Special Issue Paper

QJEP

Quarterly Journal of Experimental Psychology
1–14

Article reuse guidelines:
sagepub.com/journals-permissions
DOI: 10.1177/17470218251324185
qjep.sagepub.com
Sage

Transfer asymmetry: Tversky's contrast model of similarity for human perceptual-motor learning

Motonori Yamaguchi

Abstract

In choice–reaction tasks, responses are faster if stimuli and responses are spatially compatible than if they are incompatible, even when the locations of the stimuli are irrelevant to the task. This stimulus–response (S-R) compatibility effect that occurs based on task-irrelevant stimulus and response features is known as the Simon effect. The Simon effect can be eliminated or even reversed after training with spatially incompatible S-R mappings only for a short duration, indicating that newly acquired incompatible S-R associations transfer to the Simon task. This transfer effect is usually reduced when the context of the training task is altered at test, suggesting that the expression of learned S-R associations depends on the similarity between the learning and test contexts. However, there can be cases where transfer occurs from one context to another but not in the reverse direction (i.e., transfer asymmetry). Transfer asymmetry is problematic for many models of psychological similarity, which would predict that transfer is symmetrical between two contexts. This study shows that Tversky's set-theoretic model of similarity—the contrast model—is a useful framework for understanding how transfer symmetry arises in human perceptual-motor learning. The results of the two experiments imply that the similarity of contexts depends not only on features that overlap between the contexts but also on features that are distinctive to them.

Keywords

Simon effect; transfer of learning; context effect; response mode; procedural reinstatement

Received: 24 February 2024; revised: 7 February 2025; accepted: 11 February 2025

There is abundant evidence that learning is context-specific. Since the classic demonstration by Thorndike and Woodworth (1901), this has been observed in a variety of task domains, including memory recall (Tulving & Thomson, 1973), analogical reasoning (Gick & Holyoak, 1983), mathematical problem-solving (Ross, 1984), reading (Kolers & Roediger, 1984), and chess expertise (Sala & Gobet, 2016). Studies suggest that learned skills and knowledge are better utilised in an environment that approximates the original context in which learning has taken place (Godden & Baddeley, 1975; Healy et al., 2006; Thorndike, 1914). Although there has not been much controversy as to whether the similarity between study and test contexts plays a vital role in utilising learned skills or knowledge, the question of how the similarity of two contexts is determined still remains unresolved. This study addressed this issue by using a transfer-of-learning paradigm that has demonstrated context-specificity of perceptual-motor learning in previous studies (Yamaguchi & Proctor, 2009).

In the following sections, I first introduce the transfer of learning paradigm that has been used to examine factors influencing perceptual-motor learning and its transfer to another context (Luo & Proctor, 2016; Proctor & Lu, 1999; Proctor et al., 2007, 2009; Tagliabue et al., 2000; Vu et al., 2003; Yamaguchi et al., 2015; Yamaguchi & Proctor, 2009). Next, I will illustrate how similarity is theorised in a traditional geometric approach as well as in Tversky's set-theoretic approach, showing that the latter model can

Department of Psychology, University of Essex, Colchester, UK

Corresponding author:
Motonori Yamaguchi, Department of Psychology, University of Essex, Colchester CO4 3SQ, UK.
Email: cog.yamaguchi@gmail.com

explain the violation of the symmetry axiom of a distance metric. I will then report two experiments using the transfer of learning paradigm and argue that the contrast model provides a useful framework to understand factors influencing the transfer of perceptual-motor learning.

Transfer of learning paradigm

In the present transfer of learning paradigm, participants are tested with the Simon task (Simon & Rudell, 1967) in which they are presented with spatial stimuli (e.g., red and green circles that occur on the left or right side of the fixation mark on a computer monitor) and respond to the stimuli by pressing a left or right key (Vu et al., 2003) or by saying "left" or "right" into a microphone (Yamaguchi et al., 2015). Although participants respond to non-spatial attributes of stimuli (e.g., colours) and are asked to ignore the spatial attributes, responses are typically faster and more accurate when stimuli and responses are spatially compatible (e.g., pressing the left key to a circle on the left) than when they are spatially incompatible (pressing the left key to a circle on the right), yielding the "Simon effect." Thus, the Simon effect is defined as the differences in the speed and accuracy of responding on compatible trials than on incompatible trials. Before performing the Simon task, participants practice an "incompatible-mapping" task that requires spatially incompatible responses to stimuli before they perform the Simon task. After training with the incompatible-mapping task, the Simon effect is often reduced substantially or even reversed to favour spatially incompatible responses (Proctor & Lu, 1999). Although the tasks in the training and test phases are similar in these studies, participants are required to follow different sets of instructions in the two phases (e.g., responding to stimulus locations vs responding to stimulus colours). Hence, the influence of the training phase on the Simon effect represents a spontaneous transfer of learned incompatible stimulus–response (S-R) associations from the training task to the test task.

An issue investigated in this transfer of learning paradigm is whether newly acquired associations are specific to the training context or generalisable across different contexts (Proctor et al., 2007; Tagliabue et al., 2002; Vu, 2007; Yamaguchi & Proctor, 2009). Tagliabue et al. (2002), for example, showed that learned incompatible S-R associations with auditory stimuli transferred to the Simon task using visual stimuli. Vu (2007) also found that incompatible S-R associations acquired with visual stimuli that varied in either a vertical spatial dimension (top vs bottom) or a horizontal spatial dimension (left vs right) could transfer to the Simon task with visual stimuli that varied in a different spatial dimension (i.e., from the vertical dimension to the horizontal dimension, or vice versa). These findings suggest that newly acquired associations relied on abstract representations that can transfer across different modalities or spatial orientations.

Nevertheless, the transfer of learned spatial S-R associations has also been shown to be limited in some cases. Proctor et al. (2009) found that incompatible S-R associations acquired with lateral stimuli that varied in the physical locations (on the left or right of the fixation) transferred to visually presented lateral arrows (pointing to the left or right), or vice versa, but not to visually presented words with lateral meanings (*LEFT* or *RIGHT*). Similarly, when the transfer across spatial orientations was tested with auditory stimuli, there was little evidence that incompatible S-R associations transferred across spatial orientations (Proctor et al., 2007). Furthermore, when different types of response devices (keyboard vs joystick) were used, the transfer effect was larger when the response device for the training phase was also used in the test phase than when it was switched to a different device (Yamaguchi & Proctor, 2009). These findings imply that learned associations are specific to the training context, as it is typically observed in the learning literature (Godden & Baddeley, 1975). To explain the specificity of transfer of learning in this paradigm, we originally proposed that learned S-R associations are retrieved more effectively when more features of the training context are present in the test context (Yamaguchi & Proctor, 2009). This proposal is in agreement with the classic *Theory of Identical Elements* (Thorndike, 1914) as well as a contemporary context model of memory recall in which contextual features present at study are associated with a memory trace and serve subsequently as retrieval cues at test (Siegel & Kahana, 2014). From these findings and theories, one could argue that learned S-R associations transfer across contexts when the two contexts are sufficiently similar to each other because there are many features that overlap between them.

