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Journal
Proceedings of the Annual Meeting of the Cognitive Science Society, 43(43)

ISSN
1069-7977

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Publication Date
2021

Peer reviewed

What is the Cooperative Behavior of Moving in Shared Spaces?

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Abstract

The development of mobility technologies has led to the concept of shared spaces. In the shared space, mobilities and pedestrians share a single common space. Compared to conventional separated spaces, cooperative behaviors are critical in shared spaces because all agents can move freely at their own speed and in their directions with few constraints. An experiment was conducted using indices for own cost, others' benefit, and own loss to reveal the nature of the cooperative behaviors associated with moving. We found that compared to when people are encouraged to behave without urgency, they frequently change their speed and direction so as not to interrupt others and reach their destination more quickly when people are required to behave cooperatively. Therefore, it was concluded that both others' benefit and one's own benefit are critical for cooperative behaviors when moving in shared spaces.

Keywords: cooperative behavior; shared space; prosocial behavior

Introduction

With the development of technology for automated vehicles and the personalization of vehicles, the forms of mobility have become diverse. The concept of the the shared space, in which both mobility vehicles and pedestrians share a common single space, was proposed by Hans Monderman (Moody & Melia, 2014) and now applied to some spaces in selected cities. Shared space is designed so that the multiple agents have equal footing to share the common space, and some studies have reported safety improvement in shared spaces (Hamilton-Baillie, 2008; Kaparias, Bell, Miri, Chan, & Mount, 2012). In conventional separated spaces, the behavior of each agent is strongly constrained as the vehicles must be on the road and the pedestrians on the sidewalk. However, in a shared space, there are few constraints imposed on each agent because there is no need to divide the areas. This indicates that the mobility vehicles and pedestrians can freely move in their own directions and stop suddenly or turn sharply. Actually, various types of shared spaces have appeared recently. For example, a guiding robot or medical robot have been introduced into the crowded museums or hospitals. Therefore, cooperative behaviors of moving may play an important role when considering moving in shared spaces.

In previous studies, the nature of the cooperative behavior of moving has been examined in conventional situations such as merging and lane changing (Kauffmann, Winkler, Naujoks, & Vollrath, 2018). However, the nature of such behaviors in shared spaces, in which there are few constraints imposed on each agent, is not clear. It is necessary to use a new approach to verify cooperative behavior in shared spaces because the interactions among the agents are expected to be more complex.

Cooperative Behavior in Traffic

Before discussing cooperative behavior in traffic psychology, this section examines prosocial behavior in social psychology (Eisenberg & Mussen, 1989; Mussen & Eisenberg-Berg, 1977). Prosocial behavior has been defined as voluntary behavior to benefit others with no expectation of reward; however, prosocial behavior involves certain losses and costs. For example, a donation to a charitable organization is a prosocial behavior to assist an organization with suffering financial cost.

Cooperative behavior within traffic psychology is defined in a much narrower sense than prosocial behavior within social psychology. Some examples of specific cooperative behavior are: accelerating or decelerating a vehicle so that other vehicles can easily change lanes (Hidas, 2005; Stoll, Müller, & Baumann, 2019; Stoll, Lanzer, & Baumann, 2020); and putting on the blinker, waiting before changing lanes, and changing speed so that other vehicles can easily merge (Kauffmann et al., 2018). In particular, lane changing has often been examined as a situation that requires agents to behave cooperatively (Beller, Heesen, & Vollrath, 2013; Heesen, Baumann, Kelsch, Nause, & Friedrich, 2012). Cooperative behavior optimizes communication and coordination among agents and improves the efficiency and safety in traffic (Fiosins et al., 2016; Fujii, Yoshimura, & Seki, 2010); therefore, cooperative behavior of moving is similar to prosocial behavior.

