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Strategy influences directional control–response compatibility: evidence from an underground coal mine shuttle car simulation

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This paper examines the influence which participants' task strategy has on directional control–response compatibility. Two experiments are reported in which participants were grouped according to the strategies they reported using while driving a simulated analogy of an underground coal mine shuttle car. In Experiment 1, compatibility effects were found for participants who reported adopting the wheel-referenced instruction. No reaction time compatibility effects were observed for participants who adopted a rule-based strategy for all trials. Participants were given rule-based instruction in Experiment 2. Seven participants followed the instruction, and no reaction time compatibility effect was observed. However, 15 participants reported adopting a wheel-referenced strategy during 'compatible' trials, and directional compatibility effects were found. In summary, regardless of the instructions provided during experimental situations, individuals may identify action features which they consider helpful in achieving the task goal, and these different strategies influence directional control–response compatibility.

Keywords: stimulus–response compatibility; control–response compatibility; action intention; strategy; instruction; simulation

Introduction

Directional stimulus–response compatibility research has a long history (see Loveless 1962 for a review). Considerable evidence exists to conclude that compatible relationships between stimulus and response directions result in faster and more accurate performance (Burgess-Limerick et al. 2010; Chua et al. 2001; Fitts and Seeger 1953; Proctor and Reeve 1990; Steiner, Burgess-Limerick, and Porter 2013). While performance in consistently incompatible situations improves with practice, even after extensive practice it has not been found to reach that of consistently compatible relationships (Dutta and Proctor 1992; Fitts and Posner 1967).

Compatibility effects have been explained in theoretical terms as a consequence of attributes, features, or spatial codes being shared between stimulus and response (Hommel et al. 2001; Hommel 2009; Kornblum, Hasbroucq, and Osman 1990). Hommel (2007) suggested that perceptions of the relevance of features may vary between individuals, potentially resulting in variations in compatibility effects between people. It is possible that the perceived relevance of features, and hence the compatibility effects, may also be altered by instruction or participant intention.

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The steering configuration employed in conventional vehicles is an example of a compatible directional stimulus–response arrangement. A steering wheel is located in front of the driver facing the direction of travel and a clockwise rotation of the steering wheel changes the vehicle's heading to the driver's right. This control–response relationship is considered 'compatible' and results in fast, error-free, and automatic steering behaviour.

However, in some situations the operator's intentions, and interpretation of the situation, may influence the compatibility relationships observed (Ansorge 2002; Ansorge and Neumann 2005; Hommel 1993; Memelink and Hommel 2006; Wenke, Gaschler, and Nattkemper 2007). For wheel rotations, for example, if there is ambiguity about the movement goal, individuals choose a strategy to achieve their interpretation of the goal. Guiard (1983) examined a situation where participants held the lowest part of a steering wheel and a stimulus tone was presented to either ear. In this situation, the participants would have to move their hands to the left to turn the steering wheel to the right. The pattern of compatibility effects observed was dependent on whether visual feedback was provided. If feedback was provided, the compatibility effects were consistent with a conventional steering task. However, no consistent compatibility effect was observed when no feedback was provided and the task goal was consequently ambiguous.

Stins and Michaels (1997) carried out a similar experiment in which participants held a steering wheel with either their right or left hand at one of the two positions. The wheel was mounted horizontally and at a slight angle so that the top of the wheel was further away from the participant than the bottom of the wheel. In the compatible (or steering-consistent) condition, participants were instructed to displace the 'distal end' (top) of the steering wheel in the same direction as the stimulus light, and the reverse instruction was given in the incompatible condition. For the 'distal' or top hand position, reaction time was faster when moving towards a light stimulus than away from it, and for the proximal hand position (at the bottom of the wheel), reaction times were 'somewhat' faster when the stimulus coincided with the direction of hand movement. Individual data exhibited a compatibility effect for the distal hand position. However, for the proximal hand position, 4 out of the 16 participants showed 'wheel-compatibility effects' (the goal was similar to the distal hand position, i.e., rotate the wheel to 'turn' towards the light stimulus), 9 participants showed 'hand-compatibility effects' (moved the hand towards the light stimulus), and 3 participants showed similar reaction times for 'compatible' and 'incompatible' conditions. The authors suggested that some participants' intention was to move their hand in the direction of the light, while others intended to rotate the wheel in the direction of the light.

A further series of experiments investigated compatibility effects on wheel-rotation responses with neutral and non-neutral instructions (Wang, Proctor, and Pick 2003; Proctor, Wang, and Pick 2004; Wang, Proctor, and Pick 2007). Again, some participants chose to code responses using wheel reference, while others used hand-reference coding, resulting in different compatibility effects. Instruction was also found to influence the choice of response coding and the resulting compatibility effects.

These observations have implications for assessing the consequences of equipment design. Underground coal mine shuttle cars are free-steered vehicles commonly used to transport coal from the coal development face to the conveyor. Some shuttle cars are driven using a steering wheel located on one side and between two facing seats, attached to the inside wall of the cab (i.e., the plane of the steering wheel is coplanar with the side of the vehicle and perpendicular to the typical vehicle arrangement). Two facing seats allow the driver to change seats with each change of direction and always face the direction of travel (Figure 1). While driving in one direction (away from the face), a clockwise rotation of the steering wheel causes the car to steer to the right (a compatible directional