More interestingly and relevant to the present discussion, one of our studies (Yamaguchi et al., 2015, Experiment 3) demonstrated that the transfer of learning between two contexts was not always symmetrical. In that experiment, participants were trained with the incompatible-mapping task with either vocal (saying "left" or "right) or manual (pressing a left or right key) responses. They were then transferred to the Simon task with an alternative response mode (i.e., transfer from vocal to manual or from manual to vocal). We found that there was a transfer effect for those who switched from manual responses to vocal responses, but not for those who switched from vocal responses to manual responses. This asymmetrical transfer is difficult to explain if the transfer of learning only depends on features that overlap between contexts. Indeed, this finding is problematic for a traditional conception of psychological similarity, which assumes that psychological similarity corresponds to the subjective distance between objects or events within a psychological space

(Shepard, 1957). In the following section, I will first introduce this traditional conception of psychological similarity and explain how transfer asymmetry is problematic for this approach. I will then introduce an alternative set-theoretical approach by Tversky (1977) that is capable of accounting for transfer asymmetry.

Models of psychological similarity

The similarity of psychological objects is often formalised in terms of geometrical representations. This approach suggests that mental representations form a multidimensional psychological space in which the similarity of two objects is represented by the distance between their mental representations (Nosofsky, 1984; Shepard, 1957; Yamaguchi & Proctor, 2012). It typically assumes a Minkowski distance metric of the form,

$$d\left(A,B\right)=\left(\sum_{i}\left|a_i-b_i\right|^r\right)^{1/r} \tag{1}$$

for the distance between two psychological objects A and B, where a_i and b_i are the elements of A and B in the ith psychological dimension, respectively. If r is 2, the metric is the Cartesian distance. The similarity S between two objects is some form of an inverse function of the distance, $S(A,B)=f[d(A,B)]$, such that the smaller the value of the distance metric, the higher the degree of similarity between the objects. For instance, a popular model of categorisation, the *General Context Model* (Nosofsky, 1984), proposes a negative exponential function of the form,

$$S\left(A,B\right)=\exp\{-d\left(A,B\right)\cdot c\}$$

with S being the similarity function between the objects A and B and c being a scaling constant.

Although the geometric approach is popular and intuitive, Tversky (1977) questioned a geometrical representation of similarity and pointed out that psychological distance does not satisfy the three axioms of distance metric. These axioms include (1) minimality (the distance between two different objects is greater than or equal to the distance from an object to itself, $d\left(A,B\right)\geq d\left(A,A\right)=0$); (2) triangle inequality (the sum of the distance from Object A to Object B and the distance from Object A to Object C is greater than or equal to the distance from Object B to Object C; $d\left(A,B\right)+d\left(A,C\right)\geq d(B,C)$); and (3) symmetry (the distance from one object to another is always the same as the distance from the latter to the former, $d\left(A,B\right)=d(B,A)$). Most important, our previous study of transfer of learning indicated that the symmetry axiom is not always satisfied in perceptual-motor learning (Yamaguchi et al., 2015; also see Hicks, 1974).

In Tversky's (1977) set-theoretical approach, called the "contrast model" (see Figure 1), similarity is measured in terms of common and distinctive features of objects rather than the psychological distance between representations, which is expressed as:

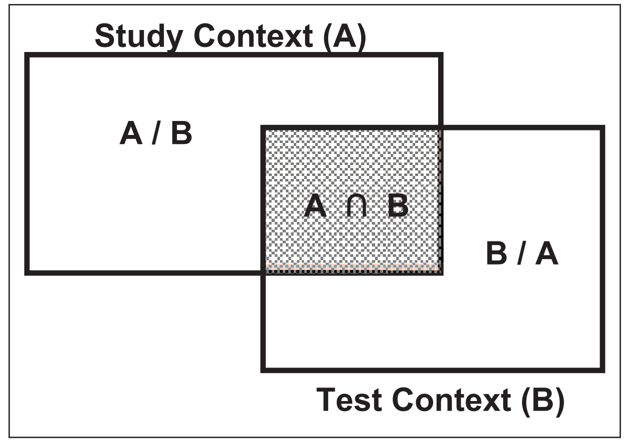

Figure 1. Illustration of Tversky's contrast model of similarity as applied to the transfer of learning paradigm.

$$S\left(A,B\right)=f\left(A\cap B\right)-\alpha f\left(A/B\right)-\beta f(B/A) \tag{2}$$

with α, $\beta \geqslant 0$. The function f could be a counting function that simply returns the number of features of the objects that satisfy a given condition; for instance, $f(A\cap B)$ may be simply a number of features that are contained in both A and B (Tversky, 1977). The model states that the similarity of A and B depend on their common features ($A\cap B$), which represents overlapping features of A and B, and two types of distinctive features, A/B and B/A, which stand, respectively, for the features contained in A but not in B and the features contained in B but not in A.

According to this model, the distinctiveness of the objects is not only a function of their commonality ($A\cap B$). Imagine a case in which school children learn the defining characteristics of animal species, such as mammals and birds, in a science class. They are then tested with exemplar animals that they have to sort into the mammal or bird category. Children may fail to identify a "penguin" as a bird because of a missing feature that is common among most exemplars from the bird category ("able to fly"), despite the fact that a penguin has all other defining features of the category. This case is represented by the distinctiveness of the category "bird" from the exemplar "penguin" ("bird" / "penguin"). In another case, children may fail to identify a whale as a mammal because of the presence of a feature that is foreign to the mammal category ("living under the sea," which is a prototypical feature of other species), despite the fact that a whale has all other defining features of the category. This case is represented by the distinctiveness of the exemplar "whale" from the category "mammal" ("whale" / "mammal").

If similarity is determined solely based on the commonality of objects ($A \cap B$), the metric would be symmetric. However, an asymmetry of similarity judgement could arise if the weights associated with the two distinctiveness terms are not equal. To give a concrete example, consider the aforementioned study of the Simon task (Yamaguchi et al., 2015) in which we found that learned incompatible S-R associations transfer from one response mode to the other (from manual to vocal) but not in the reversed direction (from vocal to manual). Let the two contexts represent the manual response and the vocal response, and suppose that there are 10 common features shared between manual and vocal responses, which can be expressed as $f(manual \cap vocal) = f(manual \cap vocal) = 10$.[1] Manual responses may have five unique features that are missing in vocal responses (e.g., using a response box, moving fingers, etc.), which can be expressed as $f(manual / vocal) = 5$). Vocal responses may also have three unique features that are missing in manual responses (e.g., using a microphone, uttering voice), which is expressed as $f(vocal / manual) = 3$). The similarity function above (Equation 2) then gives the following:

$$\begin{aligned} S(manual, vocal) &= f(manual \cap vocal) \\ &\quad - \alpha f(manual / vocal) \\ &\quad - \beta f(vocal / manual) \\ &= 10 - 5\alpha - 3\beta, \end{aligned}$$

and

$$\begin{aligned} S(vocal, manual) &= f(vocal \cap manual) \\ &\quad - \alpha f(vocal / manual) \\ &\quad - \beta f(manual / vocal) \\ &= 10 - 3\alpha - 5\beta \end{aligned}$$

If $\alpha = \beta$, then we have $S(manual, vocal) = 10 - 5\alpha - 3\alpha = 10 - 8\alpha$ and $S(vocal, manual) = 10 - 3\alpha - 5\alpha = 10 - 8\alpha$, so $S(manual, vocal) = S(vocal, manual)$. This would mean that the similarity between manual and vocal is the same in both directions, and there is an equal amount of transfer from manual response to vocal response and from vocal response to manual response. However, if $\alpha < \beta$, one can infer that $S(manual, vocal) > S(vocal, manual)$, so the similarity is larger from manual to vocal than from vocal to manual; therefore, transfer would be larger in the former direction than in the latter. The inequality of the coefficients α and β can be interpreted as participants attending more to features distinctive to one context than the other. For example, the above case could happen if trainees attended more to new features introduced in the test context than to missing features of the learning context.

