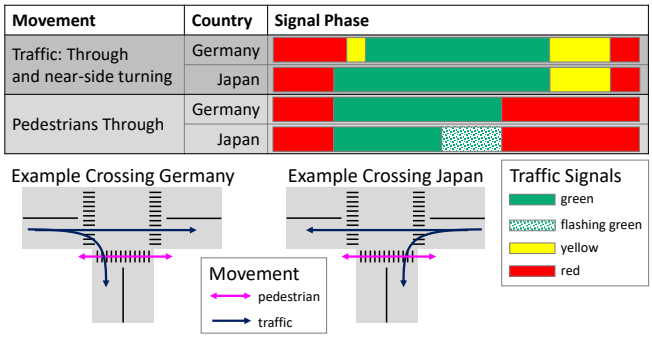

Fig. 1. Simplified signal phases in Japan and Germany (c.f. [16], [20]).

III. General Cultural Differences

One way to describe culture is "the way of life, and how knowledge, belief, art, morals, law, custom, and any other capabilities are acquired [...] as a member of society" [22]. These domains are common in that they can be regarded as exemplary parts of a conglomeration representing specific patterns of thought and action, which are passed on to individuals by their social environment. A multi-dimensional approach to identify and measure the differences between cultural groups is proposed in [23], [24]. Two of these dimensions are of utmost importance for pedestrian behavior: (i) uncertainty avoidance, and (ii) collectivism vs. individualism. Differences in these measures for Japan and Germany are shown in Fig. 2.

Uncertainty avoidance. The group's tolerance for ambiguity is covered by the term uncertainty avoidance [24]. In the case of high uncertainty avoidance, the potential for uncertain situations is reduced through rules, laws, and behavioral norms [24]. This concept can be related to risk avoidance to the extent to which members of a society feel threatened by ambiguous or risky situations with unknown outcomes [25]. For both uncertainty and risk avoidance, Asian countries and specifically Japan show higher scores compared to European Countries, and specifically Germany [25].

Collectivism. The integration of members of a society into groups is described by the term collectivism [23]. In European individualistic cultures, people tend to see themselves as distinct individuals with a unique set of characteristics striving for autonomy and independence [23]. Interpersonal relations are largely regulated by individual preferences. In contrast, encouraged values in Asian collectivist cultures are interdependence, harmony, and cohesion [26]. Members of such cultures strongly identify with their in-group as a major source of identity. It has been argued that such self-concepts (or self-construals) serve as a crucial dimension for explaining cultural differences [27]. They are conceptualized as parts of a repertoire of so-called schemata, which are constructs reflecting mental structures of implicit knowledge that provide a systematology and assignment of meaning to a given experience [28]. This assortment of self-regulatory schemata is known as the self-system [29]. During the

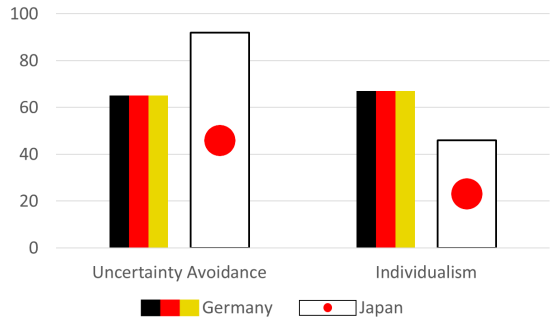

Fig. 2. Hofstede scores of uncertainty avoidance and individualism for Germany and Japan (c.f. [32])

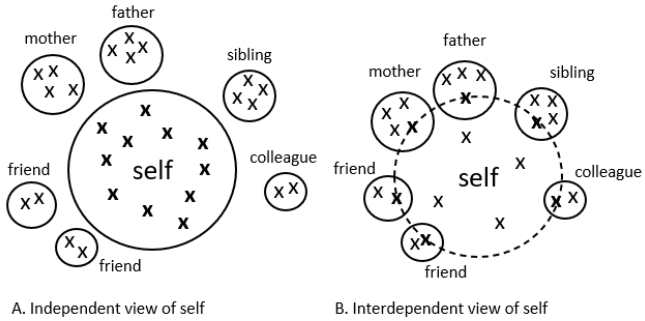

Fig. 3. A schematic representation of the self construals (c.f. [27])

occurrence of a situation, the ensuing information processing and behavioral motivation is modulated by settings of the self-system [30]. The most overarching culturally influenced components of the self-system have been identified as the independent and interdependent construals of self [27] (see Fig. 3).