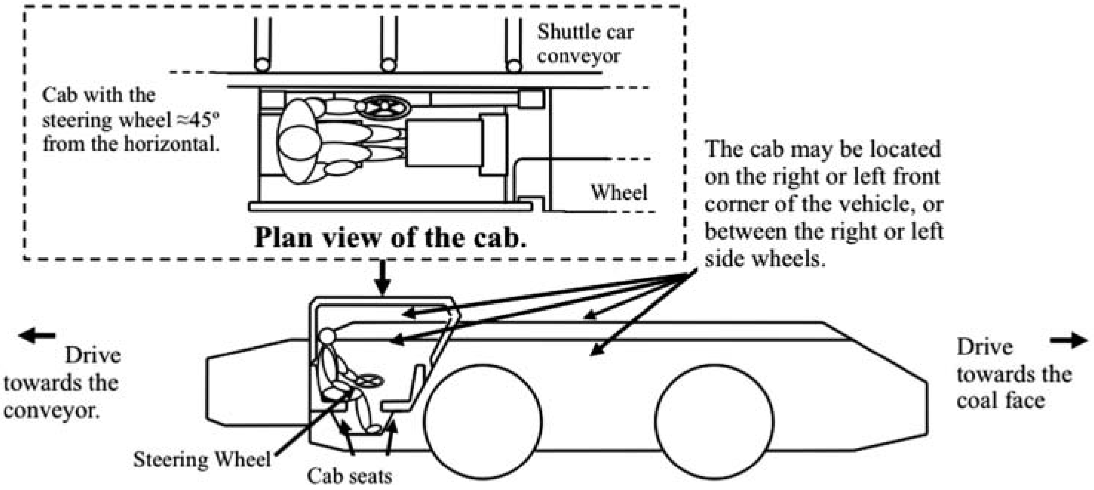

Figure 1. Diagram of a shuttle car.

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control–response relationship); however, when driving in the other direction (towards the face), a clockwise rotation of the steering wheel causes the car to turn to the left (an incompatible directional control–response relationship). Previous research (Zupanc, Burgess-Limerick, and Wallis 2007, 2011) using a virtual simulation analogous to this situation confirmed significant directional compatibility effects. However, this vehicle also presents a potential instance where there may be ambiguity in the interpretation of the relationship between the movement direction, or rotation, of the steering wheel and the consequential directional change of the shuttle car.

The spatial ability literature reports that individuals do use different strategies when learning and solving spatial tasks, and depending upon the difficulty of the task, individuals may change strategies during the task (Glück and Fitting 2003; Lohman and Kyllonen 1983). The aim of this research is to identify whether participants used different strategies while learning to drive a simulated shuttle car, and if so, what were the performance consequences?

Experiment 1: individual differences in strategies adopted with wheel-referenced instruction

Large overall compatibility effects have previously been reported using an obstacle avoidance task and virtual simulation of an underground coal shuttle car (Zupanc, Burgess-Limerick, and Wallis 2007, 2011). These data, and data collected subsequently from 12 additional participants, are examined here to determine whether individual differences existed in the steering responses in this task. The strategies reported by participants during interviews conducted at the completion of the task were used to categorise participants into different groups, and the data were examined to determine whether any systematic differences between the groups were evident.

Methods

Participants

Data from 44 adult males (aged 20–65 years, median (M) = 29 years) were used in the analysis. The 44 participants were made up of 32 participants who participated in previous experiments (Zupanc, Burgess-Limerick, and Wallis 2007, 2011) and 12 participants who had not participated in any previous shuttle car simulation experiments. The participants were recruited from The University of Queensland, St. Lucia. The participants were not susceptible to motion sickness, held a current driver's license, and had at least 2 years' driving experience. All participants had normal or corrected-to-normal vision. A cinema voucher (or equivalent in cash) was provided for participating.

Apparatus

The experiment was carried out in a fixed-base driving simulator. The scene was rendered by a Silicon Graphics Onyx 350 equipped with InfiniteReality II graphics. The scene was projected onto a wall using a BARCO 808S analogue projector. The projected image was 2.33 m high and 3.12 m wide (300 mm from the floor). The image frame rate was 72 Hz and the update rate of the simulation was 24 Hz. Image resolution was 1280 × 1024 pixels.

A Logitech MOMO Racing Force Feedback Steering Wheel was used as the input steering device. A spinning knob was attached to the top of the steering wheel. The steering wheel was secured to the side of a table, with the steering knob 900 mm from the floor. The steering wheel was positioned perpendicularly to the participants, such that the participants could comfortably hold the knob and rotate the steering wheel without constraint. An adjustable chair was placed in front of the screen at a position where the participant's face was approximately 1.5 m from the screen. The chair was adjusted so that the participant's forearm was close to a horizontal position while holding the steering wheel knob. To partially replicate the restricted visibility of a shuttle car, a black partition (1.2 m high, 2.5 m wide) was placed 800 mm from the screen. Figure 2 illustrates the