On the other hand, uncooperative behavior has negative effects on both traffic and agents. For example, unreasonable lane changing can cause serious collisions and delays (Tang, Liu, Zhang, Ke, & Zou, 2018), and drivers can experience stress and anger when asked to merge when there is only a small gap between vehicles (Riener, Zia, Ferscha, Ruiz Beltran, & Minguez Rubio, 2013). The reason why people do not always behave cooperatively is that cooperative behavior can sometimes results in their disadvantage. In actual traffic situations, pressing the brake pedal and decelerating to provide enough space for another vehicle incur cooperative costs (Stoll et al., 2019), which is consistent with the statement that prosocial behavior often involves some kind of cost.

What kind of moving is perceived as cooperative behavior? Previous studies have found that time to collision (TTC), which is calculated based on the distance and velocity between two vehicles, significantly affects cooperativeness in changing lanes (Stoll et al., 2019, 2020; Petit, Charron, & Mars, 2020). This indicates that moving behaviors that maintain an appropriate TTC between two vehicles is favorably perceived as more cooperative by other agents.

However, it is unlikely that the cooperative behavior of moving could be simply determined by using only TTC. First, a shared space is two-dimensional and involves multiple agents moving simultaneously in each direction. TTC refers to the relationship between only two agents and cannot be directly applied to shared spaces. Second, the constraints on behavior are very small in shared spaces as agents can stop suddenly and turn sharply. Therefore, while TTC is an effective index for assessing vehicles that maintain their current direction and speed due to inertia, TTC is insufficient for assessing agents that can stop suddenly and turn sharply, such as pedestrians. Therefore, the situations covered in previous studies such as merging and lane changing on highways are unable to clarify the nature of cooperative of behaviors when moving in shared spaces.

Objective

This study examined the cooperative behavior of moving in shared spaces using a new approach based on "own cost", "others' benefit", and "own loss" indices.

Own cost corresponds to driving maneuver index that consumes physical and cognitive resources, such as pressing the brake pedal as a cooperative cost in traffic research. In other words, the behaviors that require drivers to accelerate, decelerate, or turn their wheels significantly are considered as high-cost behaviors. Others' benefit corresponds to efficiency index in traffic, which has been mainly used in simulation studies. This benefit is measured by how efficiently others reach their own destination, or conversely, how long others are interrupted/disadvantaged. Own loss, therefore, can be measured by the time it takes to reach the desired destination. In sum, when required to behave cooperatively, people are more likely to absorb the costs and behave to benefit others, which ultimately leads to own loss.

The ongoing costs and the final losses in cooperative behavior can be distinguished by the differences between cooperative behavior for others and behavior without urgency. Even if the time it takes to reach one's destination, i.e., the loss, is the same, there may be a difference between cooperative behavior and non-urgent behavior based on the degree of interruption to others.

In sum, the objective of this study was to clarify the cooperative behavior of moving in shared spaces, in which there are few behavioral constraints. For this purpose, a moving task that simulated an actual shared space was developed and required participants to behave cooperatively. In particular, the cooperative behavior of moving was verified by comparing behaviors when the participants were asked to behave cooperatively and when asked to behave without urgency. The objective differences between cooperative behavior and non-urgent behavior were examined using the three indices based on prosocial behavior perspective, that is, own cost, others' benefit, and own loss.

Experiment

Method

Participants Twenty-nine graduate students at Nagoya University participated in the experiment.

Stimulus A moving task was developed referring to an actual shared space (Fig. 1). Participants were asked to control their own agent, which was depicted by the blue circle, and to reach to a destination indicated by a square. The destinations were always placed at a diagonal to the starting position of the own agent. The own agent was controlled using the stick from a Microsoft Xbox controller, and as no inertia was set for the agent's movements, the amount of stick manipulation by the participant corresponded to agent's movement at that moment.

The gray circles indicated the other agents, which changed direction and speed autonomously and randomly. The other agents were designed to slow down to half their original speed if there was another agent within 100 pixels of their direction and to stop if there was another agent within 50 pixels. Note that when the own agent contacted the other agents, the own agent become red. The number of other agents was 5, 10, or 20 (Top, middle, and bottom of Fig. 1 respectively). When the other agents went out of screen, they appeared on the other side, that is, the number of other agents on the screen was always constant in one trial.