Independent Construal of Self. For people with an *independent or individualistic construal of self*, the primary cause of action is within the preferences, internal thoughts, and feelings of the person itself [27]. The independent self still has to be responsible for its environment, but the social environment is not considered as the primary cause of action. Rather, social interaction is used to assert inner attributes as a medium for self-expression. The individual is seen to be in control and less dependent on current surroundings. The normative imperative of this culture emphasizes the autonomy of each individual and the expression of uniqueness as well as personal freedom, which, unlike social adaption and restraint, broadens the scope of options for the fulfillment of individual preferences. The goal is the consequent assertion of inner attributes and an attempt to change outer aspects, like public behaviors or social situations, according to the inner needs [31]. The independent self is usually assumed for western cultures, including Germany.

Interdependent Construal of Self. In cultures dominated by the *interdependent construals of self*, the subjective affinity to a relation or group may reach an extent to which relationships become integral units of the personal identity (see [33]). In such collectivist or interdependent construals of self, the inner self is a fluent construct that is built contingent on the social environment. Selfness is confirmed through interpersonal relationships and therefore may be differently instantiated across contexts. The uniqueness of the self does not consist of socially-independent character traits but derives from a specific configuration of relationships. A person and the behavior can only be completely understood as a part of the social context (i.e. in Japan [34]). The cultural values consist of maintaining interdependence and harmony among its members and an appreciation of one's status as a participant in a larger social unit [35]. Although Japan's orientation towards collectivism has gradually declined in the past, it is still a fundamental part of its culture [36].

IV. Specific Behavioral Differences

A. Differences in Compliance

Compliance as a multicausal behavior can be influenced by a number of factors including traffic volume [37], guard rails [38], countdown devices [37], duration of red light [39], [40], the amount of lanes [41], departure order [42], or other pedestrians awaiting nearby [43]. Although there are no studies comparing the compliance rate of pedestrians in Japan and Germany directly, Japanese pedestrians are observed to have a slightly lower rate of violations (2% - 7%) [39], [44] compared to German pedestrians (5.8 % - 39%) [40], [45]. However, studies comparing the cultural differences of Japanese and French pedestrians [5], found a difference in compliance of pedestrians initiating the violation versus pedestrians following others [41], [48]. These differences in compliance will be discussed in more detail below, as they are indicating a fundamental cultural difference between Japanese and European pedestrians, like French and Germans.

Initiators. Japanese pedestrians appear to initialize a red-light crossing less frequently (1.5%) than French pedestrians (55%) [41], [48]. Among others, the probability to cross at the red light depends on the duration of the light period and therefore on the passed waiting time: the longer the waiting time, the higher the likelihood to cross illegally [41], [49]. According to these findings, pedestrians may have a maximum waiting time at signalized crossings. Compared to their French counterparts, Japanese pedestrians cross closer to the light change, shortly before the light turns green [41] and not before the light for vehicles turns yellow [48], again indicating a stronger compliant attitude or fear of accidents. These findings indicate that the maximum waiting time before an illegal crossing is culture-dependent (a visualization of waiting/departure times and other relevant variables is provided in Fig. 4). Findings concerning the departure time are not consistent, showing that French pedestrians are more

[5] A strong similarity between northern French and German pedestrian behavior is assumed due to spatial proximity and shared EU norms in traffic regulations. Because of a lack of studies that directly compare compliance between Japan and Germany, Japan-France-comparing studies are consulted. Between Japan and other Asian countries, there is a heterogeneity of traffic safety [46] and compliance levels [44], [47]. Therefore, studies investigating pedestrian behavior in other Asian countries are not included, since this is outside the scope of this article.