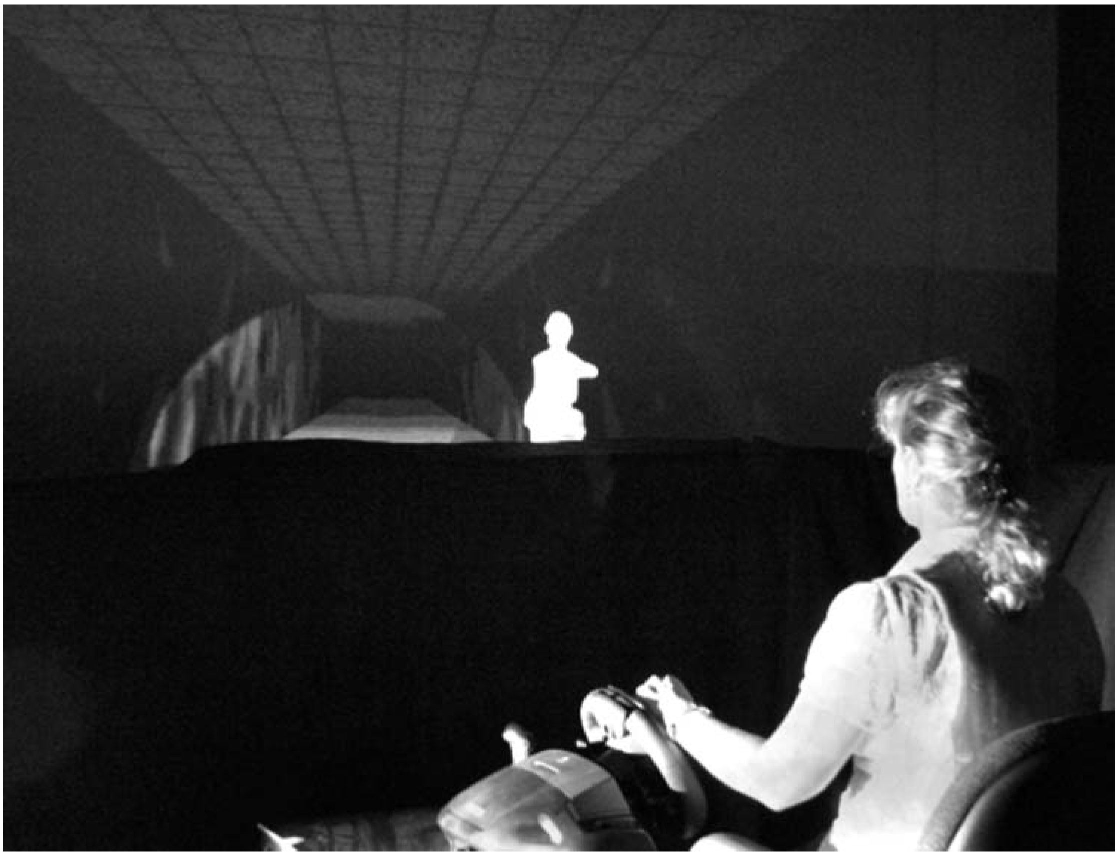

Figure 2. Photograph of simulation in progress.

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simulated mine road, the miner, an illuminated region (which represents the vehicle's headlights), and a person holding the steering knob with her left hand.

Stimuli

The simulated environment consisted of a straight, textured underground mine road, 5 m wide and 3 m high. The virtual shuttle car travelled at a constant speed of 10 km/hr. The simulation included a pair of semicircular illuminated areas which represented the shuttle car's headlights and moved in accordance with the shuttle car's heading. A simulated 'miner' randomly appeared six times on each trial, 400 mm to the left or right of the centre of the road to simulate a situation in which an avoidance manoeuvre is required. The miner was visible for 5.7 s, and the time period between each appearance of the miner randomly varied from 9 to 15 s.

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Design and procedure

The experimental task was an obstacle avoidance driving task involving driving a straight path along an underground mine road and avoiding a miner whenever the image appeared. The experimental trials were approximately 2 minutes duration.

Twelve compatible trials (carried out by one hand) alternated with 12 incompatible trials (carried out by the other hand). Allocation of the compatible or the incompatible trial to either the right or left hand, and whether the participant started with a left or right hand, was randomised and counterbalanced across participants. At the completion of the 24 trials, a short debriefing interview was carried out where participants were asked to describe the strategy they implemented during the trials.

The task instruction provided to the participants could be termed 'wheel-referenced'. The steering device was described to participants as 'steering wheels' located to either side of the participant rather than the normal position in front of the driver. Instruction did not label movement direction when turning the wheel as 'left', 'right', 'forward', or 'backwards'. Movement direction instruction was provided by using the words 'rotate this way' or 'that way' to 'turn that way' in conjunction with pointing the required direction.

For compatible trials, a clockwise rotation of the steering wheel (while holding the knob) steers the vehicle right and a counter-clockwise rotation steers the vehicle left. For incompatible trials, a counter-clockwise rotation of the wheel steers the vehicle right and a clockwise wheel rotation steers the vehicle left.

Dependent measures and data analysis

Reaction time. Reaction time data were calculated for avoidance manoeuvres in which no steering error was made, and a marked change in steering wheel angle ($\geq 20°$) in the correct direction was evident following the appearance of the miner. Reaction time was defined as the time from the moment the miner first became visible to the moment when the participant started to steer in the correct direction.

Steering direction errors. A steering direction error was deemed to have occurred if participants made a steering input of 20° or more that caused the shuttle car to turn towards the miner, ≥ 250 ms after the miner became visible. Recording of errors was conservative, that is, regardless of how many steering errors were actually made between 250 ms and 2 s after the miner appeared, only one error was recorded.

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At the conclusion of the experiment, the participants were interviewed to gain information about their understanding of the experiment and the strategies they adopted to complete the task. The participants' self-reported strategies were recorded and summarised.

Mixed-design (repeated measures) analysis of variance (ANOVA), with one between-subjects factor (group) and two within-subject factors (compatibility and block), was employed. Where data violated the sphericity assumption, the Greenhouse-Geisser corrected p-values are reported (✶).

Results

Different strategies were reported during the debriefing interviews and summarised in Table 1. One strategy described by participants was to swap between an 'automatic' driving behaviour during compatible trials, and using a rule during incompatible trials (Auto+Rule group, $N = 18$). Participants reported that the compatible trials required little or no thought (e.g., they said it 'steered like a car'), however, use of a rule (e.g., 'push forward turns right, pull back turns left') during incompatible trials required rehearsal and continued cognitive attention. Some participants reported trying various different rules during incompatible trials (Auto+More Than One Rule group, $N = 10$), and other participants did not use a rule, but said they 'visualised what to do', 'imagined reversing a car', or 'go with the flow' (Auto+No Rules group, $N = 5$).

Another strategy reported was to use only one rule during both compatible and incompatible trials (Rule+Rule group, $N = 8$). Participants actively rehearsed and applied the rule during all the trials. Other participants reported trying different rules during all the trials (Several Rules group, $N = 3$).

Only the data from the Auto+Rule group and the Rule+Rule group were used in the analysis, that is, only those participants who maintained the same strategy throughout all the trials were included. Those participants, who changed their strategy in some way or used ambiguous strategies, were not included in the analysis.

Reaction time

The reaction time data from two consecutive compatible or incompatible trials were grouped into each of six blocks. Figure 3 shows separate mean reaction time for the Auto+Rule and Rule+Rule groups.

One mixed-design (repeated measures) ANOVA with one between-subjects factor (group) and two within-subject factors (compatibility and block) was carried out on the reaction time data.

A statistically significant main effect of compatibility was evident, $F(1, 24) = 15.85$, ${\eta_p}^2 = 0.4$, $p = 0.001$, indicating that reaction time was faster in compatible trials ($M = 0.795$ s) than incompatible trials ($M = 0.86$ s). No improvement in reaction time was found across blocks, $F(2.43, 58.22\ ✶) = 2.15$, ${\eta_p}^2 = 0.08$, $p = 0.12$. There was no main effect of group evident, $F(1, 24) = 0.07$, ${\eta_p}^2 = 0.003$, $p = 0.8$; however, the compatibility × group interaction was statistically significant, $F(1, 24) = 11.21$, ${\eta_p}^2 = 0.32$, $p = 0.003$, indicating that there was little difference between compatible and incompatible trials for the Rule+Rule group ($M = 0.827$ s and 0.838 s, respectively), while the Auto+Rule group responded faster in compatible trials ($M = 0.762$ s) than incompatible trials ($M = 0.882$ s). The interactions block × group, $F(5, 120) = 0.28$, ${\eta_p}^2 = 0.01$, $p = 0.92$, compatibility × block, $F(3.33, 79.95\ ✶) = 1.63$, ${\eta_p}^2 = 0.06$, $p = 0.18$, and

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Table 1. Strategies reported.