The size of task screen was 1000×1000 pixels, the agent was 30 pixels in diameter, and the destination was 80 pixels.

The frame rate was 50 fps and all agents could move up to 4 pixels in each X/Y direction per frame.

One trial was defined as the time taken by the own agent controlled by the participant to reach their destination, with one set consisting of 24 trials.

Procedure At first, the participants were presented with the screenshots of the task and given an explanation about the own agent, the other agents, and the destination, and were asked to reach their own destinations. The participants were instructed to "imagine an actual space where many people come and go to reach each destination such as airports, hospital, or shopping center".

A total of five sets of the moving task were performed after the practice set without other agents so that participants could become used to manipulating the controller. Set 1 was also practice set to help the participants become familiar with the other agents. Set 2 was performed without any instructions, and Sets 3, 4, and 5 were performed after one of the following instructions was provided: "Reach your destination while considering the others around you", for the cooperative condition; "Imagine that you have enough time to reach your destination", for the non-urgent condition; and "Imagine that you have an urgent issue and need to reach your destination quickly", for the urgent condition.

The number of other agents was set to either 5, 10, or 20 in one trial, and eight trials for each were performed. The order of the three instructions and the order of 24 trials were counterbalanced.

Afterward, the participants answered the following two rating questions about their own behaviors on a seven-point scale (1: do not agree at all; 7: entirely agree): "My behavior involved assistance for others" and "My behavior resulted in some loss for myself". These rating scores were regarded as the subjective assistance score and loss score respectively.

For the analysis, the following three behavioral indices were measured in this experiment. Absolute acceleration indicated the magnitude of the change in the speed of the own agent. High absolute acceleration meant that the participant frequently manipulated their controller. Completion time indicated the time until the own agent reached its own destination. Short completion time meant that the own agent move smoothly. Interruption rate indicated how often others were interrupted by the own agent before the own agent reached its own destination. This index was calculated by dividing the time spent interrupting others with the completion time. A small interruption rate meant that the other agents moved smoothly.

The analysis was conducted as follows. First, the values for each index in Set 2 without instructions were considered as the baseline for each participant. Then, the differences between the values in Sets 3, 4, and 5 and the baseline values were calculated. Finally, a 3 (instruction: cooperative, urgent, and non-urgent) $\times$ 3 (the number of other agents: 5, 10, and 20) within-participant ANOVA was conducted. Particularly we focused on a comparison between the cooperative and the