In general, we have $S(manual, vocal) > S(vocal, manual)$, if $f(manual / vocal) > f(vocal / manual)$ and $\alpha < \beta$ or if $f(manual / vocal) < f(vocal / manual)$ and $\alpha > \beta$; transfer of learning is asymmetrical. If either $f(manual / vocal) = f(vocal / manual)$ or $\alpha = \beta$, we have $S(manual, vocal) = S(vocal, manual)$; the transfer is symmetrical. Therefore, the contrast model suggests that distinctive features of the contexts determine whether transfer is symmetrical or asymmetrical.

This study

An asymmetrical pattern of transfer has been observed in motor learning (Hicks, 1974) and other cognitive domains (Amitay et al., 2012; Ni et al., 2023). For example, bilateral motor training often shows greater transfer from a non-preferred limb to a preferred limb than the reverse direction (Hicks, 1975; Kumar & Mandal, 2005; Taylor & Heilman, 1980). Similarly, perceptual learning shows transfer from more invariant visual structures to less invariant structures (Yang et al., 2024) or from clear visual displays to noisy displays (Dosher & Lu, 2005) but not in the reverse directions. Although the exact mechanisms of learning in these different domains may vary, it is clear that overlapping features between two contexts alone cannot explain these asymmetrical patterns of transfer of learned skills between contexts. Instead, as illustrated above by Tversky's contrast model, some distinctive features of the training and test contexts contribute to the expression of learned skills in new contexts.

In this study, two experiments using the transfer of learning paradigm as introduced above were conducted. The results of these experiments demonstrated both symmetrical and asymmetrical patterns of the transfer effect across different contexts. Because the two experiments used the same basic experimental design, the method is described together in the following "Methods" section. To give an overview of the method, participants performed two phases, "training" and "transfer," or only the transfer phase without the training phase (control group). For those who had the training phase, they performed the incompatible-mapping task with one of two possible response modes (see Figure 2). In Experiment 1, the response modes were either moving one index finger from a centre key to one of the two keys ("finger-move training") or pressing two keys with the left and right index fingers ("keypress training"). In Experiment 2, the response modes were keypresses on the keyboard ("keyboard training") or on a response box ("response-box training"). In both experiments, there was also a control group who did not perform any training. In the transfer phase, all participants performed the Simon task with either the same response mode as that used in their training phase or the alternative response mode. Because the main analysis was on task performance (i.e., the Simon effect) in the transfer phase, results from different response modes in the transfer phase were analysed and reported separately in each experiment. Thus, in Experiment 1A, participants performed the Simon

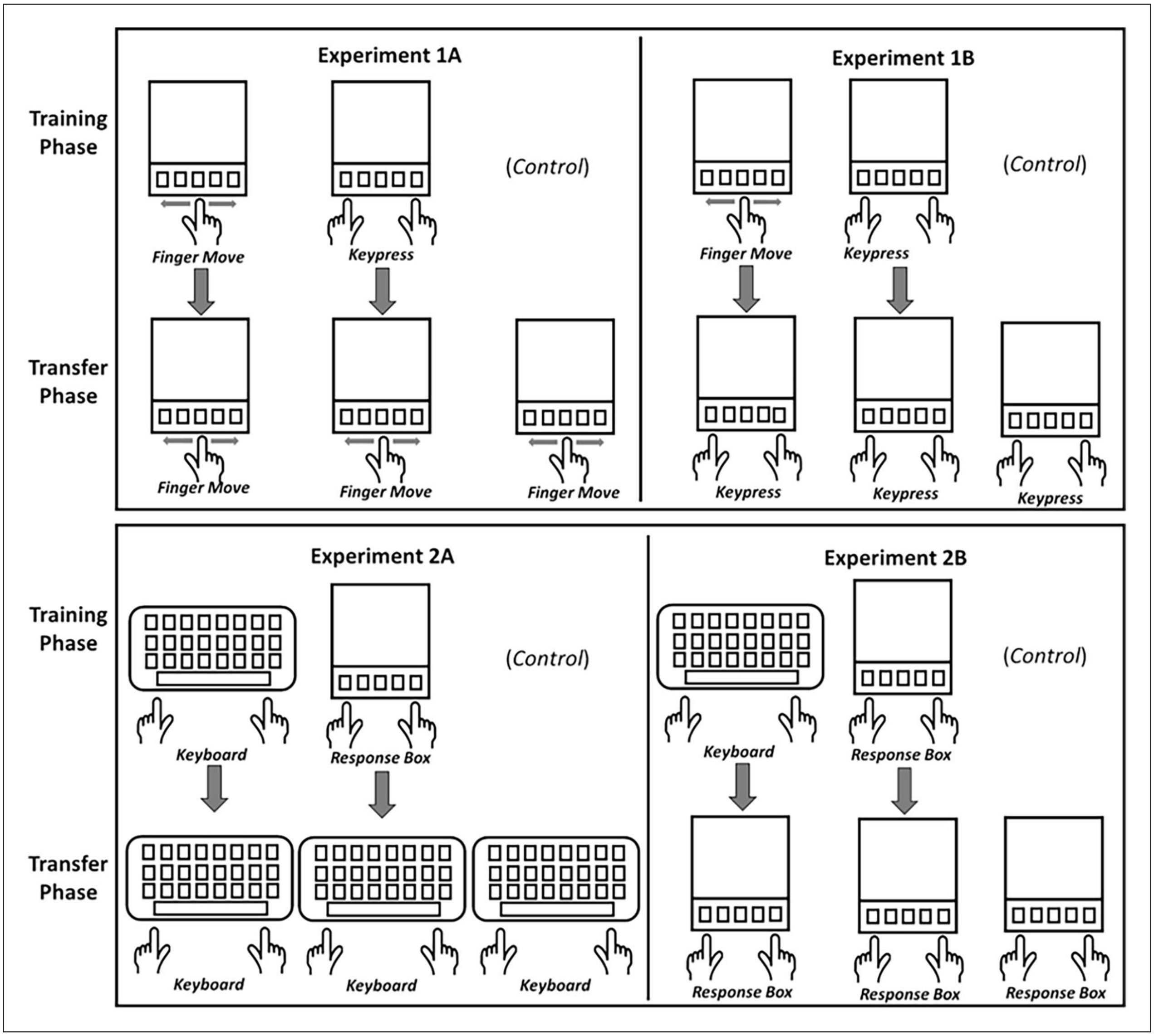

Figure 2. Illustration of the training and transfer phases in Experiments 1 and 2.

task in the finger-move condition ("finger-move transfer"), and in Experiment 1B, they performed the Simon task in the keypress condition ("keypress transfer"). Similarly, in Experiment 2A, participants performed the Simon task in the keyboard condition ("keyboard transfer"), and in Experiment 2B, they performed the Simon task in the response-box condition ("response-box transfer"). We separated the analyses for different response modes in the transfer phase because performance with different response modes was measured differently and was not necessarily comparable to each other (Yamaguchi et al., 2015; Yamaguchi & Proctor, 2009). The main focus was whether the transfer of incompatible associations occurred between different response modes in the training and transfer phases to the same extent as that between the same response mode.