Group	Compatible trials	Incompatible trials
Auto+Rule (18 adults)	Reported comments such as the following to describe their strategy during compatible trials: • was automatic; • did not require any thought; • purposely did not think about what I was doing otherwise I started making errors; • felt more like a steering wheel when I rotated myself slightly towards the wheel; • trusted my instincts and tried not to think about it; • it felt natural; • steered like a car.	Reported that they used one of the following ‘rules’ and that it required moderate to high levels of concentration and rehearsal of the rule throughout the experiment. • push forward turns right, pull back turns left; • when miner was on the right, pull back, when miner was on left side push forward; • miner on right pull towards myself, miner on left push away, had to remind myself; • turn towards the miner, to the side where he was, and I avoid him; • I only had to think ‘push forward goes right’, I did not have to think anything else.
Rule+Rule (8 adults)	They reported that they used one of the following ‘rules’ during both compatible and incompatible trials, and that they had to concentrate on both sides, although some reported that the compatible side felt a bit easier, or made ‘more sense’: • when the miner was on the right then pull behind to turn left, when miner is on the left, forward goes right; • push forward when need to go towards ‘that’ wall, pull backwards to go towards ‘that’ wall; • forward goes right, back goes left; • push forward goes left, and did not have to think about pull back goes right.	

(*continued*)

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Table 1. (*Continued*)

Group	Compatible trials	Incompatible trials
Auto+More than one rule (10 adults)	They reported similar comments as the Auto+Rule group's comments about strategies used during compatible trials.	Reported trying different rules during incompatible trials, and that it required concentration and rehearsal: ● started using the miner as a cue (e.g., when miner was on right, push forward, etc.), and then changed to 'push forward goes right, pull back goes left'; ● started with 'steer towards the miner to avoid him' and then changed to 'push forward goes right, pull back goes left'; ● started with 'forward turns right, back turns left' and then changed to 'when the miner was on the right then go back, when miner was on the left then go forward'.
Auto+No rules (5 adults)	They reported similar comments as the Auto+Rule group's comments about strategies used during compatible trials.	They reported not using a rule, but instead: ● imagined reversing a car; ● tried to use the forward goes right, back goes left but could not because he could not automatically remember which way was right or left; ● did not have to think about it, just 'go with the flow'; ● mentally visualised what he had to do, did not use a 'rule', seems to be more a 'feel'.
Several rules (3 adults)	They reported trying to use several different rules during the trials.	

Note: The description of the 'rules' was different depending upon whether the compatible (or incompatible) trials were on the right or left side of the participant.

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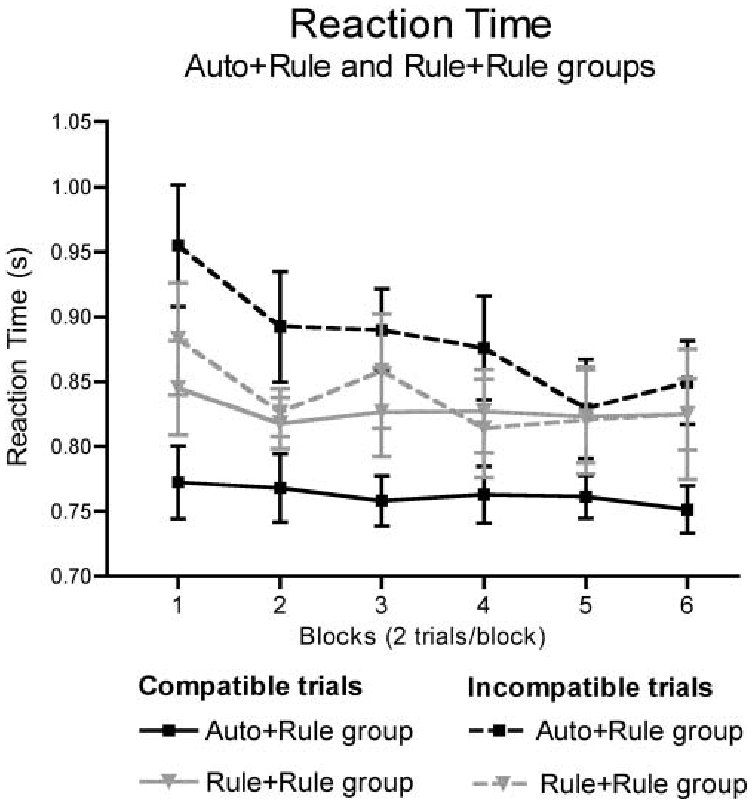

Figure 3. Mean reaction time in seconds for the Auto+Rule and Rule+Rule groups in Experiment 1 (two trials per block, error bars are standard error of the mean (SEM)).

compatibility × block × group, $F(5, 120) = 0.35$, $\eta_p{}^2 = 0.01$, $p = 0.88$, were not statistically significant.

A two-way repeated measures ANOVA was carried out to further investigate the difference between the groups' compatible trials, and a statistically significant main effect of group was found, $F(1, 24) = 4.3$, $\eta_p{}^2 = 0.15$, $p = 0.049$, with the Auto+Rule group having faster responses in compatible trials, overall, than the Rule+Rule group.

Analysis indicates that the reaction time compatibility effect for the Auto+Rule group remained at block 6, $t(17) = 3.9$, $p = 0.001$, while there was no compatibility effect for the Rule+Rule group in block 1, $t(7) = 0.7$, $p = 0.5$.

Steering direction errors

The steering direction errors from two consecutive compatible or incompatible trials were grouped into each of the six blocks. Steering direction errors were converted to a percentage of the total possible number of errors (12 per block data point). Figure 4 illustrates mean percentage steering direction errors for the Auto+Rule and Rule+Rule groups.

