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# Pedestrian gestures increase driver yielding at uncontrolled mid-block road crossings

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ABSTRACT

To protect pedestrians, many countries give them priority at uncontrolled mid-block crosswalks or pedestrian crossings. However, the actual driver yielding rate is not always satisfactory (only 3.5% in this study). To increase the yielding rate, this study proposed eleven pedestrian gestures to inform drivers of their intent to cross. The gestures were evaluated based on the process of human interaction with environment. Four gestures were selected as candidates to test in field experiments based on scores for visibility, clarity, familiarity and courtesy (see illustration in Fig. 2): (1) right elbow bent with hands erect and palm facing left (R-bent-erect), (2) left elbow bent with hands level and palm facing left (L-bent-level), (3) left arm extended straight to left side with palm erect facing left (L-straight-erect), and (4) a 'T' gesture for "Time-out". In the experiment, confederate pedestrians waiting at the roadside displayed the gestures (baseline: no gesture) to 420 vehicles at 5 sites in Beijing, China. When pedestrians used the L-bent-level gesture, the vehicle yielding rate more than tripled of that in the baseline condition. The L-bent-level gesture also resulted in a significant decrease in driving with unchanged speed (63.5–38.8%) and had no significant side effects in terms of drivers' horn use or lane changing. The effects of such gestures in other contexts such as when pedestrians are in the crosswalk and when they are interacting with turning vehicles are discussed, together with the applications in training vulnerable pedestrian groups (children or elderly) and facilitating pedestrian detection by drivers.



## 1. Introduction

### 1.1. Road rights at unsignalized crosswalks

Pedestrian safety worldwide is threatened: number of pedestrian deaths and their proportion among all road fatalities in low, middle and high income countries are 227,835 (45%), 161,501 (29%) and 22,500 (18%) (Naci et al., 2009). To protect pedestrians, engineering approaches (e.g. traffic lights), together with educational approaches have been stressed (Hebert Martinez and Porter, 2004). However, for efficiency or cost reasons, traffic lights are usually not installed in places that do not meet certain warrants on pedestrian or vehicle volume, etc. (General Administration of Quality Supervision, 2006). To compensate for the potential risk resulted from limited protection facilities, traffic laws in many countries require drivers to yield to pedestrians at these sites (e.g. Hakkert et al., 2002, China State Council, 2005). However, the marked crosswalks have still been found to be dangerous, even when compared with unmarked ones (Koepsell et al., 2002). In fact, Zegeer et al.'s (2002) comparison of 2000 marked and unmarked crosswalks in the USA showed that on multi-lane roads with vehicle volume higher than 12,000 per day, marked crosswalks could be riskier than their unmarked counterparts. Although this has been claimed to be the result of pedestrians' decreased carefulness in crossing (Leden et al., 2006), drivers' not obeying the yielding regulation contributes much to the problem. In Ibrahim et al.'s (2005) observation in Malaysia, most pedestrians had difficulty in crossing because the drivers did not yield to them. Várhelyi (1998) also observed that 95% drivers in Sweden did not give way when pedestrians were present. It is therefore important to explore which approaches may help to increase driver yielding rates.

### 1.2. Strategies to promote yielding

According to Lewin's equation (Sansone et al., 2004), human behaviors are determined both by the person and the environment:

$$\text{Behavior} = f(\text{person},\ \text{environment})$$

In the context of driver yielding behavior, the "person" element refers to top-down factors like drivers' attitude toward pedestrians, their understanding of the right of way, or their driving skills.

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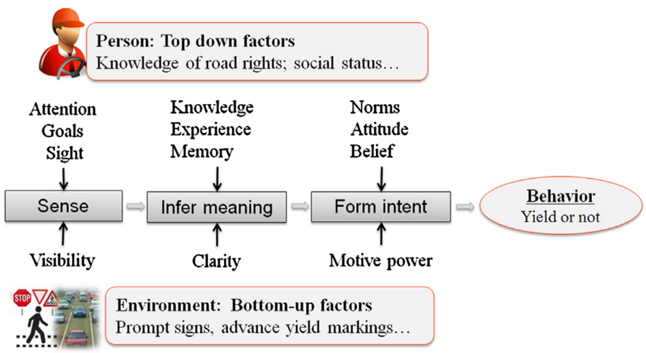


**Fig. 1.** Drivers' interaction with the environment (elaborating Lewin's equation in the driver yielding context based on the SIFT model).

Such personal factors have been found to influence drivers' yielding rate in natural observations. Piff et al.'s (2012) observations in San Francisco found that drivers with higher social status are less willing to yield to pedestrians. Ibrahim et al. (2005) also explained that drivers' observed failure to stop was because they either did not care about pedestrians or because of their misunderstanding of the rules of the road. Meanwhile, environmental factors are bottom-up determinants of behaviors. Researchers have identified several such factors influencing yielding behavior including speed limits (Turner et al., 2007), pedestrian's distance from the kerb (Himanen and Kulmala, 1988), pedestrian's clothes (Harrell, 1993) and the number of pedestrians waiting to cross (Sun et al., 2003).

Theoretically, both types of factor help to understand driver yielding behavior. When it comes to actively manipulate factors to get a higher yielding rate, however, personal factors like social status are impossible or much more difficult to control than environmental factors. Therefore, previous studies aiming to increase driver compliance have resorted to changing the latter, on the basis that environmental information can make a difference when processed in the human mind properly. The SIFT model (Straker, 2008) states that an individual's inner process of interacting with the outer world has four phases: sensing, inferring meaning, formulating intent and translating into actions. Based on this model, the "person" element in Lewin's equation (Sansone et al., 2004) in the context of driver yielding can be elaborated as in Fig. 1. First, drivers sense the surrounding environment, mostly via vision. For instance, drivers may see a line of white triangular markings on the road ahead of a crossing. Second, drivers interpret what the scene means. In the above example, they may remember that the marking is a reminder of crosswalks ahead, and they need to yield to pedestrians. Third, considering that not yielding is against traffic regulations, they form a yielding intention. Finally, the driver translates the intention into action: braking. This process also stands when applied to explain drivers' responses to other treatments such as prompt signs that remind with text "yield to pedestrians" (Van Houten and Malenfant, 1992; Huybers et al., 2004; Benekohal et al., 2007), pedestrian activated flashing beacons (Schroeder, 2008) and responsive warning lights that flash when pedestrians are detected (Hakkert et al., 2002).