From the results of the prior study (Yamaguchi & Proctor, 2009), we expected that training with spatially incompatible S-R mappings in the training phase would result in a reduction of the Simon effect in the transfer phase, indicating the transfer of newly acquired incompatible S-R associations. Moreover, the learning specificity principle (Thorndike & Woodworth, 1901) predicts that the larger the reduction of the Simon effect would be, the more similar the context of the transfer phase is to that of the training phase. If such contextual similarity is determined by the overlap between features of the two contexts ($A \cap B$), there should be similar reductions of the Simon effect regardless of which response mode was used in the training or transfer phase. That is, when there is a transfer effect from response mode A to response mode B, then there should be a similar magnitude of the transfer effect from response mode B to response mode A. Such results would be consistent with a geometric model of similarity, which assumes symmetric similarity between two contexts. However, if contextual similarity is determined not only by the overlap between the two contexts ($A \cap B$) but also by their distinctive features (A/B and B/A), the transfer effect could be larger from one response mode to the other than vice versa, as proposed by the contrast model.

Methods

Participants

Three hundred and ninety-five undergraduate students at Purdue University participated in this study ($N = 198$ in Experiment 1; $N = 197$ in Experiment 2). All participants received course credits towards their introductory psychology courses. They reported having normal colour vision and corrected-to-normal visual acuity. The gender or age of these students were not recorded, but they were predominantly between 18 and 22 years old, as in the typical university student population. The experimental protocol was approved by the Institutional Review Board of Purdue University, and all participants filled out a written consent form before they took part in the experiments. They received experimental credits towards their introductory psychology courses. In Experiment 1A (finger-move transfer), there were 32 participants in the control group, 33 in the finger-move training, and 32 in the keypress training. In Experiment 1B (keypress transfer), there were 33 participants in the control group, 35 in the finger-move training, and 33 in the keypress training. In Experiment 2A (keyboard transfer), there were 34 participants in the control group, 32 in the keyboard training, and 32 in the response-box training. In Experiment 2B (response-box transfer), there were 33 participants in the control group, 32 in the keyboard training, and 32 in the response-box training.

Apparatus, stimuli, and procedure

The apparatus consisted of a personal computer and a 14-inch VGA monitor. The experiment was controlled by Micro Experimental Laboratory (MEL 2.0; Psychology Software Tools, Pittsburgh, PA). Stimuli were white filled circles for the training phase and red and green filled circles for the test phase. The diameter of the circles was 1 cm. Stimuli appeared on the left or right of a fixation cross presented at the centre of the screen. The distance between a circle and the fixation cross was 7.5 cm. In Experiment 1, responses were registered by a five-key response box, in which the leftmost and rightmost keys were assigned to the left and right responses, respectively, which were 7.5 cm apart. The response box was placed in front of the computer screen so that the centre key was aligned with the midline of the screen. In Experiment 2, responses were registered by a standard QWERTY keyboard or the five-key response box (same as that used in Experiment 1). For the keyboard condition, the "z" and "/" keys at the ends of the bottom row were assigned to the left and right responses, respectively, which were 17 cm apart.

The experiment was conducted individually under a dim light. Participants were seated directly in front of the computer monitor at an unrestricted viewing distance of approximately 55 cm. The training and transfer phases consisted of 84 and 156 trials, respectively. The first 12 trials were considered as a warm-up in both phases and were not included in the analysis. In Experiment 1, one-third of the participants responded to stimuli by pressing the left or right key on the response box in the training phase. For these keypress responses, each trial started with the fixation cross at the screen centre for 1,000 ms, followed by the imperative stimulus (circle) on the left or right of the fixation. Another third of the participants responded to stimuli by moving the index finger of their dominant hand from the central key on the response box (Home key) to the left or right key in the training phase. For these finger move responses, each trial started with the message "HOME KEY!!" at the screen centre. When participants held down the home key, the fixation cross appeared for 1,000 ms, followed by the imperative stimulus, after which participants moved the index finger to either one of the response keys. If the index finger was lifted from the home key before the stimulus appeared, the message "HOME KEY!!" was presented again, and the timer was reset. In both response conditions, a circle was presented until a response was made or for 1,500 ms if no response occurred. An error tone was presented from the internal speaker when a wrong response key was pressed. The tone duration was 500 ms, and its frequency was 400 Hz. The interval between a response and the next trial was 1,500 ms for both correct and incorrect responses. In all conditions, response time (RT) was the interval between stimulus onset and depression of a response key. Participants were instructed to respond to circles on the left by pressing the right key and circles on the right by pressing the left key. The remaining one-third of the participants did not perform the training phase and served as the control group to examine whether a significant transfer effect was observed in either of the training conditions. Experiment 2 was essentially the same as Experiment 1, except that responses were made by pressing the left and right keys on the response box or on a keyboard.

In the transfer phase, the procedure was identical to that of the training phase except that circles were coloured in green or red, and participants pressed the left or right key according to the colour. The colour-key mapping was counterbalanced across participants. In Experiment 1A, all participants performed the transfer phase by moving the index finger to the left or right key (finger-move transfer);

Table 1. A summary of mean response time (RT in milliseconds) and percentage error (PE) in the training phase of Experiments 1 and 2 (values in parentheses are standard errors of means).

Experiment	Training condition	RT		PE	
1		Experiment 1A: finger-move transfer			
	Finger-move	554	(22.44)	0.51	(0.13)
	Keypress	371	(14.37)	1.92	(0.33)
		Experiment 1B: keypress transfer			
	Finger-move	523	(17.70)	0.79	(0.20)
	Keypress	364	(8.81)	1.10	(0.21)
2		Experiment 2A: keyboard transfer			
	Keyboard	418	(16.10)	1.70	(0.31)
	Response box	387	(13.54)	1.13	(0.22)
		Experiment 2B: response-box transfer			
	Keyboard	391	(13.99)	1.61	(0.28)
	Response box	353	(8.96)	1.23	(0.22)

Table 2. A summary of mean response time (RT in milliseconds) and percentage error (PE) as a function of stimulus–response compatibility and training condition in the transfer phase of Experiments 1 and 2 (values in parentheses are standard errors of means).