One mixed-design (repeated measures) ANOVA with one between-subjects factor (group) and two within-subject factors (compatibility and block) was carried out on the steering direction error data.

A main effect of compatibility was evident with participants making fewer errors in compatible trials ($M = 4.8\%$) than incompatible trials ($M = 12.8\%$), $F(1, 24) = 28.8$, $\eta_p{}^2 = 0.55$, $p < 0.001$. A statistically significant error rate improvement occurred across blocks, $F(3.74, 89.67) = 13.82$, $\eta_p{}^2 = 0.37$, $p < 0.001$, and contrasts revealed that the improvement occurred between blocks 1 and 3. The main effect of group was not

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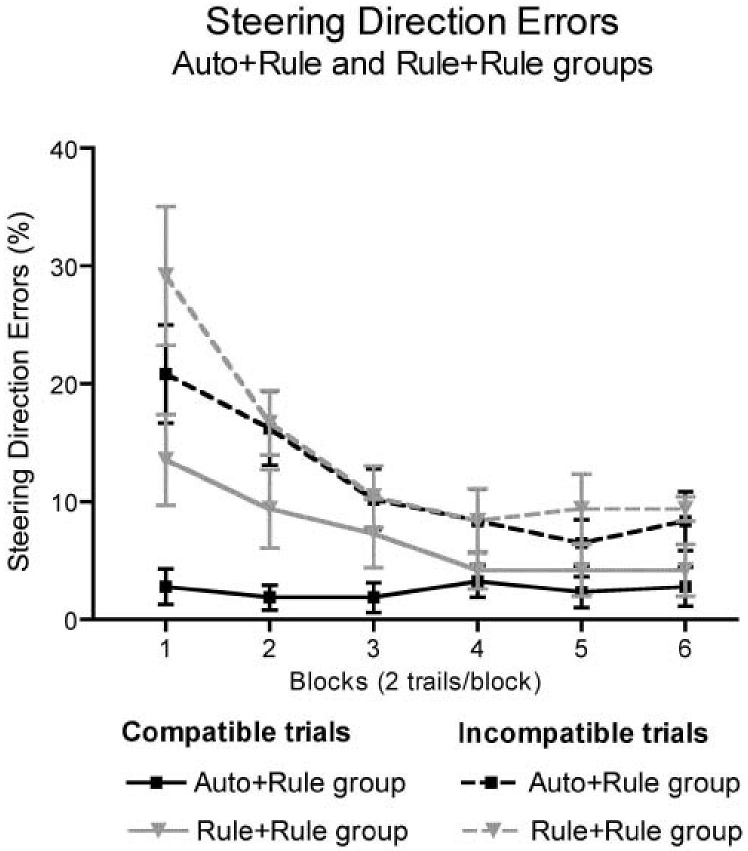

Figure 4. Mean percentage steering direction errors for the Auto+Rule and Rule+Rule groups in Experiment 1 (two trials per block, error bars are SEM).

statistically significant, $F(1, 24) = 2.7$, $\eta_p^2 = 0.1$, $p = 0.11$. The statistically significant compatibility × block interaction indicates that incompatible trials decreased at a greater rate than compatible trials, $F(3.35, 80.48 \star) = 4.01$, $\eta_p^2 = 0.14$, $p = 0.008$. The interactions, compatibility × group, $F(1, 24) = 0.69$, $\eta_p^2 = 0.03$, $p = 0.41$, block × group, $F(5, 120) = 2$, $\eta_p^2 = 0.08$, $p = 0.086$, and compatibility × block × group, $F(5, 120) = 0.4$, $\eta_p^2 = 0.02$, $p = 0.85$, were not statistically significant.

Analysis indicates that the error rate compatibility effect between compatible and incompatible trials for the Auto+Rule group was extinguished at block 4, $t(17) = 1.7$, $p = 0.1$, and at block 2 for the Rule+Rule group, $t(7) = 1.8$, $p = 0.1$.

Discussion

The aim of this analysis was to identify the strategies used by participants when learning to drive a simulated shuttle car and the consequence of the use of different strategies on control–response compatibility effects. As observed previously (Guiard 1983; Stins and Michaels 1997; Wang, Proctor, and Pick 2003), compatibility effects differed depending upon the strategies used by participants. In the task instruction, the steering control was referred to as a ‘steering wheel’ and the word ‘rotate’ was used to describe the wheel movement. Wheel-referenced task features were emphasised in the task instruction, so it was assumed that participants would make use of this reference frame to code responses. The Auto+Rule group did use this reference frame, however, other participants (the Rule+Rule group) did not.

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Reaction time and error rate compatibility effects were found in the performance of the Auto+Rule group. These participants reported that during compatible trials they did not have to think about what they were doing, and that it felt ‘automatic’. Better performances occurred in compatible trials with fewer errors (although this was extinguished in block 4) and faster reaction time as compared to incompatible trials, illustrating a performance advantage for the self-reported ‘automatic’ mapping. A number of participants reported that, during compatible trials, if they started thinking about what they were doing they started making errors. This suggests that conscious self-monitoring of performance during compatible trials may interfere with the coding process, and potentially inhibits automatic response selection. During incompatible trials, participants in the Auto+Rule group reported that they identified an explicit rule which described the movement direction of the control and the intended movement outcome, and actively rehearsed the rule during the trials. The rule may have been based solely on the movement of the knob and the resulting movement of the shuttle car, or they cued the movement of the knob to the location of the miner (the obstacle to be avoided). A few participants attempted to take advantage of the reversed steering configuration and changed the avoidance task into a targeting task (‘drive toward/into the miner’), however, it is likely that performance benefits did not eventuate from this strategy because participants reported that they had to continually rehearse the rule, ‘drive towards the miner’.

Compatibility effects were not found for reaction time for the Rule+Rule group, and the error rate compatibility effect was extinguished in block 2. Participants in the Rule+Rule group reported that they identified at the beginning of the first two trials (a ‘compatible’ and an ‘incompatible’ trial) that moving both steering knobs in a particular direction produced the same directional response of the shuttle car. They identified a rule, for example, ‘forward goes right, back goes left’, and used this rule, or action goal, for all trials. They reported that they needed to continually concentrate on, or rehearse, the rule. The use of this strategy is evident in the similarity of reaction time performance during ‘compatible’ and ‘incompatible’ trials. This group did not use the wheel-reference frame as suggested in the task instruction, but chose another strategy which did not result in performance benefits for the ‘compatible’ trials (see Proctor, Wang, and Pick 2004).