Emphasizing mental activities, the SIFT model focuses on the personal element (Straker, 2008). In Figure 1, rrequirements for "environment" elements corresponding to the first three phases have also been added. "Visibility" refers to how easy a treatment can be identified from surroundings. "Clarity" means that the intended meaning of a treatment should not be misinterpreted, and "Motive power" requires that a treatment has to connect with a motivator that can push the driver toward a desired action. In other words, a treatment should have high visibility to facilitate the sensing phase, as well as high clarity to avoid misinterpretation, and a strong connection with motivators to encourage intent formation. In fact, in traffic sign design and evaluation, understandability (i.e. clarity) and conspicuity (i.e. visibility) have been considered by experts to be the most important two principles (Dewar, 1988).

Considering the three criteria, previous mainstream treatments can be assessed as in Table 1 (for the moment, please ignore the grayed columns). All the treatments have medium to high visibility, and can convey the meaning clearly after training. Among them, prompt signs can stimulate different motivations, depending on the text on the sign. Most of them can remind drivers of the law (Van Houten and Malenfant, 1992; Huybers et al., 2004; Benekohal et al., 2007), while others may encourage yielding via social approval (Nasar, 2003). Advance yield markings ahead of crosswalks can also increase yielding by informing drivers of approaching crossings nearby (Huybers et al., 2004). In addition to these static approaches, flashing beacons and responsive lights can dynamically show the position of the crosswalk, thus increased visibility and law awareness.

Although the above treatments have been successful in terms of effectiveness, hidden dimensions may undermine them (see the last 3 columns of Table 1). First, all the facilities need to be built by a third party (e.g. the transport ministry) beyond the drivers and pedestrians who are main parties involved in the context. Another important attribute of the treatments is whether they are responsive – i.e., can be activated by the user. This is important because responsive treatments like pedestrian activated flashing beacons (Schroeder, 2008) and responsive lights only operate when needed, thus they are less disturbing to drivers when no pedestrians are around. Compared with devices that operate regardless of pedestrians' existence, the responsiveness attribute of a signal also enforces the connection between the yielding behavior and the signal, thus facilitating drivers' future responses to such warnings. Unfortunately, responsive facilities are currently very expensive to install.

This study therefore aims to explore an alternative approach to traditional driver warnings. Besides the three basic requirements (visibility, clarity, motive power), the method must be able to work without any need to install equipment by a third party and should also be responsive and cheap to apply. A promising candidate that satisfies all the requirements is to allow pedestrians, in a sense, to "step out, *tell* drivers their crossing intention, and *ask* drivers to yield". Of course, the road context is often very noisy and complex, thus potentially effective ways to "tell" and "ask" in this context must be non-verbal. Some possible strategies can be gleaned from the way drivers communicate with each other using blinkers, headlamps, horn-use, car movements and gestures (Renge, 2000).

**Table 1**
Comparison of approaches aiming to increase driver yielding rate.

| Treatments | Visibility | Clarity | Motive power | Initiator | Cost | Responsive |
|---|---|---|---|---|---|---|
| Prompt signs | Medium/high | High | Law; social approval | Govt. | Medium | No |
| Yield markings | High | High | Law | Govt. | Medium | No |
| Flashing beacons | High | High | Law | Govt. | High | No/yes |
| Responsive lights | High | High | Law | Govt. | High | Yes |
| Pedestrian gestures | High | Varying | Social influence | Pedestrians | Low | Yes |

Among these approaches, gestures can be easily understood, indicating their potential for use by pedestrians. In fact, Renge (2000) found that, although novice drivers do not clearly understand informal device-based signals (e.g. blinkering headlights to cars cutting in), they perform better in explaining informal gesture-based signals. Moreover, gestures are natural, cost-efficient, and can be used whenever and wherever needed. These advantages therefore motivated us to explore how they may influence drivers' behaviors at uncontrolled crosswalks.

### 1.3. Pedestrian gestures as a candidate

Recall that we have stated three basic dimensions that can be used to assess a signal: visibility, clarity and motive power. In terms of visibility, gesturing is dynamic and therefore can be more prominent than using signs and markings. Underwood et al.'s (2003) work showed that drivers' attention was more easily attracted to moving than static objects. In terms of clarity, different gestures have varying clarities, thus we need to choose the most effective. For the motivation element, driver compliance may be attainable due to commanding or polite gestures, which can map to two compliance gaining strategies: "assertion" and "direct request" (Kellermann and Cole, 1994). However, it is also possible that the gestures may not work because people are more likely to comply with authority (the official traffic controls) than with ordinary pedestrians (Cialdini and Goldstein, 2004).

To our knowledge, the only study on pedestrian gestures in the literature is by Crowley-Koch et al. (2011) conducted in Chicago and western Michigan. They compared drivers' yielding rates under three conditions: (1) no gesture or prompt, (2) extended arm (where pedestrians "extend the right arm into the crosswalk at 90 degrees" with the palm facing drivers), and (3) raised arm (where pedestrians "held the left hand up at chest height in front of the body with the elbow bent, palm facing the driver"). The results indicated that the yielding rate increased in the latter two conditions compared with no prompt.[1] However, some points need to be considered in this pioneering work. First, seven of the ten sites in their study had only 2 lanes (the other three had 3 or 4), and the reported vehicle volumes were low. In other words, pedestrians' risk at these sites was low. Since vehicle speed is usually lower on narrow roads (Godley et al., 2004), drivers are more likely to yield at these sites. Second, the study did not report the gestures' effect in other aspects except for the actual "yielding rate". In some cases, drivers may have slowed down to see what was going on as a natural response to novel stimuli (i.e. a gesture), without the real intention of yielding. Although the overt behavior (slow down) may be the same, the interpretation (i.e. curious about novel stimuli vs. want to yield) ultimately determined whether the gestures would still be effective in the long term. In addition, gestures may be effective in increasing yielding rates but at the same time cause other problems. For example, the drivers may use the horn at pedestrians, which is frequently observed in daily life (in this study, the horn-use rate is 15.3%). Side effects like this were not evaluated. Finally, some gestures are culture dependent (Archer, 1997), as a proper gesture in one culture may cause problems in a different one. In fact, the "extended arm" seemed to be a gesture for "flagging a taxi" in China, which may not gain a high yielding rate. To avoid such problems, an evaluation of gestures and of drivers' understanding is needed, based on the three basic elements already mentioned: visibility, clarity, and motive power.