Experiment	Training condition	RT				PE			
		Compatible		Incompatible		Compatible		Incompatible	
1		Experiment 1A: finger-move transfer							
	Control	586	(18.05)	631	(17.79)	0.70	(0.46)	1.89	(0.40)
	Finger-move	592	(17.78)	604	(17.51)	1.66	(0.45)	1.14	(0.40)
	Keypress	604	(18.05)	625	(17.79)	0.52	(0.46)	0.78	(0.40)
		Experiment 1B: keypress transfer							
	Control	415	(14.14)	430	(13.02)	2.81	(0.55)	3.30	(0.42)
	Finger-move	455	(13.73)	468	(12.64)	2.80	(0.54)	2.34	(0.41)
	Keypress	460	(14.14)	455	(13.02)	2.28	(0.55)	2.02	(0.42)
2		Experiment 2A: keyboard transfer							
	Control	470	(15.43)	480	(13.74)	3.36	(0.64)	4.19	(0.54)
	Keyboard	516	(15.90)	495	(14.16)	4.05	(0.66)	2.22	(0.55)
	Response box	500	(15.90)	492	(14.16)	2.48	(0.66)	2.26	(0.55)
		Experiment 2B: response-box transfer							
	Control	483	(14.09)	496	(13.38)	2.61	(0.62)	5.00	(0.59)
	Keyboard	478	(14.31)	468	(13.59)	2.43	(0.63)	2.26	(0.60)
	Response box	454	(13.88)	450	(13.18)	4.01	(0.61)	2.98	(0.58)

in Experiment 1B, they performed the transfer phase by pressing the left or right key (keypress transfer). In Experiment 2A, participants performed the transfer phase by pressing the left or right key on a keyboard (keyboard transfer); in Experiment 2B, they performed the transfer phase by pressing the left or right key on the response box (response-box transfer).

Results

Trials for which RT was shorter than 100 ms or longer than 1,500 ms were discarded (0.07% and 0.26% for the training and transfer phases in Experiment 1; 0.04% and 0.20% for the training and transfer phases in Experiment 2). Mean RT for correct responses and percentage errors (PEs) were computed for each participant and summarised in Table 1 for the training and in Table 2 for the transfer phase. Figure 3 summarises the Simon effect in RT in the transfer phase. The following analyses focused on the transfer phase.

In Experiments 1A and 1B, RT and PE were first submitted to 3 (training condition: control vs keypress vs finger-move) $\times$ 2 (S-R compatibility: compatible vs incompatible) analyses of variance (ANOVAs) separately. The first variable was between-subject, and the second variable was within-subject. In Experiments 2A and 2B, RT and PE were first submitted to 3 (training condition: control vs keyboard vs response box) $\times$ 2 (S-R compatibility: compatible vs incompatible) ANOVAs. A significant

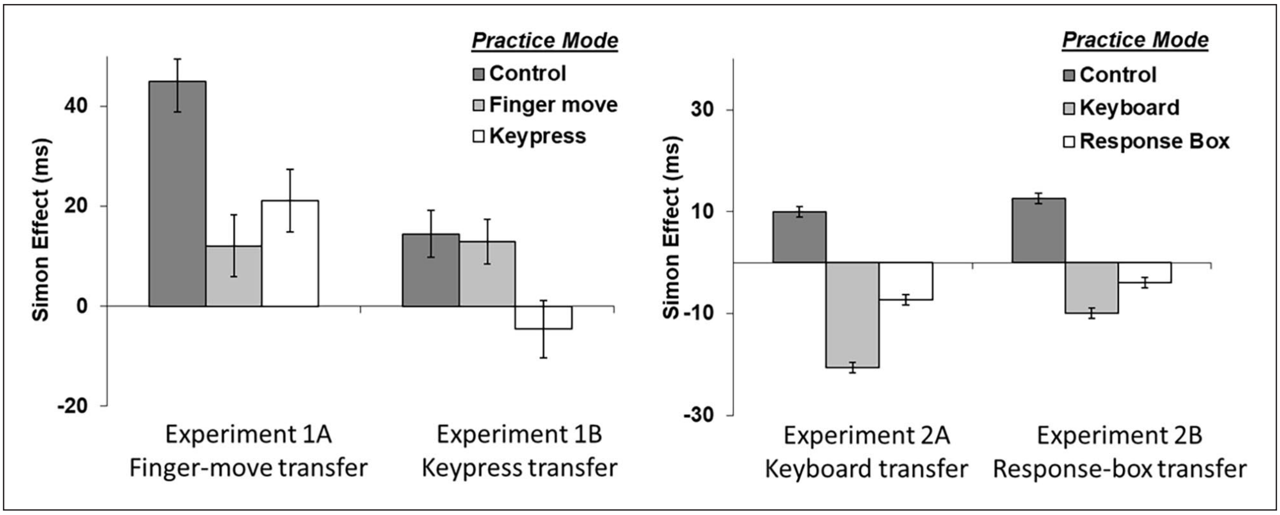

Figure 3. The Simon effects in the transfer phase of Experiments 1 and 2. Error bars indicate one standard error of means.

interaction between the two variables in the ANOVA was followed up by comparisons of the Simon effect from the two training groups to that from the control group. We computed Bayes factors (BF) based on two-tailed independent-sample *t*-tests comparing the Simon effect from each training group to the control group, against the null hypothesis that there was no difference between the conditions. A significantly smaller Simon effect was expected for a training group if training with the incompatible-mapping task transferred to the Simon task. *BF* greater than 3 was taken as moderate evidence for the transfer effect, and *BF* greater than 10 was taken as strong evidence for the transfer effect. *BF* less than 0.33 was taken as moderate evidence for a lack of the transfer effect, and *BF* less than 0.10 was taken as strong evidence for a lack of the transfer effect. *BF* between 0.33 and 3 was taken as inconclusive. The analyses were performed in R Studio (R Core Team, 2021) with the following packages: tidyverse (Wickham et al., 2019), BayesFactor (Morey & Rouder, 2022), afex (Singmann et al., 2023), multcomp (Hothorn et al., 2008), and emmeans (Lenth, 2022). The experimental data and analysis scripts are available on the Open Science Framework (OSF) page (https://osf.io/vd2mc/).

Experiment 1A: finger-move transfer

In this experiment, participants practised the incompatible-mapping task either by moving the index finger from the centre key to the left or right key (finger-move training) or by pressing the left or right key with two fingers (keypress training). The control group had no practice with the incompatible-mapping task. All performed the Simon task by moving the index finger from the centre key to the left or right key (finger-move transfer).

For RT, there was a significant main effect of S-R compatibility ($F(1, 94)=62.67$, $MSE=523.40$, $p<.001$, $\eta_p^2=.400$), but that of training condition was not significant ($F(2, 94)<1$, $MSE=20{,}026.66$, $p=.787$, $\eta_p^2=.005$). The interaction between the two factors was significant ($F(2, 94)=9.00$, $MSE=523.40$, $p<.001$, $\eta_p^2=.161$). The Simon effect was 45 ms for the control group, 12 ms for the finger-move training group (i.e., those who had the same response mode in both phases), and 21 ms for the keypress training group (those who switched the response mode in the transfer phase). The Simon effect after the finger-move training was smaller than that of the control group ($t(63)=4.33$, $p<.001$, $BF=374.47$). The Simon effect after the keypress training was also smaller than that of the control group ($t(63)=3.15$, $p=.002$, $BF=14.43$). Therefore, significant transfer effects were observed, and BFs provided strong evidence for the transfer effect, regardless of the response mode used in the training phase.