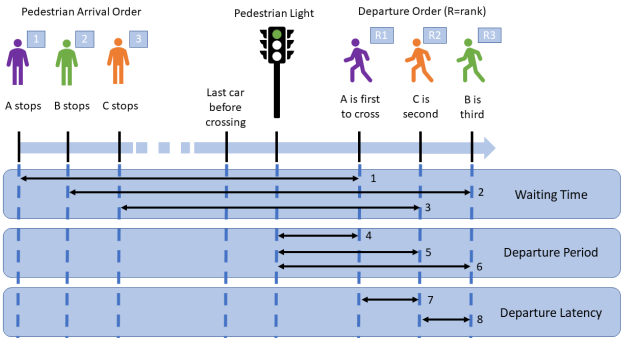

Fig. 4. Visualization of the different culture-relevant variables. Waiting times (1-3) and departure periods (4-6) refer to pedestrians (A-C). (7-8) are the departure latencies of C (after the departure of A) and B (after the departure of C). (c.f. [39])

likely to cross sooner legally after the light turned green [39], as well as the opposite case [41].

Followers. As the presence of other waiting pedestrians exerts social pressure on rule abidance of others, the probability of a pedestrian crossing at the red light decreases as the number of waiting pedestrians increases [39], [43]. This effect is larger in Japan, reducing up to 70% of red light violations than in France (-37%) [39]. Other crossing initiators, however, may encourage waiting pedestrians to follow them against red. The probability of following depends on many factors, like proximity and gender [42], and is based on an amplification process called mimetism or mimetic processes [42], [43], [50]. In one study, Japanese pedestrians were overall only half as likely to be influenced by other crossing pedestrians as their French counterparts [39]. However, further analysis showed that Japanese pedestrians incorporate both already crossing and still waiting pedestrians. French pedestrians, on the other hand, base their decision purely on other already crossing pedestrians [48]. This model reflects a comparatively more expansive mimetic process for Japanese that comprises more cues of the social environment than that of French pedestrians. Departure latencies did not differ between the countries [39].

There are no definitive results on the following behavior in Germany. Observations, however, show a difference in compliance for consecutive crossings, e.g. with a pedestrian island. Here, rule violations are significantly more frequent at the second crossing (39%) compared to the first crossing (3.1%) [40]. We did not find any similar analysis for multi-stage crossings in Japan, as they appear to be implemented less frequently.

B. Differences in Accidental Risk and Risk Perception

Pedestrians are the most vulnerable group of road users and their behavior is difficult to anticipate. In Japan, they are involved in 36% of road traffic-related deaths [51], whereas in Germany they form about 15% of cases [52]. Nevertheless, the death rates in both countries are comparable with 1.4 in Japan and 0.6 in Germany per 100,000 inhabitants and are considered very low compared to the rest of the world [53]. Senior citizens are at the greatest risk of mortality in this regard. In contrast to Japan, young adults between the ages of 18 and 24 also represent a risk group in Germany [51]. In fact, Japan has approximately 24% fewer deaths in this age range compared to the international average [51].

In both countries, walking on foot is considered a relatively popular mode of transportation: 54.5% of Germans report participating in transportation as pedestrians on a daily basis, and another 23.9% walk 1-3 times a week [54]. 71.1% of Japanese report walking in the neighborhood for daily errands [55]. The high level of pedestrian participation in road traffic highlights the high relevance of pedestrian research and suggests a certain sense of safety among pedestrians given the alternative travel modes available.

In general, risk avoidance is more prevalent in Japan than in Germany [32]. To the best of our knowledge, there are no comparative studies to date between Japan and Germany that systematically examine pedestrians' subjective risk perception. In different studies, it was reported that Japanese pedestrians [44] require a longer time-gap (16s) to consider a crossing safe compared to German pedestrians (5-6s) [10], [56] These findings are consistent with the higher risk aversion in Japan and correspond to the gap acceptance (see section IV-C). The frequency and duration of uncertainty behavior (freezing, abandoning, accelerating) during crossing at red is also more pronounced in Japan compared to France (10%, 1.5s vs. 5%, 1.22s) [57]. The difference is particularly pronounced when Japanese walk alone but is also visible among followers. In contrast, the hesitation tendency is purely observed among initiators in France [57]. The authors suggested that Japanese sometimes tend to cross inadvertently at red by solely relying on social cues, even if provided by rule violators. Japanese perceive transportation in general, including driving by car or bike, as less safe than western countries, such as the USA [58].