Gestures have good visibility due to their dynamic features when compared with static signs (see Section 1.2). However, to ensure that drivers can see pedestrians at a distance, comparison of the visibility of different gestures is still necessary. The "motivator" of traditional treatments is based on enforcement of the law and driving tests. Gestures do not currently have such a legal status. Nevertheless, a possible motivator is the courtesy dimension indicating whether a gesture is politely requesting or forcefully commanding a right to cross. "Assertion" and "Direct request" are compliance gaining techniques that change behavior via social influence (Kellermann and Cole, 1994), so they may indirectly reflect whether a gesture has a strong driving force. Moreover, this dimension is helpful in that when all other aspects are equivalent, courtesy gestures may help to maintain a harmonious relationship among road users. In addition to these basic dimensions, general ergonomic principles for evaluating traffic signs also include familiarity (Ben-Bassat and Shinar, 2006), which can facilitate the learning of signals.

To sum up, pedestrians' rights at unsignalized crosswalks are potentially at risk in many parts of the world. To increase driver yielding rates, researchers have proposed several environmental changes to remind drivers including yield markings, prompt signs, and responsive lights. Although such measures can be effective, they need to be built by official authorities, and may have high cost implications. An alternative or supplementary solution has therefore been proposed that pedestrians themselves actively use arm gestures to ask drivers to stop. The following Section 2 evaluates eleven gestures for visibility, clarity, familiarity and courtesy. Four of them were then selected to be evaluated in field experiments described in Section 3 to explore how different gestures influenced drivers' yielding, horn-use and lane changing behaviors. Section 4 discusses the implications and limitations of the gestures.

## 2. Evaluation of gestures

The evaluation process is necessary for two reasons. The first is that observation of behavior can only reflect a response, but cannot reveal mental activities that motivated it. For instance, a driver may slow down to see what is happening when the pedestrian is making a gesture rather than yield due to understanding the pedestrians' request. The other purpose of the evaluation is to screen the gestures in order to balance the experiment implementation cost and inclusion of many gestures. To avoid omitting potentially effective gestures, eleven were included in the study. However, if all the eleven were directly tested in field experiments, 24,000 crossing attempts would have been necessary.[2] But, after the screening process which resulted in four gestures, only 1000 attempts were needed.

### 2.1. Participants

As part of the research, thirty-two drivers, recruited in a continuing education class and on the road in Beijing, China, participated in the pedestrian gesture evaluation. Two were taxi drivers and the others were private car owners. The age range was from 25 to 56, with an average age of 36. Among them, 44% were males. On average, they had been licensed drivers for 6.9 years and usually drive for 1.9 h on a daily basis. They were paid 25 RMB for their participation.

[1] No statistical test results were provided, but the baseline yielding rate was 1.9–31.5% across the 10 sites, much lower than the yielding rate for the latter two conditions which were respectively 9–63.6%, and 18.5–68.8%.

[2] Number of attempts for testing eleven gestures: 2 (back and forth) × 12 levels (baseline, eleven gestures) × 100 times/level = 24,000 times. Similarly, number of attempts needed for testing four gestures: 2 (back and forth) × 5 levels (baseline, four gestures) × 100 times/level = 1000 times.

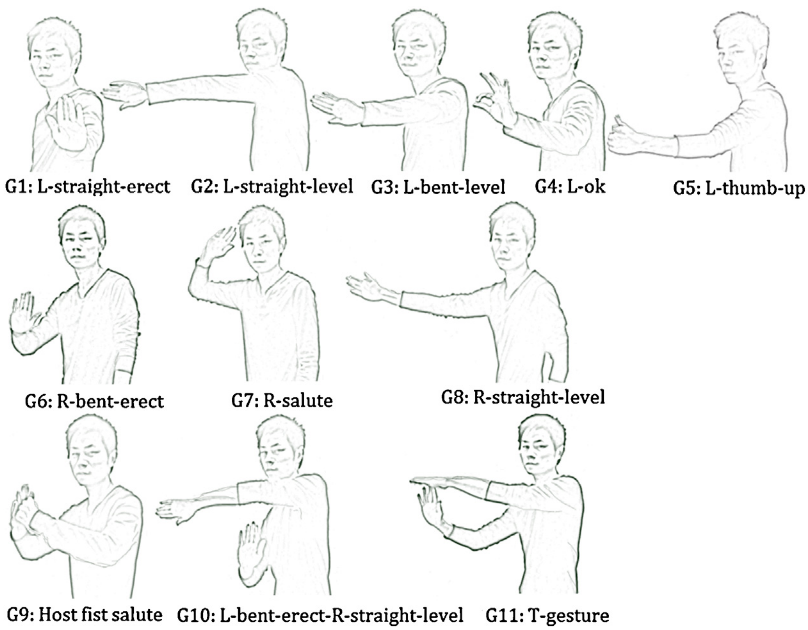


**Fig. 2.** Illustration of the eleven proposed and evaluated gestures. The first row shows five Left-arm gestures: L-straight-erect, L-straight-level, L-bent-level, L-ok, and L-thumb-up. The second row has three Right-arm gestures: R-bent-erect, R-salute, and R-straight-level. The final three gestures in the last row were performed with both arms: Hold fist salute, L-straight-level-R-bent-erect, and T-gesture. "Straight" and "bent" refer to the state of the arm or elbow, while "erect" and "level" refer to the state of the hands. The order number "GX" means the *X*th Gesture.