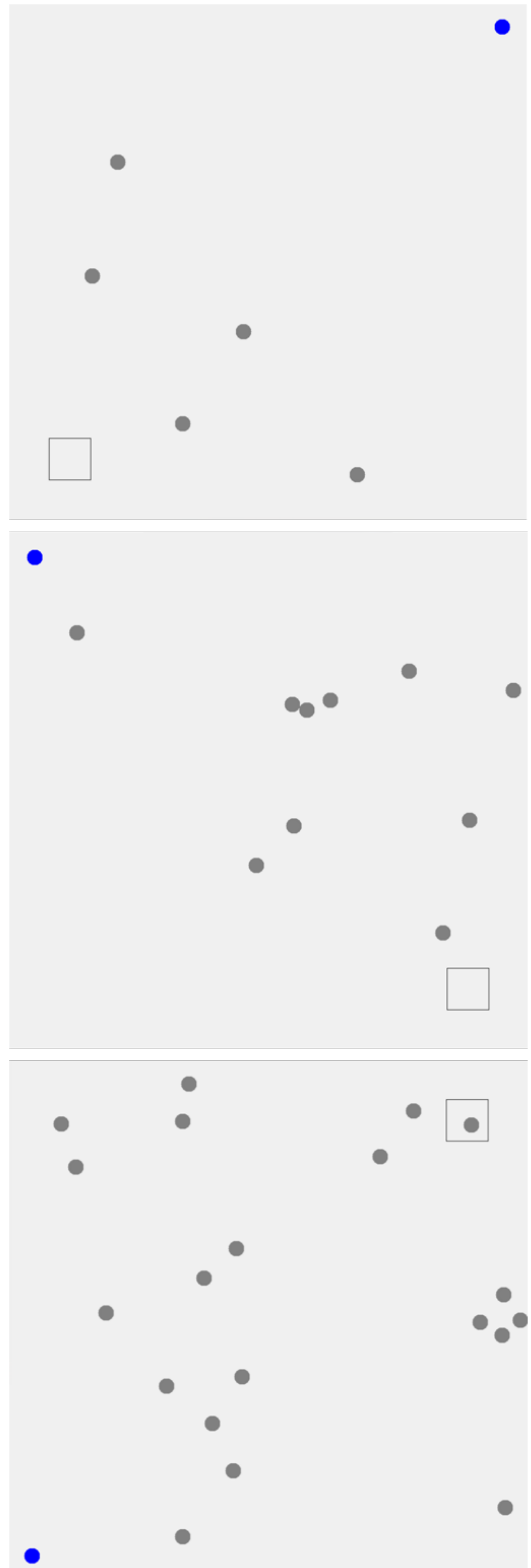

Figure 1: Moving Task

non-urgent condition.

Results

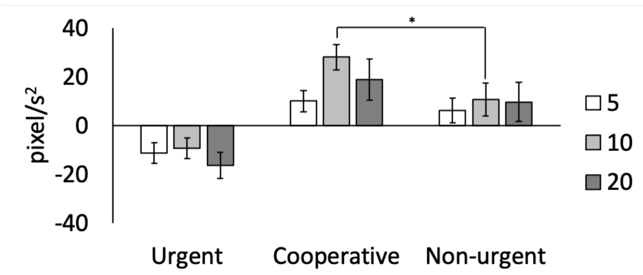

Figure 2: Absolute acceleration. Error bars mean standard errors. Asterisks mean significant differences between the cooperative and the non-urgent conditions.

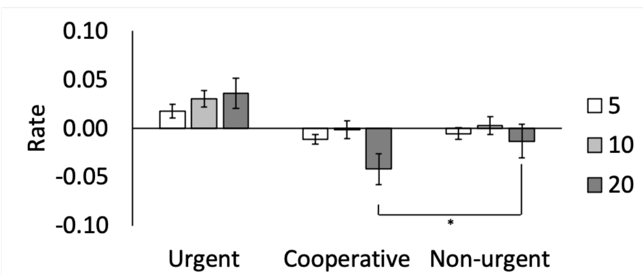

Figure 3: Interruption rate

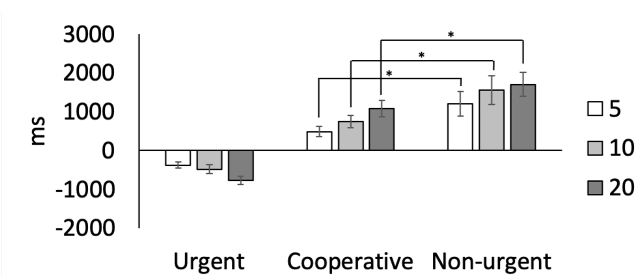

Figure 4: Completion time

Absolute acceleration The ANOVA result for absolute acceleration (Fig. 2) showed that the main effect of instruction was significant ($F(2,56) = 16.93, p < .001$), but there was no difference between cooperative and non-urgent conditions ($t(56) = 1.84, p = .069$). The main effect for the number of other agents was not significant ($F(2,56) = 1.35, p = .266$). Meanwhile, the interaction between instruction and the number of other agents was marginally significant ($F(4,112) = 2.36, p = .057$). The three simple main effects of instruction were all significant (5: $F(2,168) = 5.96, p = .003$; 10: $F(2,168) = 16.04, p < .001$; 20: $F(2,168) = 15.4, p < .001$). However, the planned comparisons showed that there was a significant difference between the cooperative and the non-urgent conditions only when the number of other agents was 10 ($t(168) = .2.63, p = .009$). Therefore, compared to when encouraged to behave without urgency, participants frequently change the speed of their own agent when they were encouraged to behave cooperatively in a situation with a moderate number of other agents.