C. Differences in Gap Acceptance

To decide whether a gap in traffic to the next car is large enough to cross the street safely, distance and velocity cues can be used. Slower vehicles can increase the time gap due to their larger distance [56], [59]. In addition, there are indications that with reduced cognitive resources (e.g. due to distractions), the velocity information may only have a minor influence than the distance information [60], [61]. Also, the complexity of the environment (e.g. variation in texture, clutter, complexity of lighting, distractors like other pedestrians and cars, etc.) influences the decisions [62], thus behavior in simulations is not always directly comparable with behavior in real environments, if the complexity is not carefully matched.

Pedestrians in Japan and France show a similar time to decide to cross, but French pedestrians required a smaller gap (9s) compared to Japanese pedestrians (16s) to consider a crossing safe in an observational study in an area with a speed limit of 50 km/h [44]. In Japan, female pedestrians required larger gaps (19s) compared to male pedestrians (11s) [44]. In Germany, different studies show that pedestrians

require a time gap of 5-6s to decide for a safe crossing, both in a real environment [10], [56], as well as in a simulated environment [59] with a speed limit of 50 km/h.

D. Differences in Pedestrian Velocity

The reported velocity of pedestrians in Japan is 1.5 - 2.4 m/s during the crossing [63], [64]. However, the walking speed changes over time, with smaller velocities (1-2 m/s) in the first, and larger velocities (2.5 - 3.5 m/s) in the second half of the crossing time [65]. This is most likely an effect of the onset of the pedestrian flashing green signal (PFG), which is specific for Japan [65]. In addition, pedestrians were found to accelerate in conflict areas with the traffic. When crossing at signalized crossroads, pedestrians showed a higher velocity on the lane, where the flowing traffic could turn into, regardless of which direction the pedestrians approached the crossing [65]. For unsignalized crossings, it was found that the implementation of refuge islands decreased the pedestrian velocity from 2.4 m/s to 1.5 m/s [64]. This is most likely an effect of a reduced perceived crossing risk [64].

Even though there are no PFGs in Germany, the light may switch to red during pedestrian crossing and could induce a change in velocity. Observational data, however, does not show any such change, as pedestrians show a very high continuity in their velocity (95.59%) [10]. Even more, most of the pedestrians are either walking (appr. 75%, 1.21 - 1.54 m/s) or fast walking (appr. 21%, 1.57 - 1.72 m/s) [10]. Although pedestrians do run on some occasions, it is not frequently observed.

V. Discussion

In the previous section, similarities and differences between Japanese and German pedestrians have been shown and are summarized in Table I. In the following section, the reported findings are set into perspective, related to each other and their potential causes. In addition, different research areas are highlighted, where there is insufficient data but a high likelihood of cultural differences.

Surrounding/external factors. There are several apparent differences in regulations and infrastructure between Germany and Japan. Most important for the pedestrians are differences in the signal phases (incl. pedestrian flashing green lights), the penalties for illegal crossings, and countdown devices. Although countdown devices [37] and penalties for traffic violations [66] tend to have a positive impact on compliance, it is only minor.

The pedestrian flashing green light (PFG), however, has a major impact on pedestrian behavior in Japan. As reported, Japanese pedestrians tend to increase their velocity both for the onset of the PFG as well as in conflict areas [65]. Although there is no PFG signal in Germany, a similar effect should appear if the pedestrian light switches to red while there are still pedestrians on the road. Assuming that [10] observed such cases, there appears to be no change in velocity. Signal times, including the transition between signal groups, should allow for a safe continuation of the crossing [16], [20]. Vehicular signals are often delayed in Germany and could lead to less interaction between near-side pedestrians and turning traffic. However, these effects would not explain the increased velocity of far-side pedestrians in Japan [65]. Hence, we suggest that the change of velocity as well as the general higher velocity can be attributed to cultural differences, most likely a higher need for safety and uncertainty avoidance. As pedestrian dynamics are a very important factor in the prediction of pedestrian behavior [5], such cultural differences may have a major influence on the performance of autonomous vehicles. More studies directly comparing German and Japanese pedestrians' behavior have to be conducted to find a more definitive picture of the differences in velocity.