### *2.2. Materials*

After reviewing webpages searched with the keyword "pedestrian gestures" (in Chinese) and referring to daily experience, eleven gestures were selected as evaluation candidates. An illustration of the gestures can be seen in Fig. 2. The following shows the sources of these gestures (some have several).

G1, G5: Adapted from internet news introducing how to cross the road safely.[3]
G1, G2, G3, G6: Daily observation in Beijing, China.
G3, G8: Crowley-Koch et al. (2011) had the two gestures.
G4, G7, G5, G9: Adapted from other contexts to show praise, respect or request.
G10: Integrating G2 and G6 to increase visibility.
G11: A gesture often used to represent "stop, terminate, and halt" in sports.

Gesture photographs (not diagrams as in Fig. 2) used in the evaluation were taken from drivers' viewpoints using models displaying the gestures at the kerb with one foot on an unsignalized crosswalk. Both female and male versions of the pictures were taken. Thus, 22 color pictures were used in the evaluation.

A short questionnaire with six questions was developed to evaluate each arm gesture. The questions and are as follows:

**Q1**. Can you see pedestrian clearly? (7 point Likert scale, test *visibility*)
**Q2**. What do you think his/her gesture means in the current context? ____________
**Q3**. How definite is the gesture in conveying the meaning you answered in Q2? (7 point Likert scale, test *clarity*)
**Q4**. How often do you see this gesture on the road? (7 point Likert scale, test *familiarity*)
**Q5**. Is the pedestrian commanding or politely asking someone to do something? (7 point Likert scale, test *courtesy*)
**Q6**. What are you most likely to do in this case? (Multiple choice, choose among five responses: Speed up; Do not change speed; Pass by the pedestrian with reduced speed; Slow down to let the pedestrian cross; Stop to let pedestrians pass).

For all the 7 point Likert scale, higher values represent better visibility, stronger clarity, higher familiarity, and more courtesy, and the neutral response is 4. The questions were constructed so that all the dimensions stated in Section 1.3 could be evaluated. An additional question about stated behavior when coming across such gestures was included to compare with actual behavior in the subsequent field test.

### *2.3. Procedure*

The gesture photographs were printed out in color format and shown to the drivers one by one in random order. First, participants were instructed to notice that the pedestrians in all pictures were standing at a marked but uncontrolled mid-block crosswalk. Then for each gesture, both male and female versions of the gestures were given to participants before answering the corresponding survey questions. They were told to ask the researchers standing beside if they could not see a gesture clearly in the photograph. (In these rare instances, as they would not be able to answer the other questions, researchers showed them the gesture to help them finish the evaluation.) To minimize the experimenter effect, researchers did not look directly at participants during the evaluation except when explaining the task. They changed the pictures whenever a gesture evaluation was completed.

### *2.4. Results*

Since the meanings of the gestures were gained from an open-ended question, the answers were coded into eight categories as

[3] Example: news from Shenzhen city describing a social program called "Civilized and Courteous Zebra": http://dnsb.cnnb.com.cn/portal.php?mod=view&aid=3609 (accessed 07.04.13).

**Table 2**
Evaluation results of eleven gestures by thirty-two drivers.

| Category | Answers | Ranked gestures (negative → positive) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | G4 | G8 | G7 | G5 | G9 | G2 | G10 | G6 | G11 | G3 | G1 |
| Meaning (%) | Yield | 16 | 13 | 25 | 19 | 41 | 28 | 28 | 47 | 6 | 34 | 41 |
| | Yield (stop) | 9 | 19 | 6 | 6 | 28 | 44 | 56 | 28 | 91 | 53 | 47 |
| | Yield (slow down) | 3 | 3 | 0 | 3 | 6 | 6 | 6 | 22 | 0 | 13 | 13 |
| | Yield to drivers | 31 | 13 | 3 | 9 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Flag a taxi | 0 | 34 | 0 | 6 | 3 | 9 | 0 | 0 | 0 | 0 | 0 |
| | Ask for a lift | 3 | 0 | 3 | 28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Other | 16 | 3 | 56 | 19 | 9 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Not clear | 22 | 16 | 6 | 9 | 13 | 13 | 9 | 3 | 3 | 0 | 0 |
| Attribute (Likert Scale 1–7) | Visibility | $4.6^0$ | 6.4 | 6.0 | 5.6 | 4.9 | 5.9 | 5.8 | 5.6 | 5.8 | 5.8 | 6.1 |
| | Clarity | $2.8^*$ | 5.4 | $3.3^*$ | 4.8 | $3.7^0$ | 4.7 | $4.2^0$ | 4.9 | 5.8 | 5.0 | 6.2 |
| | Familiarity | $2.1^*$ | 5.2 | $3.0^*$ | $3.4^0$ | $2.2^*$ | $4.1^0$ | $2.3^*$ | $4.3^0$ | $3.6^0$ | $4.6^0$ | 5.9 |
| | Courtesy | 4.3 | $4.5^0$ | 4.5 | 5.3 | 5.0 | $3.5^0$ | $3.2^*$ | $3.9^0$ | $2.8^*$ | $3.3^*$ | $3.3^0$ |
| Response (%) | Speed up | 13 | 6 | 3 | 0 | 3 | 0 | 3 | 0 | 3 | 0 | 3 |
| | No change | 34 | 34 | 34 | 38 | 16 | 6 | 16 | 13 | 9 | 6 | 0 |
| | Pass (slow down) | 28 | 19 | 38 | 16 | 28 | 13 | 22 | 16 | 3 | 3 | 3 |
| | Yield (slow down) | 19 | 16 | 9 | 22 | 38 | 53 | 38 | 56 | 19 | 72 | 72 |
| | Yield (stop) | 6 | 25 | 16 | 25 | 16 | 28 | 22 | 16 | 66 | 19 | 22 |

*Note*: $X^*$ denotes $X$ is significantly lower than 4 (neutral value in the 7-point Likert scale); $X^0$ means X is not significantly different to 4, and all other attribute values are significantly higher than 4.

shown in Table 2. The category "**Yield**" includes answers such as "please let me cross first", while "**Yield** (**stop**)" and "**Yield (slow down)**" refers to answers that clearly stated the way of yielding, such as "stop, I want to cross the road" or "I plan to cross, please slow down." These three categories were the "intended" meanings of requests to yield. However, there were other additional answers: "**Flag a taxi**", "**Ask for a lift**", "**Yield to drivers**" (e.g. "you go first"), and "**Not clear**". The category "**Other**" refers to answers that only indicated the general meaning of the gesture regardless of the current context (e.g. R-salute: "salute", L-ok: "Ok" and L-thumb-up: "praising me").