Interruption rate As well as absolute acceleration, the ANOVA result for the interruption rate (Fig. 3) showed that the main effect of instruction was significant ($F(2,56) = 21.14, p < .001$), but there was no difference between the cooperative and the non-urgent conditions ($t(56) = 1.77, p = .081$). The main effect of the number of other agents was not significant ($F(2,56) = 1.08, p = .344$). The interaction between instruction and the number of other agents was significant ($F(4,112) = 3.31, p = .013$), and the three simple main effects for instruction were all significant (5: $F(2,168) = 3.57, p = .030$; 10: $F(2,168) = 4.65, p = .010$; 20: $F(2,168) = 23.9, p < .001$). However, the planned comparisons showed that there was a significant difference between the cooperative and the non-urgent conditions only when the number of other agents was 20 ($t(168) = 2.52, p = .012$). Therefore, when there were a large number of others and participants were encouraged to behave cooperatively, they did not interrupt others as much as when they were encouraged to behave without urgency.

Completion time The ANOVA result for completion time (Fig. 4) showed that the main effect of instruction was significant ($F(2,56) = 38.12, p < .001$) and that the main effect of the number of other agents was marginally significant ($F(2,56) = 2.65, p = .079$). Furthermore, there was a significant difference between the cooperative and non-urgent conditions ($t(56) = 3.01, p = .003$). Again, the interaction between instruction and the number of other agents was also significant ($F(4,112) = 8.98, p < .001$), and the three simple main effects of instruction were all significant (5: $F(2,168) = 18.65, p < .001$; 10: $F(2,168) = 31.54, p < .001$; 20: $F(2,168) = 49.4, p < .001$). Similarly, the planned comparisons showed that the completion time in the cooperative condition was significantly shorter than in the non-urgent condition regardless of the number of other agents (5: $t(168) = 2.75, p = .006$; 10: $t(168) = 3.10, p = .002$; 20: $t(168) = 2.39, p = .017$). Therefore, compared to when they were encouraged to behave without urgency, they reached their destination more quickly when participants were encouraged to behave cooperatively. The results of the completion time and the interruption rate showed that when participants were encouraged to behave without urgency, they took longer time to reach their destination; however, this did not reduce the interruption to others. Meanwhile, when they were encouraged to behave cooperatively, the participants reached their destinations quickly by suppressing the interruptions to others, which allowed others to reach their

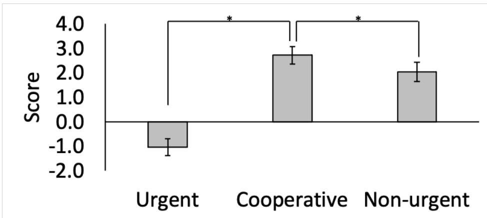

Figure 5: Subjective assistance score

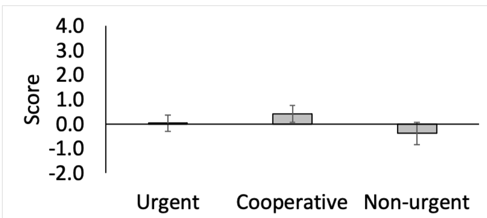

Figure 6: Subjective loss score

destinations smoothly.

Subjective rating Regarding two subjective questions, each difference between the three conditions and the baseline was calculated as a score and one-factor ANOVAs were conducted (Figs. 5 & 6) . As a result, the significant main effect of the assistance score was significant ($F(2,56) = 102.99, p < .001$) and there were significant differences among three conditions (urgent & cooperative: $t(56) = 13.48, p < .001$; cooperative & non-urgent: $t(56) = 2.47, p = .016$; non-urgent & urgent: $t(56) = 11.00, p < .000$); however, no main effect of the loss score was found ($F(2,56) = 2.34, p = .105$). Therefore, compared to when encouraged to behave without urgency, the participants attempted to assist others when they were encouraged to behave cooperatively; however, this did not result in subjective loss.