Cultural/internal factors. During the occurrence of a situation, the ensuing information processing and behavioral motivation is likely modulated by settings of the self-concept [30]. It can therefore be proposed that in a given situation, individuals (such as pedestrians) evaluate self-relevant environmental cues contingent on their culture-biased self-concept. This likely affects their attention, situational interpretation, and resulting behavior. It could lead, for example, to different probabilities of perceiving objects on the road, different risk assessments, or compliance levels. We presume that the origin of intercultural differences across pedestrians can therefore be partially located in these general differences between the cultures themselves and point to implications of the two self-concepts for traffic-related variables.

The collectivist dimension in Japanese culture appears to express itself in compliance-related decisions: Japanese pedestrians display a difference in initiating a crossing on a red light and following someone else already crossing, incorporating not only the initiators but also waiting pedestrians in their decision to cross [48]. These findings suggest an expansive mimetic process for the Japanese that focuses on multiple cues of the social environment. It reflects the higher environmental orientation of the less individualist Japanese culture, contingent on an interdependent concept of the self and others. Therefore, cultural differences seem to be reflected even at a basal level in attentional processes, mediated by mimetic behavior or a Japanese bias toward social cues. Studies analyzing the gaze behavior, e.g. by utilizing eye-tracking, could reveal more insights in terms of such cultural biases. French pedestrians, for example, have shown that other pedestrians are rarely looked at [67]. Others have observed that male French pedestrians tend to miss more light changes while observing the traffic to cross against the red light [68]. However, relevant data for both Japan and Germany has not yet been reported.

Japanese followers also showed a higher probability and duration of uncertainty (i.e. freezing, abandoning, accelerating) [57]. This can be an indication that the Japanese sometimes tend to cross inadvertently at red, being unaware of risk by solely relying on social cues and therefore do not necessarily have anti-compliant intentions. The longer duration of uncertainty behavior compared to French pedestrians serves as an indicator for a lower uncertainty tolerance of the

TABLE I

SUMMARY OF EXPLICIT DIFFERENCES IN PEDESTRIAN BEHAVIOR.

Variable	**Japan**	Sources	**Germany**	Sources
velocity	1.4 - 3 m/s	[63], [65]	1.57 - 1.72 m/s	[10]
accelerations	accelerations in conflict zones and after flashing green onset	[65]	no significant accelerations observed	[10]
gap acceptance	16s	[44]	5-6s	[10], [56], [59]
compliance-rate at signalized crossings	93% - 98%	[39], [44]	61% - 94.2%	[40], [45]
initiation of red-light crossings	1.5%	[41]	t.b.d.	
fine for red-light violations	160 € (20,000 ¥), potential criminal charges	[19]	5-10 € (634 - 1,268 ¥), up to 1 demerit point	[18]
fatality rates	1.4 per 100,000 citizens	[53]	0.6 per 100,000 citizens	[53]
traffic orientation	driving on the left		driving on the right	
number of intersections	1.35 per 1000 citizens	[20]	1.0 per 1000 citizens	[16]

Japanese, as described in the literature [32]. However, a selective comparison of uncertainty behavior between Germans and Japanese is still missing.

Comparing the compliant behavior between Japanese and German pedestrians, Japanese consistently show very high compliance [39], [44], whereas a larger variance in the German data is observed. Depending on the study, it is ranging from medium up to comparably high compliance [40], [45]. The extremely high compliance rate of the Japanese coincides with their stronger identification of the self with social expectations and rules, which stems from the more collectivist understanding, suggesting that cultural orientation influences compliance. In the example of multi-stage crossings, German pedestrians show similar compliance rates at the first crossing as Japanese pedestrians [39], [45]. On the second crossing, however, German pedestrians are significantly less compliant [40]. This behavior is comparable to a late crossing in Japan, starting on a pedestrian flashing green signal, or continuing to cross at a flashing green signal although the pedestrian should turn around [65]. These behaviors are technically illegal, but most likely perceived with less social scrutiny. The high level of compliance of the Japanese seems not sufficient to dissuade them from continuing to cross the road, even though abortion would be indicated. This creates a tension between the general belief in rule compliance and the situationally personalized goal of crossing the street. According to cognitive dissonance theory [69], aborting in favor of compliance would evoke a sense of discomfort resulting from revising the personal intention of crossing. To avoid this unpleasant arousal, the pedestrian continues the indentured crossing at the expense of breaking the rules. Unfortunately, there are few publications on pedestrian compliance at traffic lights in Germany. Hence, more research in this direction is required to have a better understanding of the similarities and differences in compliance behavior between both countries.