In Table 2, darker backgrounds show more popular choices within each category or higher score in the gesture attributes. The results indicate that all gestures had good visibility, except G4 (L-ok) which, together with G7 (R-salute), was considered unclear in conveying meaning. Meanwhile, although gestures G5 and G8 had good clarity, this referred respectively to "asking for a lift" and "flagging a taxi" rather than "yielding". To rank the gestures in a systematic way, the evaluation criteria, in order of significance, were as follows:

(1) Correct understanding of meaning
(2) Good visibility and clarity
(3) Greater familiarity and courtesy
(4) Drivers' stated responses to the gestures (e.g. slow down, stop) were only subsidiary references to rank the gestures.

The eleven gestures were ranked based on the above criteria by three researchers with the paired comparison method. The final ranks were ordered according to their increasing appropriateness and displayed in Table 2. In the table, the dotted line separates desirable and undesirable understandings. Drivers' understanding of the first four gestures (G4, G8, G7 and G5) were mostly distributed below the dotted line. G4 was in fact interpreted as having the opposite meaning: yield to drivers. The middle three gestures (G9, G2 and G10) were better understood but still caused confusion among some: the meanings were misinterpreted or the clarity was not high. The remaining four gestures (G6, G11 G3 & G1 in bold) outperformed the others. Although none were considered particularly courteous and only G1 was familiar to drivers, important aspects of the gestures were satisfactory, especially criteria (1) and (2), with almost all correctly interpreted with high scores on visibility and clarity. Therefore, these four (G6, G11 G3 and G1) were selected to be tested in field contexts in Section 3.

## 3. Field experiments

The selected gestures from Section 2 were G6 (R-bent-erect), G11 (T gesture), G3 (L-bent-level), and G1 (L-straight-erect). These gestures, together with a baseline condition where no gesture was used, were the five levels of the independent variable and were presented to drivers randomly in our field experiments carried out in China. The dependent variable was driver responses to gestures including: speeding up, not changing speed, slowing down when passing, slowing down to yield to pedestrians, stopping to yield to pedestrians, changing lanes, and horn-use. In case of yielding, the distance between the driver and the pedestrian (when they were in the same lane) was also recorded to evaluate safety.

### 3.1. Setting

Sites that have non-signalized crosswalks usually have two or four lanes in China. The latter are wider and more dangerous for pedestrians and were therefore among four of the five experiment sites selected. All these sites were in Beijing (their characteristics are listed in Table 3). Image "a" in Figure 3 shows Cuiwei Road: on either side of the traffic barrier in the middle, there are two motor lanes, a non-motor lane and a green verge and sidewalk. Zhixin West Road has similar layout except that the road only has two lanes with no barrier dividing them. Image "b" shows Xicui Road with a mid-road barrier. On either side of the barrier, the layout has the following structure from middle of the road to roadside: two motor lanes, a green verge, a non-motor lane and a sidewalk. Zhixin East Road has similar layout except that the gap between the barriers in the crosswalk is larger. Xueyuan South Road also shares this layout except that the big trees act as separator between the motor and non-motor lanes instead of a green verge. The signs with blue background and a white triangle showing a person crossing the road indicate the position of the crosswalk, and the diamond-shape road markings remind drivers of crosswalks ahead. At all these sites, action is rarely taken against drivers do not yield, unless an accident happens due to incompliance.

**Table 3**
Characteristics of the experiment sites.

| Sites | Lanes | Vehicle volume/h | Pedestrian volume/h | Avg. vehicle speed (km/h) | Neighborhood |
|---|---|---|---|---|---|
| Zhixin East Rd. | 4 | 1152 | 153 | 38.5 | Residential area, restaurants |
| Xueyuan South Rd. | 4 | 1443 | 43 | 51.8 | Residential area, university |
| Zhixin West Rd. | 2 | 820 | 14 | 34.9 | Residential area |
| Xicui Rd. | 4 | 1369 | 24 | 45.0 | Hotel |
| Cuiwei Rd. | 4 | 1969 | 207 | 43.6 | Residential area, park |

**Table 4**
Drivers' responses to selected gestures (G6, G11, G3, G1).

| Gestures/responses (%) | No change | Pass (slow down) | Yield (slow down) | Yield (stop) | Use horn | Change lane |
|---|---|---|---|---|---|---|
| Baseline (no gesture) | 63.5 | 32.9 | 2.4 | 1.2 | 15.3 | 5.9 |
| R-straight-erect | 51.8 | 42.2 | 1.2 | 4.8 | 24.1 | 9.6 |
| Time-out | 55.7 | 32.9 | 5.1 | 6.3 | 19.0 | 8.9 |
| L-straight-erect | 46.6 | 44.3 | 4.5 | 4.5 | 18.2 | 12.5 |
| L-bent-level | 38.8 | 48.2 | 4.7 | 8.2 | 12.9 | 10.6 |


**Fig. 3.** Photographs of the experiment sites: "a" shows the layout of Cuiwei Road (similar to Zhixin West Road), and "b" shows Xicui Road (similar to Zhixin East Road and Xueyuan South Road).