Discussion

The objective of this study was to clarify the cooperative behavior when moving in a shared space, in which there are few behavioral constraints. The experiment compared the behavior when the participants were directly required to behave cooperatively and when required to behave without urgency.

Nature of the Cooperative Behavior of Moving

The experimental results clarified the nature of the cooperative behavior of moving in a shared space. When people are encouraged to behave cooperatively, they frequently change their speed and direction, attempt not to interrupt others, and reach their own destination more quickly, compared to when encouraged to behave without urgency. Changing speed and direction is regarded as a cooperative cost as it demands physical and cognitive resources. Paying such costs reduces interruptions to others and brings benefit as others can reach their destination more efficiently. Such behaviors have been regarded as cooperative behaviors in previous studies (Hidas, 2005; Stoll et al., 2019, 2020).

Although the requirements for cooperative or prosocial behaviors mentioned in previous studies (Eisenberg & Mussen, 1989; Mussen & Eisenberg-Berg, 1977) were met for own cost and the others' benefit, it is noteworthy that the own final benefit was also regarded important in the experiment. The results of the completion time revealed that participants reached their destinations more quickly when encouraged to behave cooperatively than when encouraged to behave without urgency. If the absolute acceleration corresponds to the ongoing cost and the completion time corresponds to the final loss of cooperative behavior, the cooperative behavior of moving could be interpreted as a behavior that involves less loss to oneself despite paying a higher cost. This was also consistent with the posteriori subjective rating. When people are encouraged to behave cooperatively, their subjective loss is not greater than in other cases even though they are attempting to assist others.

Another important aspect of this experimental task was that people did not necessarily pay a greater cost to reduce their own loss. In fact, the participants who were required to behave with urgency could keep their own costs and losses low. However, when the participants attempted to behave cooperatively, this provided their own benefit as well as their own cost and benefit to others. Therefore, it was concluded that such behavior is the cooperative behavior that people expect in their daily life. Cooperation presents a social dilemma between cost and benefit (Kollock, 1998); however, this study revealed that there is benefit to others and to themselves when displaying cooperative behavior of moving in shared spaces. The relationship between individual actions and whole outcomes in cooperative behavior should be verified by referring to the results regarding Prisoner's Dilemma game (Denison & Muller, 2016).

Future work

The following three aspects are to be addressed in future research.

The first question is whether the cooperative behavior that was directly encouraged in the experiment was also objectively perceived as cooperative. The three behavioral indices used in this study were all aggregate indices for moving trajectories; therefore, it is necessary to verify how cooperative these trajectories are objectively perceived.

The second is what the situational factors that affect the cooperative behavior of moving are. The results of this experiment were strongly affected by the number of other agents, and in some cases, no differences between the cooperative behavior and the non-urgent behavior. Furthermore, some of the graph patterns were not linear in this experiment. A similar phenomenon has been observed in previous studies that measured the willingness to cooperate (Kauffmann et al., 2018; Stoll et al., 2019, 2020). This indicates that there may be certain constraints to the number of others that can be considered when people attempt to behave cooperatively. If this is the case, both the number of other agents and the field of view may strongly influence the cooperative behavior of moving; therefore, we need to use eve movement measurements.

Finally, the third is a problem of the diversity of moving. As mentioned in the Introduction, there are few constraints imposed on each agent in shared spaces. Therefore, we need to add the number of participants and extend the experimental situation to clarify the nature of cooperative behaviors.

Conclusion

This study examined the nature of the cooperative behavior of moving by using a task that simulated a shared space in which there are fewer behavioral constraints than in conventional separated space. The results showed that compared to when encouraged to behave without urgency, people frequently change their own speed and direction, attempt not to interrupt others, and reach their destination more quickly when required to behave cooperatively. There is benefit to themselves as well as others when displaying cooperative behavior of moving in shared spaces.

Acknowledgments

Support for this work was given by the Toyota Motor Corporation (TMC) and JSPS KAKENHI Grant Number 18H05320. However, note that this article solely reflects the opinions and conclusions of its authors and not TMC or any other Toyota entity.

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