Research areas with insufficient data. Besides the research areas outlined above, there are other areas that are hardly investigated in either Japan or Germany. Gap acceptance, or the gap in flowing traffic pedestrians consider safe to cross, is a major research area in traffic psychology. Although we did not find any study directly comparing Japanese and German pedestrians, some studies point in the direction of Japanese pedestrians requiring a significantly longer time gap between vehicles to cross a street [44] than German pedestrians [56]. Unfortunately, crossing a street without signalized crossings (e.g. jaywalking) is rarely studied in both countries and requires a more thorough investigation. If the results can be replicated, the longer time-gap required by Japanese pedestrians could be attributed to a higher need for safety or differences in risk estimation processes.

We did not find any analysis of either the number of guardrails or on its potential effect in Germany or Japan. From other countries, we know that guard-rails should have a positive impact on compliance behavior [38]. From a subjective standpoint, it appears that there is a better separation of pavement to the street in Japan. This separation oftentimes consists of bushes and guardrails or chains and would have a major influence on mid-block crossings at locations without crossing devices (e.g. pedestrian light, zebra-crossing, etc.) and thus on both compliance and gap acceptance.

Autonomous vehicles should be able to predict when and whether pedestrians cross a street, most of all in places where there are no specific crossing facilities, e.g. mid-block jaywalking. The behavior of pedestrians in this scenario is not sufficiently researched in both countries to draw conclusions. There are strong indications that the body movements of hips and shoulders can indicate the intention of a pedestrian in advance to their crossing [70]. In addition, the difference in average body height [8] would suggest that German pedestrians walk faster than Japanese in general, which is not supported by observations in urban traffic environments. More research is required to identify the differences in body movements and corresponding indications of intentions across Japanese and German pedestrians.

VI. IMPLICATIONS FOR INTELLIGENT VEHICLES

Intelligent vehicles should be designed to operate and interact safely with pedestrians of different cultures. Hence, during development, the differences and similarities between cultural groups can be utilized to improve the vehicle design. For example, the higher need for safety of Japanese pedestrians, measurable by the time gap required for safe crossings, indicates that yielding cues of an autonomous

vehicle (e.g. deceleration, lights, sounds) should probably be more pronounced and explicit in Japan to be correctly identified by pedestrians.

Several differences between Japanese and German pedestrians could lead to false interpretation and prediction of pedestrian behavior and thus unsafe interactions with autonomous vehicles. For example, the change of velocity of Japanese pedestrians in the second half of the crossing could lead to a bias in learning-based approaches leading to a consistent under-estimation of the pedestrian clearing time in a German driving context. This could not only render Japanese autonomous vehicles insufficient for the German market but could result in severe safety concerns. Hence, it has to be actively counter-measured during development, e.g. using a digital reality [71] to enhance and expand training data and making the intelligent vehicle culturally fair.

These are only some examples of how cultural differences may have an implication on the design and operation of intelligent vehicles. More research is required to not only identify differences and similarities between cultural groups but how to handle and potentially utilize these cross-cultural implications.

VII. Conclusion

In this review, we summarized several differences and similarities of pedestrian behavior in Germany and Japan. We summarized recent, topical research results on compliance, accidental risk and risk perception, gap acceptance, and velocity of pedestrians in both cultural groups. Although there are several other factors of pedestrian behavior, we already found many differences between both cultural groups. For the application of autonomous driving, this is of utmost importance. It is not sufficient to consider the differences in regulations and infrastructure, but in the culturally influenced behavior in general. Research on pedestrian behavior should be always considered in the cultural context of the study and more research of the cultural differences of pedestrian behavior is required to enable autonomous vehicles to interact safely and reasonably with pedestrians in different countries.

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