## 3.2. Procedure

As shown in Fig. 4, three people were needed in each observation, one as a pedestrian and two as observers. The pedestrian waited at the edge of the road at $\mathbf{P_0}$ while Observer 1 surveyed the whole scene to detect a target vehicle that could meet the following criteria: the vehicle is on the same side of the road as the pedestrian, with no other vehicles in adjacent lanes, and no real pedestrian crossing. Once the target vehicle arrived at $\mathbf{V_0}$ (see the flag in Fig. 4), observer 1 signaled to observer 2 and the confederate pedestrian (enacted by researchers). Then the pedestrian began to walk toward the crosswalk until one of his/her feet was on it. The pedestrian stopped, turned his/her head to the left, looked at the vehicle and presented a gesture (or no gesture in the baseline condition) to the driver. If the driver yielded, the pedestrian withdrew the gesture and crossed the street; otherwise he/she withdrew their gesture and waited there until there was a gap large enough to cross. While the pedestrian was walking, both observers recorded the drivers' responses independently in a predefined datasheet. When the road had been crossed, the confederate returned to $\mathbf{P_0}$ and waited to start another trial.

Since the distance to the pedestrian may influence drivers' yielding behavior, the onset of the gesture was made at point $\mathbf{V_1}$ when the distance was sufficient for the fastest driver (calculated with the speed limit of the road) to stop if they wanted to yield ($\mathbf{V_1P_1}$ was kept roughly constant among gestures). Point $\mathbf{V_0}$ (when the observer signaled to the pedestrian) was estimated to make sure that vehicles would arrive at $\mathbf{V_1}$ when the pedestrian arrived at $\mathbf{P_1}$ from $\mathbf{P_0}$. Since the vehicle speed varied among target vehicles, sometimes the point $\mathbf{V_0}$ was adjusted according to vehicle speed.

## 3.3. Results

One hundred drivers were observed at each site, thus the sample size was 500. Cases in which two observers did not have the same data recorded were excluded. This resulted in 420 valid cases, with a valid rate of 84%. The following Table 4 shows behavior responses from the 420 drivers. No driver was observed to speed up, so the table only includes six types of response.

The overall yielding rate (including both slowing down and stopping to yield) at all sites was 8.6%, with an average yielding distance

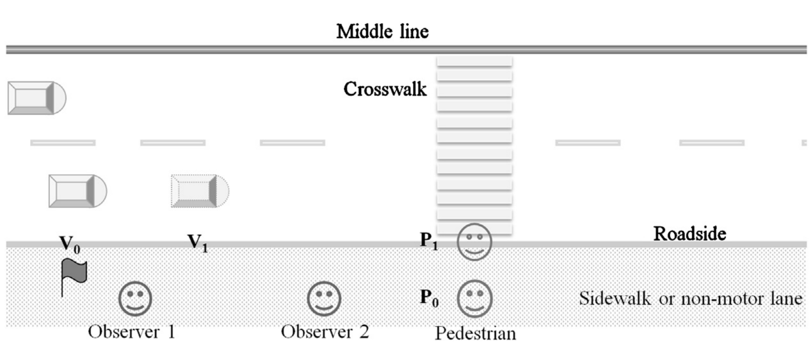


**Fig. 4.** Experiment procedure diagram.

of 8.1 meters ahead of pedestrians. This rate is far lower than the driver self-reported yielding rate in Section 2 (91%). In the baseline condition (i.e. with no gesture), only 3.5% of the drivers yielded to the pedestrian, and up to 63.5% of them did not even change speed. Instead, they chose to use their horn (15.3%) or change lanes (5.9%) to make sure they could continue forward without being disturbed.

Since the first four responses – no change, pass (slow down), yield (slow down), yield (stop) – indicated increasing levels of yielding, they were regarded as the four values of an ordinal variable: yielding degree. A sum rank test using Kruskal–Wallis H was conducted to explore the effects of the gestures. Although the yield behaviors differed among the gestures ($\chi^2 = 12.8$, df = 4, $p = .012$), a post hoc test with Mann–Whitney $U$ showed that only the last gesture in Table 4 (G3: L-bent-level) significantly differed with the baseline on yielding behavior ($Z = -3.45$, $p = .01$, after Dunn–Sidák correction). All other gestures did not differ from each other significantly ($p > .05$). Fisher's exact test also showed that drivers' horn use did not differ in response to different gestures ($p = .405$), nor in the case of lane changing behavior ($p = .661$).

Consequently, the final selected gesture was L-bent-level (see Fig. 5). While the yielding rate was still not high with this best performing gesture, the increase in drivers' yielding rate (3.5–12.9%), and the decrease in drivers' passing by with unchanged speed (63.5–38.8%) indicated a promising prospect. Moreover, the side effects of the gesture (horn use and lane changing) did not differ with that of the baseline.

**Fig. 5.** Examples of the best-performing gesture: G3 (L-bent-level).[5]

## 4. Discussion

Although Chinese law gives the right of way to pedestrians at uncontrolled mid-block crosswalks (China State Council, 2005), the baseline yielding rate is only 3.5%. The evaluation of eleven proposed pedestrian gestures according to their visibility, clarity, familiarity and courtesy resulted in four gestures – G6 (R-bent-erect), G11 (T gesture), G3 (L-bent-level), and G1 (L-straight-erect) – that satisfied the major criteria. Field experiment with them identified G3 (L-bent-level) as the final choice for increased yielding and slowing down without bringing about side effects. This section first discusses the effect of gestures on yielding in the light of current literature and then presents the potential theoretical and practical contributions of the research. Possible limitations of the study are also discussed.

### 4.1. Effect of gestures

As noted above in Section 1.3, Crowley-Koch et al. (2011) compared two gestures (extended arm and raised arm) and their effects in increasing drivers' yielding. Although they did not illustrate the gestures with pictures, their verbal descriptions ('*extend arm*: extend the right arm into the crosswalk at 90 degree with the palm facing drivers'; '*raised arm*: hold the left hand up at chest height in front of the body with the elbow bent, palm facing the driver') suggested that the extended arm gesture was similar to G8 (R-straight-level) and the raised arm similar to G3 (L-bent-level). Although the extended arm treatment was found to be effective in their study, the G8 (R-straight-level) was not selected in the evaluation step in the current study. The evaluation results showed that although 41% of the participants reported yielding when coming across this gesture, 34% of the surveyed drivers thought this gesture meant flagging a taxi, and 13% even thought the pedestrian was yielding to drivers. This suggests gestures are indeed not universal (Archer, 1997).