For PE, the main effects of S-R compatibility ($F(1, 94)=1.49$, $MSE=3.16$, $p=.225$, $\eta_p^2=.016$) and training condition ($F(2, 94)=1.21$, $MSE=8.66$, $p=.301$, $\eta_p^2=.025$) were not significant, but these variables interacted ($F(2, 94)=3.72$, $MSE=3.16$, $p=.028$, $\eta_p^2=.073$). The Simon effect was 1.19% for the control group, –0.51% after the finger-move training, and 0.26% after the keypress training. The Simon effect after the finger-move training was smaller than that of the control group ($t(63)=2.33$, $p=.023$, $BF=2.40$). The Simon effect after the keypress training was not reliably smaller than that of the control group ($t(63)=1.84$, $p=.071$, $BF=1.05$). Although the Simon effect was significantly smaller only after the finger-move training, BFs were inconclusive for both training conditions.

Experiment 1B: keypress transfer

Participants in this group also practised the incompatible-mapping task either by moving the index finger (finger-move training) or by pressing the keys with two fingers (keypress training), whereas the control group had no practice. All performed the Simon task by pressing the keys with two fingers (keypress transfer).

For RT, there was a significant main effect of S-R compatibility (F(1, 98) = 6.93, MSE = 428.80, p = .010, η_p^2 = .066). The main effect of training condition was not (F(2, 98) = 2.66, MSE = 11697.79, p = .075, η_p^2 = .051). The interaction between these variables was significant (F(2, 98) = 4.41, MSE = 428.80, p = .015, η_p^2 = .082). The Simon effect was 15 ms for the control group, –5 ms after the keypress training (i.e., those who had the same response mode in both phases), and 13 ms after the finger-move training (those who had different response modes in the two phases). The Simon effect after the keypress training was smaller than that of the control group (t(64) = 2.56, p = .013, BF = 3.82). The Simon effect after the finger-move training was not significantly different from that of the control group (t(66) = 0.26, p = .793, BF = 0.26). BF also provided moderate evidence for the transfer effect after the keypress training; however, it provided moderate evidence for a lack of the transfer effect after the finger-move training. These outcomes indicated the specificity of the transfer effect; that is, the transfer occurred only when the response mode in the two phases matched.

For PE, the ANOVA showed no significant main effect of S-R compatibility (F(1, 98) < 1, MSE = 6.21, p = .838, η_p^2 < .001), or of training condition (F(2, 98) = 1.39, MSE = 9.65, p = .254, η_p^2 = .028). There was no interaction between the two variables (F(1, 98) < 1, MSE = 6.21, p = .513, η_p^2 = .014). The Simon effect was 0.49% for the control group, –0.25% for the keypress training group, and –0.45% for the finger-move training group. The Simon effect after the finger-move training (t(63) = 1.10, p = .277, BF = 0.42) or after the keypress training (t(63) = 0.90, p = .374, BF = 0.35) were not significant, and BFs were inconclusive.

Summary of Experiment 1

Experiment 1 showed that when the transfer phase used the finger-move condition (Experiment 1A), the transfer effect was obtained in RT, regardless of the training condition. However, when the transfer phase used the keypress condition (Experiment 1B), the transfer effect was only obtained in RT after the keypress training but not after the finger-move training. Thus, the context-specificity of the transfer effect was observed for the finger-move transfer condition but not for the keypress transfer condition, demonstrating a transfer asymmetry. For PE, the results were not clear-cut because BFs were inconclusive in all conditions.

Experiment 2A: keyboard transfer

Participants in this experiment practised the incompatible-mapping task with the response box (response-box training) or the keyboard (keyboard training), whereas the control group had no practice. All performed the Simon task with the keyboard (keyboard transfer).

For RT, main effects of S-R compatibility (F(1, 95) = 3.61, MSE = 487.97, p = .060, η_p^2 = .037) and training condition (F(2, 95) = 1.17, MSE = 14,027.89, p = .316, η_p^2 = .024) did not reach significance, but their interaction was significant (F(2, 95) = 7.92, MSE = 487.97, p < .001, η_p^2 = .143). The Simon effect was 10 ms for the control group, –7 ms after the response-box training (those who switched the response mode in the transfer phase), and –21 ms after the keyboard training (i.e., those who had the same response mode in both phases). The Simon effect after the keyboard training was smaller than that of the control group (t(64) = 4.27, p < .001, BF = 321.41). The Simon effect after the response-box training was also smaller than that of the control group (t(63) = 2.28, p = .026, BF = 2.19). However, BF provided strong evidence of the transfer effect for the former, but it was inconclusive for the latter.

For PE, there was no main effect of S-R compatibility (F(1, 95) < 1, MSE = 8.40, p = .332, η_p^2 = .010) or of training condition (F(2, 95) = 2.13, MSE = 15.22, p = .124, η_p^2 = .043). However, these variables interacted (F(2, 95) = 3.49, MSE = 8.40, p = .034, η_p^2 = .068). The Simon effect was 0.83% for the control group, –1.82% for the keyboard training group, and –0.22% for the response-box training group. The Simon effect was smaller after the keyboard training than that of the control group (t(64) = 2.37, p = .021, BF = 2.60). The Simon effect after the response-box training was not significantly different from that of the control group (t(64) = 1.04, p = .304, BF = 0.40). Nevertheless, BFs were inconclusive for both training conditions.

Experiment 2B: response-box transfer

One group of participants practised the incompatible-mapping task with the response box (response-box training), the other group practised it with the keyboard (keyboard training), and the control group had no practice. All performed the Simon task with the response box (response-box transfer).

For RT, main effects of S-R compatibility (F(1, 94) < 1, MSE = 671.18, p = .920, η_p^2 < .001) and training condition (F(2, 94) = 1.64, MSE = 11,972.17, p = .200, η_p^2 = .034) were not significant, but they interacted (F(2, 94) = 3.35, MSE = 671.18, p = .039, η_p^2 = .067). The Simon effect was 13 ms for the control group, –4 ms after response-box training, and –10 ms after keyboard training. The Simon effect after the response-box training was not significantly different from that of the control group (t(63) = 1.99, p = .051, BF = 1.32). The Simon effect after the keyboard training was smaller than that of the control group (t(63) = 2.43, p = .018, BF = 2.91). However, BFs were inconclusive for both comparisons.