Questions arise from these results. What compatibility effects would occur if the task instruction was rule based, rather than wheel referenced? Would participants use the instructed strategy? If not, what strategy was used, and what were the performance consequences? A subsequent experiment was conducted to examine these questions.

Experiment 2: rule-based instructions

The purpose of this experiment was to investigate performance consequences when participants were provided with a rule-based task instruction; to identify whether participants used this strategy; and if participants did not, what strategy did they use and what performance resulted.

Methods

Participants

Twenty-two male adults, whose ages ranged from 21 to 40 years ($M = 28$ years) participated in this experiment. The participants were recruited from The University of Queensland, St. Lucia. The constraints on participating were that participants had not

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participated in any previous shuttle car simulation experiment, were not susceptible to motion sickness, held a current driver's license, and had at least 2 years' driving experience. All participants had normal or corrected-to-normal vision. A cinema voucher (or equivalent in cash) was provided for participating.

Procedure

In this experiment, eight compatible trials alternated with eight incompatible trials. At the completion of the 16 trials, a short debriefing interview was carried out in which participants were asked to describe the strategy they implemented during the trials.

Task instruction

The participants who were to carry out compatible trials using their right hand were instructed that 'the two steering knobs {*point to each knob*} operate in the same way, that is, pushing the knob forward will turn the shuttle car left and pulling back will turn it right'.

The participants who were to carry out compatible trials using their left hand were instructed that 'the two steering knobs {*point to each knob*} operate in the same way, that is, pushing the knob forward will turn the shuttle car right and pulling back will turn it left'.

All participants were instructed to maintain a central position in the tunnel, and to manoeuvre around the miner as promptly as they could when the image of the miner appeared. Information was not provided on how often the image would appear, or the time interval between appearances.

Measures and data analysis

The dependent measures and the data analysis were as detailed in Experiment 1. The independent variables were compatibility (compatible and incompatible), group (Auto+Rule or Rule+Rule), and block. The participant's self-reported strategies were recorded at the completion of the trials.

Mixed-model (repeated measures) ANOVAs were carried out to assess whether there were any group effect differences between the Auto+Rule group in the first analysis and the Auto+Rule group in the second analysis, and similarly any group effects between the Rule+Rule groups from both the analyses.

Results

Participants reported their steering strategy at the completion of 16 trials, and all participants could be grouped into an Auto+Rule group or a Rule+Rule group (Table 2). Seven participants reported that they used the rule-based stratagem during all trials. They reported that they had to concentrate on the rule, and that steering in the 'compatible' and 'incompatible' trials felt similar. These participants were grouped in the Rule+Rule group.

Those participants who reported that their responses felt quite 'automatic', requiring little or no thought, during compatible trials, and had to rehearse the rule during incompatible trials were grouped into the Auto+Rule group ($N = 15$). One person reported using a different rule ('when miner on that side, go forward'), but continued to use this rule during incompatible trials.

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Table 2. Strategies reported.

	Compatible trials	Incompatible trials
Auto+Rule group (15 adults)	Reported comments such as the following to describe their strategy during compatible trials: • felt more natural, I did not have to rehearse so much; • I did not have to think about it; • feels normal; • more intuitive, I could think of other things; • when I did think about it I made mistakes; • I did not have to make a decision; • it was just like a steering wheel.	Reported comments such as the following to describe their use of the rule during incompatible trials: • I continually rehearsing the rule; • required lots of concentration; • not natural; • I had to think about it before moving; • rehearsed rule, but I still forgot when the miner appeared; • consciously tell myself the rule (only used 1 rule 'back to left'); • used the miner as a cue (rule used 'when miner on that side go forward'); • I had to say the rule verbally to be able to make a decision.
Rule+Rule group (7 adults)	Reported comments such as the following to describe their use of the rule during compatible and incompatible trials: • I concentrated on both sides; • I continually moved the wheel back and forth to remind which way to goes; • it did not feel natural, I had to stay conscious; • (compatible side) did feel more natural than other side (incompatible); • I used the same rule on both sides ('when miner on the left pull back, when miner on the right push forward'); • both sides felt similar, both became easier; • did not feel different; • I used the same technique on both sides, I am not good at switching between techniques.	

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Reaction time

The reaction time data from two consecutive compatible or incompatible trials were averaged for each of the four blocks. Figure 5 shows the separate mean reaction time for the Auto+Rule and the Rule+Rule groups.

Three separate mixed-design (repeated measures) ANOVAs with one between-subjects factor (group) and two within-subject factors (compatibility and block) were carried out on the steering direction errors in blocks 1–4.

A statistically significant main effect of compatibility was found, $F(1, 20) = 16$, $\eta_p{}^2 = 0.44$, $p = 0.001$, with faster reaction time in compatible trials ($M = 0.79$ s) than incompatible trials ($M = 0.88$ s). Although the main effect of group was not statistically significant, $F(1, 20) = 2.5$, $\eta_p{}^2 = 0.1$, $p = 0.13$, the compatibility × group interaction was statistically significant, $F(1, 20) = 6.8$, $\eta_p{}^2 = 0.25$, $p = 0.017$, with slower reaction time during the Auto+Rule group's incompatible trials ($M = 0.95$ s). An unpaired *t*-test with Welch's correction found that the Rule+Rule group's incompatible trials at block 4, $t(19) = 2.3$, $p = 0.034$, were significantly faster than the Auto+Rule group's incompatible trials. The main effect of block, $F(2.2, 43\ \star) = 0.12$, $\eta_p{}^2 = 0.01$, $p = 0.9$, and interactions block × group, $F(3, 60) = 0.8$, $\eta_p{}^2 = 0.05$, $p = 0.48$, compatibility × block, $F(3, 60) = 0.3$, $\eta_p{}^2 = 0.02$, $p = 0.83$, and compatibility × block × group, $F(3, 60) = 1.2$, $\eta_p{}^2 = 0.06$, $p = 0.3$, were not statistically significant.