Similar to Crowley-Koch et al.'s (2011) finding on the effectiveness of the raised arm gesture, G3 (L-bent-level) proved effective in increasing yielding when compared with the baseline. However, considering that this gesture was not significantly better than the other three selected gestures (G6, G11, G1), it only stood out by a slim margin. The evaluation results on clarity and familiarity shows that this gesture is no better than G1 (L-straight-erect). Crowley-Koch et al. (2011) explained that G3 (L-bent-level) was a ubiquitous representation of halting. This interpretation, however, cannot explain the slight difference between G1 (L-straight-erect) and G3 (L-bent-level) since the former also means "stop" or "forbidden". A possible reason is the visibility difference. In a static scenario, as in the evaluation, the drivers were not at the wheel and the scene was static. Therefore, the visibility requirement was not high, and both gestures were evaluated as satisfactory. In a real setting, however, drivers' eyes are flooded with complex visual data and must approach pedestrians from a distance. Therefore, visibility becomes more important. With G3 (L-bent-level), drivers can see the whole arm of the pedestrian whereas only the palm can be seen in G1 (L-straight-erect).

It should be noted that even with the effective G3 (L-bent-level) gesture, the yielding rate is still relatively low (12.9%). However, this does not mean that pedestrian gestures cannot make a difference. For one thing, the drivers that slowed down when passing by increased by 15.3%, which arguably means that such drivers might yield if the gestures were implemented as part of a traffic safety campaign, for instance. Moreover, the effectiveness of a gesture also depends on where, when, and how long it is used. In the current study, the gestures were only displayed at the roadside by stationary pedestrians for several seconds to the nearest driver. Without these restrictions, a gesture may be more effective. There are two common scenarios where gestures might be used with more relaxed limits: (1) pedestrians can cross the road while maintain the gesture to vehicles approaching subsequently; (2) pedestrians who previously stopped in the crossing can display gestures to approaching drivers for a sufficient time to reinitiate crossing. Although the effects of gestures in these two scenarios cannot be confirmed easily in field experiments,[4] a higher yielding rate might be expected for two reasons. First, previous research has

[4] To make the scenarios realistic, pedestrians need to be on the road when drivers are approaching. However, drivers' speeds far away are hard to predict, thus the moment the pedestrian appears cannot be determined easily. What's more, to compare the effectiveness of the gestures with that of the baseline, drivers should be exposed to identical treatments in aspects other than gesture conditions (e.g. pedestrians' distance from drivers). In this case, researchers acting as the confederate pedestrians need to pass in front of vehicles without even showing their intention with gestures in the baseline condition in the "cross while displaying gesture" scenario. This implementation would be very risky, especially when multiple crossings are needed.

[5] The heads of the models are masked to protect privacy, but it can still show the direction they are looking which is the approaching direction of vehicles. Note that in countries where vehicles drive on the left side, the gestures and head direction should be reversed to the right.

found that assertive pedestrians standing farther from the kerb they are already were more likely to gain the right of way (Himanen and Kulmala, 1988; Harrell, 1993). Second, when pedestrians are crossing the road, the intended meanings of gestures (i.e. please yield) are more obvious because some misinterpretations of the gestures can be excluded naturally. For instance, in the case of pedestrians who used G8 (R-straight-level), drivers will not think that they are flagging a taxi. Theoretically, these two reasons will lead to a higher yielding rate, which is consistent with the authors' observations of daily life in China. Another potential extended use of gestures would be at intersections where vehicles turning right fail to yield to pedestrians, thus becoming hazardous to pedestrians (Abdulsattar et al., 1996). Turning vehicles usually slow down to ensure a safe turn. Given that lower speed can increase the possibility of yielding (Himanen and Kulmala, 1988; Turner et al., 2007), an additional increase in the yielding rate may be expected if gestures were applied in this situation as compared with that of the mid-block crosswalks.

### 4.2. Theoretical implications and practical applications

The integration of existing theories, together with the three added features to evaluate gestures, has theoretical implications beyond the context of this study. As noted in Section 1.2, Lewin's equation (Sansone et al., 2004) is a very general conceptual framework about the interaction of person and environment, thus it is not easy to use in practice. On the other hand, the SIFT model (Straker, 2008) is a detailed model that focuses on the inner activity of person, but rather neglects the influence of the environment. Their integration makes it more practical for future studies to evaluate existing countermeasures as well as develop new strategies based on psychological process of perception and decision making. The three environmental features added to three corresponding internal phases in order to induce desired behaviors are visibility, clarity and motive power. In Fogg (2009) behavioral model (FBM) of persuasive design, the power of a design in changing behavior depends on three components: ability, motivation and trigger. In other words, people will behave in an intended manner when a task is easy, motivating and contains a signal related to the intended behavior. Clearly, "visibility" can make the yielding task easier, thus can be mapped to the "ability" component in FBM whereas "Motive power" is essentially the same as the "motivation" component. The "clarity" feature means that the target only has one exclusive meaning attached to it, which not only makes the task easier, but also function like a "trigger". This mapping between the three components and such a widely used behavior model indicates that these features are not confined to the current study but reflect general requirements of approaches when trying to alter behavior via the environmental change. The rest of this section discusses the clarity and motive components in detail.