For PE, main effects of S-R compatibility ($F(1, 94) = 2.47$, $MSE = 7.95$, $p = .119$, $\eta_p^2 = .026$) and training condition ($F(2, 94) = 3.13$, $MSE = 11.50$, $p = .062$, $\eta_p^2 = .048$) were not significant, but their interaction was significant ($F(2, 96) = 4.96$, $MSE = 7.95$, $p = .009$, $\eta_p^2 = .095$). The Simon effect was 2.43% for the control group, –0.35% for the response-box group, and –0.17% after the keyboard transfer. The Simon effect was smaller after the response-box training group than that of the control group ($t(63) = 2.55$, $p = .013$, $BF = 3.74$). The Simon effect was also smaller after the keyboard training than that of the control group ($t(63) = 2.51$, $p = .015$, $BF = 3.40$). Both BFs provided moderate evidence for the transfer effect.

Summary of Experiment 2

When the transfer phase used the keyboard (Experiment 2A), the Simon effect in RT was smaller both after the keyboard training and after the response-box training, but BF provided strong evidence for the transfer effect only for the former condition and was inconclusive for the latter. The Simon effect in PE was also significantly reduced only after the keyboard training, but BFs were inconclusive for both training groups. When the transfer phase used the response box (Experiment 2B), the Simon effect in RT was reduced significantly after the keyboard training but not after the response-box training, whereas BFs were inconclusive in both cases. However, in PE, the Simon effect was reduced significantly both after the keyboard training and after the response-box training, and BFs provided evidence for the transfer effect for both training groups. Hence, the results were somewhat mixed, but there was no indication of context specificity or transfer asymmetry in Experiment 2.

General discussion

Context-specificity of learning indicates that the similarity between study and test contexts plays an important role in utilising what learners have learned in the past (Godden & Baddeley, 1975). Previous studies found that the reduction of the Simon effect was larger when the response mode in the transfer phase (pressing keys on the keyboard vs deflecting a joystick to the left or right) was the same as that of the training phase than when it differed, indicating context-specificity of the transfer effect (Proctor et al., 2007, 2009; Yamaguchi et al., 2015; Yamaguchi & Proctor, 2009). These findings imply that newly acquired S-R associations are transferred to the Simon task more effectively when the response mode in the training was the same than when it was different. It was suggested that features that are shared by two different response modes serve as retrieval cues for the learned S-R associations (Yamaguchi & Proctor, 2009). This would mean that the similarity between the training and transfer phases is determined by overlapping features of the two contexts (Siegel & Kahana, 2014). This feature overlap account agrees with Thorndike's (1914) theory of identical elements, but it predicts that the transfer of S-R associations is symmetric between two contexts (see Kahana, 2002). This account faces difficulty explaining the present results.

In Experiment 1, the Simon effect was reduced after training with the incompatible-mapping task as compared to the Simon effect from the control group who did not have prior training with the incompatible-mapping task. When the response mode of the transfer phase required moving the index finger from the centre key to the left or right key (finger-move transfer), there was little statistical evidence that the transfer of learning from the incompatible-mapping task to the Simon effect was context-specific (see also Tagliabue et al., 2002; Vu, 2007). When the response mode of the transfer phase required pressing the left or right key with the two index fingers (keypress transfer), the transfer effect was only reliably observed when the same response mode was used than when a different mode was used in the training phase, indicating context-specificity of the transfer effect (see also Proctor et al., 2007; Yamaguchi & Proctor, 2009). These results demonstrated transfer asymmetry.

These outcomes can be interpreted as indicating that the similarity of the finger-move response to the keypress response is greater than the similarity of the keypress response to the finger-move response, which appears paradoxical if the similarity of the two contexts is determined only by their overlapping features. Based on the contrast model (Tversky, 1977), the asymmetry is possible when similarity also depends on distinctive features of the two contexts. One could argue that the number of distinctive features of the keypress response (i.e., features that were contained in the mental representation of the keypress response but not in that of the finger-move response) was greater than the number of distinctive features of the finger-move response. For instance, both the finger-move and keypress responses required pressing the same two response keys, but the finger-move required using one finger, whereas the keypress response required using two fingers that were also placed on the left and right positions. Because "response" in the Simon task could be represented in terms of the key locations as well as the finger locations (Hommel, 1993), more response features could have contributed to the formation of new spatially incompatible associations between stimuli and response features that were present in the keypress response but not in the finger-move response (e.g., left and right finger positions), which could give rise to the transfer asymmetry observed in this experiment.

It is also possible that the finger-move response involves directional response coding (moving to the left or right) or locational response coding (pressing a key on the left or right), whereas the keypress response involves two different locational response codings (based on the locations of keys and fingers). Without prior experience with the keypress response, participants would adopt the directional response code to represent the finger-move response, which differed from the locational codes for the keypress response in the transfer phase, preventing the learned S-R association from transferring from the finger-move response to the keypress response. However, with prior experience with the keypress response, participants might have adopted the location response code to represent the finger-move response in the transfer phase, allowing the learned S-R associations to transfer from the keypress response to the finger-move response. Similar flexible response coding was suggested by a finding of Wang et al. (2007) for the counterclockwise or clockwise rotations of a steering wheel in a Simon-like task for which tone pitch was relevant and tone location (left or right) was irrelevant. When the steering wheel triggered a cursor to move left or right ballistically, the cursor showed little influence on the Simon effect. However, following a condition in which the wheel-movement directly controlled the cursor's movement in a continuous fashion, the ballistically triggered cursor influenced the Simon effect in a similar manner to the continuously controlled cursor. This line of reasoning is akin to the transfer-appropriate-processing framework (Morris et al., 1977), which argues that retrieval of memory depends on a functional match between the processes that take place in the study and test contexts.

In Experiment 2, the reduction of the Simon effect tended to depend on the type of response mode used in the training phase rather than whether the response mode was the same as that in the transfer phase. The reductions of the Simon effect after training with the keyboard tended to be more reliable, in terms of statistical significance testing, than that after training with the response box. This pattern of results suggests that new S-R associations were acquired better with the keyboard, possibly because of the larger distance between keys or the greater number of intervening keys (Chen & Proctor, 2014), but they were retrieved equally well with the keyboard or response box in the transfer phase. The results provided little evidence of context-specificity of transfer. Thus, the similarity of the keyboard to the response box is the same as the similarity of the response box to the keyboard, which may be because incompatible S-R associations were formed between the same number of response features for the two response devices (e.g., both modes including two key locations and two finger locations).

It is not immediately clear how geometric approaches of similarity would account for the results of this study. As psychological similarity is considered to be a function of the psychological distance between two objects (Shepard, 1957), the geometrical models should always predict symmetrical transfer. An alternative approach may be a recent model based on quantum geometry (Pothos et al., 2013), which is also able to account for the effect of comparison order on similarity judgements. Although it is a geometric model, the quantum approach distinguishes between S(A,B) and S(B,A), but it does so by taking into account the distinctive features of the subject, *A/B* for S(A,B) and *B/A* for S(B,A), more than those of the referent, *B/A* for S(A,B) and *A/B* for S(B,A). This is a consequence of the mechanics assumed in the quantum model, which has the property that the dimensionality of similarity judgement is determined by the dimensionality of the subject; that is, the greater the dimensionality of the subject, the more distinctive features of the subject the similarity judgement would consider. Hence, if one knows more about A than B, the similarity of A to B gets smaller than the similarity of B to A, $S(A,B) < S(B,A)$, as there are more distinctive features of A (*A/B*) than those of B (*B/A*; Pothos & Busemeyer, 2013). In Experiment 1, participants are arguably more familiar with the keypress response than the finger-move response, as the former is more consistent with how a keyboard is usually used. Then, the quantum theory may predict that transfer from the keyboard response to the finger-move (Experiment 1A) would be less likely than transfer from the finger-move to the keyboard (Experiment 1B), which is opposite to what we found. Unlike these geometrical models, the contrast model's set-theoretical formulation of similarity can account for the results of the two experiments in this study.