An analysis was carried out to identify any group effects between the Auto+Rule group (first 4 blocks) in Experiment 1 and the Auto+Rule group in this analysis. No significant main effect of group was found, $F(1, 31) = 0.9$, $\eta_p{}^2 = 0.03$, $p = 0.4$. A similar analysis was carried out for the Rule+Rule groups in both analyses and a statistically

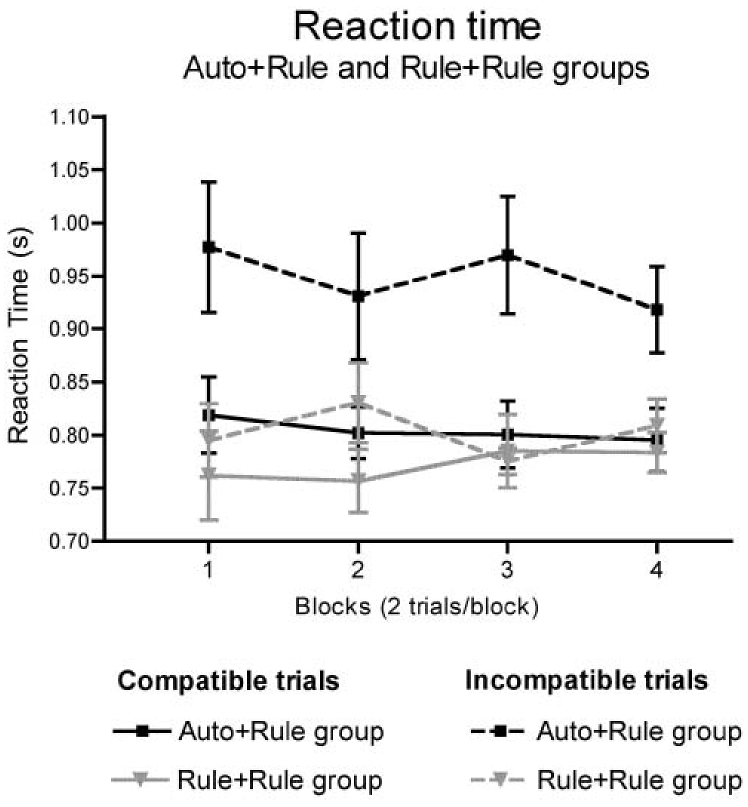

Figure 5. Mean reaction time in seconds for the Auto+Rule and Rule+Rule groups in Experiment 2 (two trials per block, error bars are SEM).

significant main effect of group was found, $F(1, 13) = 4.8$, $\eta_p^2 = 0.27$, $p = 0.048$. The Rule+Rule group ($M = 0.79$ s) that received the rule-based instruction had an overall faster reaction time than the Rule+Rule group ($M = 0.84$ s) that received the wheel-referenced instruction.

Steering direction errors

The steering direction errors from two consecutive compatible or incompatible trials were grouped into each of the four blocks. Steering direction errors were converted to a percentage of the total possible number of errors (12 per block data point). Figure 6 shows separate mean percentage steering direction errors for the Auto+Rule and Rule+Rule groups.

Three separate mixed-design (repeated measures) ANOVAs with one between-subjects factor (group) and two within-subject factors (compatibility and block) were carried out on the steering direction errors in blocks 1–4.

The main effect of compatibility was statistically significant, $F(1, 20) = 29.2$, $\eta_p^2 = 0.59$, $p < 0.001$, with fewer errors made in compatible trials ($M = 3.5\%$) than incompatible trials ($M = 14\%$). A statistically significant improvement in error rate occurred between blocks 1–4, $F(3, 60) = 11.8$, $\eta_p^2 = 0.37$, $p < 0.001$. The statistically significant compatibility × block interaction, $F(3, 60) = 5.03$, $\eta_p^2 = 0.2$, $p = 0.004$, indicates that most of the improvement occurred in incompatible trials. No main effect of group was evident, $F(1, 20) = 0.1$, $\eta_p^2 = 0.01$, $p = 0.74$; however, the compatibility × group interaction, $F(1, 20) = 4.13$, $\eta_p^2 = 0.17$, $p = 0.056$, indicates that most of the

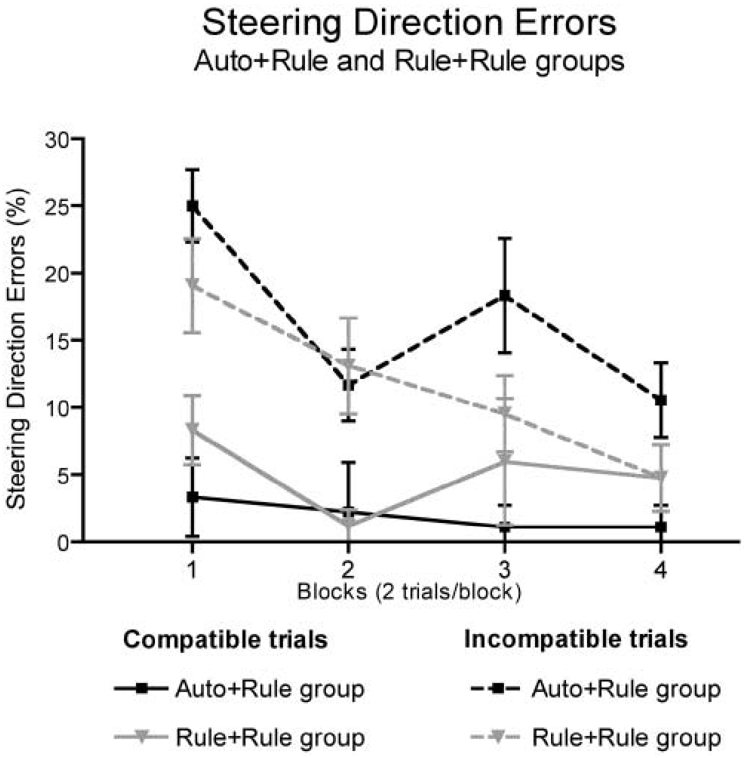

Figure 6. Mean percentage steering direction errors for the Auto+Rule and Rule+Rule groups in Experiment 2 (two trials per block, error bars are SEM).