Overall, the gestures used in our research, together with responsive lights (Hakkert et al., 2002) and signs (Van Houten and Malenfant, 1992) all try to encourage drivers to yield. In this context, clarity requires these signals to have strong association with the request to yield to pedestrians, or more specifically, associate with "the presence of pedestrians" and "the need to yield to them". The signals' connection with pedestrians' presence can be assessed in terms of time and meaning. In terms of time, prompt signs and yield markings can trigger drivers to pay attention to approaching crosswalks or potential pedestrians. Their appearances are not always associated with the presence of pedestrians waiting to cross, so the time connection between signal and target is weak. In contrast, responsive lights and gestures are always accompanied by pedestrians, thus the time connection is strong. In terms of meaning association, gestures are a direct signal of pedestrians' presence and intent, but the traditional triggers such as prompt signs rely on a memory extraction of how they are associated with pedestrians (as part of the 'inferring meaning' phase in the SIFT model). The direct association is so important that ergonomic guidelines have one requirement for traffic signs, known as "physical representation", which stresses the similarity between the content of the sign and the reality it represents (Ben-Bassat and Shinar, 2006). These time and meaning associations of gesture and pedestrian mean that gestures outperform traditional treatments in their connection with pedestrian presence. However, this does not mean that all gestures are effective as they also must have a conceptual association with "yielding to pedestrians", beyond merely signaling "the presence of pedestrian". This is why the stated meaning and clarity are very important in the evaluation of gestures in Section 2. Before the evaluation, the attribute "courtesy" was considered important for social influence and a harmonious transportation environment. However, all of the polite gestures were excluded because courteous gestures such as G7 (R-salute) and G9 (Host fist salute) had various interpretations. It was evident that they were associated with a request, but the specific content of the request was not clear. This implied that two-step gestures that first show the request and then display a gesture showing gratitude if drivers' yield may be effective and harmonious triggers–e.g. combine G3 (L-bent-level) and G5 (L-thumb-up). The reward may encourage more drivers to yield voluntarily in future.

Traditional traffic management treatments mainly rely on respect for the law as the motivation (see Table 1), which is very effective because authority is an important determinant of compliance identified in social psychology (Cialdini and Goldstein, 2004). In the current study, the gap between reported and observed yielding rates was very large (12.9% vs. 91%). Self-reported measures usually suffer from bias in questions that have social desirability like "yield to pedestrians" (Lajunen et al., 1997). If this bias is the reason for the difference, it can be inferred that drivers know they *should* yield, but they simply refuse to do so. Another explanation is that when answering the survey, drivers need to "choose" a response among the available answers. This process resulted in yielding choices in some drivers. In reality however, drivers may simply follow their habits and ignore the crosswalk without even making the effort to "choose". Whatever the explanation, it indicates that drivers lack the motivation to yield. A possible reason is the low authority level (Cialdini and Goldstein, 2004) when the gestures were used by the researchers. Suppose that police officers displayed the gestures, the yielding rate may have soared. This problem might therefore be alleviated by integrating the gestures into traffic regulations.

Besides the lack of authority, other potential causes for low compliance are multiple (recall the top down factors in Figure 1): drivers' may be unwilling to be interrupted when driving in a state of flow (Chen and Chen, 2011) or they misunderstand who has the right of way (Hatfield et al., 2007). These possibilities indicate that although an environmental change (i.e. bottom-up factors in Fig. 1) is a quick and rough solution, understanding the intrinsic reason for the low yielding rate may offer alternative clues. It is therefore suggested that future research should approach the driver yielding issue from top-down, looking at why drivers lack the motivation to yield and how to stimulate it.

In addition to these theoretical implications for future work, a practical implication from the study is that pedestrians should be trained to make the 'L-bent-level' gesture to approaching vehicles. Currently, a commonly seen slogan for pedestrians is "first stop, second look, and third cross". This way of crossing places low demands on the driver's side but may overload pedestrians, especially young children and the elderly who are vulnerable groups worldwide (Zegeer and Bushell, 2012). In future, we propose that using an appropriate "gesture" may become the third step, as a signal of intent to cross. In this way, drivers share some of responsibility as they need to look at the pedestrian gestures and act accordingly. For this reason, the gesture should be included in the formal training to obtain a driving license. In the case of pedestrians, the gesture is easy to learn and convenient to display with one hand, thus even small children can master it easily. Several ways could be adopted to educate pedestrians: children can be educated in school to cross marked crosswalks with the gesture. Signs telling pedestrians how to use the gestures might be posted nearby or by means of an official website or microblog of the transport authorities.

The gesture could improve pedestrian safety in another way. In intelligent transportation systems, detection of pedestrians and their crossing intention via machine learning is very important in assisting drivers in case of visual failure (Kohler et al., 2012). Since shape based detection has already been used as a cue in pedestrian detection system (Gavrila and Munder, 2007), a pedestrian displaying a gesture might make it easier to distinguish between pedestrians that want to cross the road from those who simply wander near the crosswalks.

The side effects of using gestures considered in this paper were horn use and lane changing. In a survey conducted in Japan, horn use made 60.1% of pedestrians feel noisy, startled and irritated (Takada et al., 2012). Lane change was also included as a side effect because it decreased the predictability of vehicle behaviors. However, it is notable that these two phenomena did not increase as a result of the gesture use in our research. Nevertheless, there may be some other potential problems. For instance, if the vehicle volume is high and only the vehicles close to the pedestrians yield, then it is risky to cross since vehicles out of sight may dart out in an adjacent lane. Pedestrians should be more careful to avoid such situations if the nearby vehicle is a big one such as buses that can block pedestrians' sights. Another potential side effect of using a gesture is that it is displayed to gain pedestrians' right of way, potentially increasing the perception of their assertiveness and aggression. It should also be noted that the gestures were only tested in China, so whether the findings could be extended to other culture is unknown. Theoretically, so long as a gesture does not bear alternative meaning to "yielding", it can be implemented in driver training to build a connection with yielding need, just as the recognition training of other traffic signs like yield markings. However, a signal that was conventionally understood or even already used by some pedestrians would be better. For instance, in this study, the G3 'L-bent-level' gesture is a natural response of many Chinese people when blocking or stopping something undesirable.

## 5. Conclusions

Four out of eleven gestures ('R-bent-erect', 'T gesture', 'L-bent-level', and 'L-straight-erect') were judged by Chinese drivers as winner when evaluated for visibility, clarity and their level of familiarity. Field experiments showed that only the 'L-bent-level' gesture significantly increased the drivers' yielding rate (or drivers slowing down when passing through). This gesture had no significant side effects in terms of horn use or lane changing. Therefore, it is suggested that pedestrians be trained to use the gesture and drivers be trained to properly interpret and respond to it.

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