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compatibility effect occurred in the Auto+Rule group. At block 4, a compatibility effect was evident for the Auto+Rule group, $t(14) = 3.5$, $p = 0.003$, but the compatibility effect was extinguished for the Rule+Rule group at block 3, $t(6) = 0.75$, $p = 0.5$. A significant three-way interaction was found, $F(3, 60) = 2.9$, ${\eta_p}^2 = 0.13$, $p = 0.042$, indicating that the compatibility effect was different across blocks for each group. Contrasts revealed that the significant interaction occurred between blocks 1 and 2, and 3 and 4.

An analysis was carried out to identify any group effects between the Auto+Rule group (first 4 blocks) in Experiment 1 and the Auto+Rule group in this analysis. No significant main effect of group was found, $F(1,31) = 0.2$, ${\eta_p}^2 < 0.01$, $p = 0.6$. A similar analysis was carried out for the Rule+Rule groups in both analyses and no statistically significant main effect of group was found, $F(1,13) = 0.4$, ${\eta_p}^2 = 0.03$, $p = 0.5$.

Discussion

The purpose of this experiment was to investigate whether participants adopted a rule-based task strategy, as instructed, for all trials, and the performance consequences of using different strategies.

About two-thirds of the participants (Auto+Rule group) reported that they used a wheel-referenced strategy for compatible trials and the rule-based strategy for the incompatible trials. They reported that steering during compatible trials required no conscious thought, and that it felt natural and intuitive. During incompatible trials, these participants used the instructed rule. They reported that they had to concentrate and rehearse the rule continually. The expected compatibility effects were found with more errors and slower reaction time in incompatible trials.

The remaining participants (Rule+Rule group) used the one rule-based strategy for all the trials. The compatibility effect for error rate was extinguished by block 3, and there was no compatibility effect for reaction time in most blocks. The Rule+Rule group's incompatible trials were faster than the Auto+Rule group's incompatible trials, and the mean reaction time for the Rule+Rule group's incompatible trials (0.802 s) were similar to the Auto+Rule group's mean reaction time for compatible trials (0.804 s). For this experiment, where the participants are given a rule-based instruction, the Rule+Rule group's reaction time performance for all trials was similar to the Auto+Rule's compatible trials, indicating that the Rule+Rule group's performance may have benefited from using a rule-based strategy when a rule-based instruction was provided.

The analysis to identify overall group differences between the Auto+Rule groups from Experiment 1 (first 4 blocks) and Experiment 2, and the Rule+Rule groups from Experiment 1 (first 4 blocks) and Experiment 2, found a significant difference only for reaction time between the Rule+Rule groups. Not only was the Rule+Rule group's reaction time performance in this experiment faster than the Rule+Rule group in Experiment 1, but it was similar to the Auto+Rule group's performance in compatible trials.

General discussion

Memelink and Hommel (2005) comment that laboratory experiment instructions do not determine the coding of stimuli and responses, but only suggest the coding. Situational context, which may highlight some task features more than others, and an individual's intentions are also crucial in the interpretation of task goals, and these factors can influence response coding. Our results are consistent with this observation and demonstrate that participants develop strategies and action intentions that they consider helpful to

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achieve a task goal, that participants may use different strategies to achieve a goal, and that different compatibility effects occur as a consequence of different strategies.

Significant subgroups of participants in our experiments reported using strategies contrary to the task instruction, and different compatibility effects were found. In Experiment 1, the Rule+Rule group noticed that moving the steering knobs in the same direction (e.g., moving both knobs 'forward') achieved the desired steering response for all trials and they weighted this action feature in favour of a wheel-referenced coding. An automatic control–response coding was not accessed, and overall, poorer performances resulted.

The Auto+Rule group, in Experiment 1, followed the task instruction and the expected compatibility effects were found. For these individuals it is possible that the steering layout provided features that were similar enough to a normal steering wheel for them to make use of automatic response coding for compatible trials. However, they needed to identify a rule to use during the incompatible trials, and they continually switched between the different coding processes.

We investigated the effects of providing rule-based instruction for the same task (Experiment 2). Again, a significant subgroup of participants adopted a wheel-referenced coding during compatible trials. However, those participants who used the rule for all trials, with no compatibility effect evident, achieved the same reaction time performance as the Auto+Rule's 'automatic' responses during compatible trials. Also, the Rule+Rule group in Experiment 2 had a faster reaction time than the Rule+Rule group in Experiment 1.

It is suggested in the spatial ability literature that strategy variability in spatial tasks is both a factor of the person and the task (Glück and Fitting 2003; Lohman and Kyllonen 1983). Individuals may have personal preferences when learning, or solving, spatial tasks or problems. We can speculate that, in this task, if the instruction provided is similar to the preferred method of coding the control–response relationship, then some performance benefit occurs. However, if the preferred strategy is dissimilar, then poorer performances may occur. The effect of instruction on action coding has been discussed previously (e.g., Memelink and Hommel 2006; Wang, Proctor, and Pick 2003; Wenke, Gaschler, and Nattkemper 2007), and our experiments may suggest that instruction can have some influence on performance.

These results have implications for design of equipment control. Designers may not be aware that individuals can differ in how they interpret a task, and consequently, a control design that is considered to enable optimal performance may do so for only a proportion of operators. Comprehensive usability testing (which includes debriefing sessions) should identify individual performance differences, and these differences should be analysed to determine whether the control design is an influencing factor in the performance differences. The use of virtual simulation to assess the design of controls is one way of examining these issues prior to final design decisions being made (Burgess-Limerick, Zupanc, and Wallis 2012, 2013).

In conclusion, our results suggest that debriefing participants can provide valuable information for the interpretation of compatibility research in both real world and laboratory settings. We found that different action intentions (strategies) resulted in different compatibility effects, and an automatic coded response is not necessarily adopted during compatible control–response situations. In fact, when task instruction favours personal strategy preferences, the use of rule-based strategy may result in similar performances to that of an 'automatic' task performance. These results also have practical implications for both equipment design and operator training: where the design of a control–response relationship is ambiguous, the choice of instruction during the early stages of training may have a positive or negative impact on training time depending upon the approach trainees take to the task.

About the authors

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