It should be noted, however, that although the contrast model is a useful framework to understand the transfer of learning, its set-theoretical formulation is equivocal as to the cognitive mechanisms underlying similarity judgement. Transfer asymmetry has been observed consistently in bilateral motor learning (Hicks, 1974), but the direction of asymmetry has been difficult to predict (Sainburg & Wang, 2002). For example, Parlow and Kinsbourne (1989) found that training with a non-preferred arm transferred to a preferred arm better than the reversed direction, whereas Taylor and Heilman (1980) found that the opposite was the case. This flexibility seems to arise from the specific properties of the learning tasks. The contrast model assumes that object properties are fixed, but their psychological representations can change according to the weights associated with the distinctive features (α and β in Equation 2). In the current form, the contrast model allows such flexibility based on free parameters, but how these parameters behave in different task settings is not determined within the framework. Incorporating some mechanisms that constrain these free parameters is necessary to derive specific predictions in a particular transfer context.

In a previous study, Navarro and Lee (2001) designed their cluster analysis based on the contrast model and applied to experimental data to find that people do seem to use distinctive features in their similarity judgement. Rorissa (2004) also used the contrast model to formulate a structural equation model and found that distinctive features accounted for the variance in the similarity judgement of images. These findings support the contrast model's assertion that psychological similarity depends on both common and distinctive features of objects. On the contrary, Evers and Lakens (2014) tested the contrast model in terms of its concept of diagnostic features, features that determine similarity judgement of objects, and obtained results that questioned the model. Shannon (1988) also questioned the validity of the concept of feature as the basis of a cognitive model, echoed with Wittgenstein's (1953) claim that objects cannot be defined by sets of features. As Shannon argued, the contrast model can help understand some orderly patterns of data and offers a theoretical framework to characterise similarity judgement in relation to common and distinctive features, but one can still question whether similarity judgement indeed relies on features as such. An alternative view may be expressed in terms of underlying psychological processes, as in the transfer-appropriate-processing framework (Morris et al., 1977), and it is unclear how the concept of features relates to that of processing. Hence, the specification of features continues to be a challenging task for Tversky's framework.

Concluding remarks

Perceiving the similarities and differences between different contexts is crucial for adaptive human behaviour, to utilise prior learning in an environment that is ever-evolving. Strictly speaking, there are no two identical contexts that one could encounter in everyday life, but human cognition is so flexible that what is learned in one context can be utilised in another context. If one fails to perceive the similarity between contexts, learning may be completely useless. To understand the effectiveness of learning, it is important to promote a theoretical understanding of similarity perception. The use of a transfer of learning paradigm is a useful method to advance such theoretical efforts. As in previous studies of the transfer of learning paradigm using different response modes (Yamaguchi et al., 2015; Yamaguchi & Proctor, 2009), this study demonstrated that learned incompatible S-R associations do not always transfer from one response mode to another response mode. The finding from Experiment 1 is especially troublesome for a geometric model of similarity as transfer should be bidirectional if it depends on the similarity of two contexts. Instead, the results support Tversky's (1977) suggestion that psychological distance does not always satisfy the symmetry axiom of a distance metric. Although his contrast model is still too general to generate specific predictions for the present experiments, the model still provides a useful interpretative framework for the underlying psychological representations that gave rise to the results in the present experiments.

Author's note

This study was conducted when the author was a PhD student at Purdue University.

Acknowledgements

The author would like to thank his PhD supervisor, Robert W. Proctor, who passed away on 30 October 2023.

Declaration of conflicting interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author received no financial support for the research, authorship, and/or publication of this article.

ORCID iD

Motonori Yamaguchi https://orcid.org/0000-0002-8405-9741

Data accessibility statement

The data from this experiment are publicly available at the Open Science Framework website:https://osf.io/vd2mc/

Note

1. Here the numbers are arbitrary and are only used for an illustrative purpose.

References

Amitay, S., Zhang, Y.-X., & Moore, D. R. (2012). Asymmetric transfer of auditory perceptual learning. *Frontiers in Psychology*, *3*, Article 508.

Chen, J., & Proctor, R. W. (2014). Conceptual response distance distinguishes action goals in the Stroop task. *Psychonomic Bulletin & Review*, *21*, 1238–1243.

Dosher, B. A., & Lu, Z. L. (2005). Perceptual learning in clear displays optimizes perceptual expertise: Learning the limiting process. *Proceedings of the National Academy of Science*, *102*, 5286–5290.

Evers, E. R. K., & Lakens, D. (2014). Revisiting Tversky's diagnosticity principle. *Frontiers in Psychology*, *5*, Article 875.

Gick, M. L., & Holyoak, K. J. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, *15*, 1–38.

Godden, D. R., & Baddeley, A. D. (1975). Context-dependent memory in two natural environments: On land and underwater. *British Journal of Psychology*, *66*, 325–331.

Healy, A. F., Wohldmann, E. L., Sutton, E. M., & Bourne, L. E., Jr. (2006). Specificity effects in training and transfer of speeded responses. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *32*, 534–546.

Hicks, R. E. (1974). Asymmetry of bilateral transfer. *American Journal of Psychology*, *87*, 667–674.

Hommel, B. (1993). Inverting the Simon effect by intention. *Psychological Research*, *55*, 270–279.

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous Inference in General Parametric Models. *Biometrical Journal*, *50*(3), 346–363. https://doi.org/10.1002/bimj.200810425

Kahana, M. J. (2002). Associative symmetry and memory theory. *Memory & Cognition*, *30*, 823–840.

Kolers, P. A., & Roediger, H. L., III. (1984). Procedures of mind. *Journal of Verbal Learning and Verbal Behavior*, *23*, 425–449.

Kumar, S., & Mandal, M. K. (2005). Bilateral transfer of skill in left- and right-handers. *Laterality*, *10*, 337–344.

Lenth, R. V. (2022). *emmeans: Estimated marginal means, aka least-squares means* (R Package Version 1.8.3). https://CRAN.R-project.org/package=emmeans

Luo, C., & Proctor, R. W. (2016). Transfer of an implied incompatible spatial mapping to a Simon task. *Acta Psychologica*, *164*, 81–89.

Morey, R. D., & Rouder, J. N. (2022). *BayesFactor: Computation of Bayes factors for common designs* (R Package Version 0.9.12-4.4). https://CRAN.R-project.org/package=BayesFactor

Morris, C. D., Branford, J. D., & Franks, J. J. (1977). Levels of processing versus transfer appropriate processing. *Journal of Verbal Learning and Verbal Behavior*, *16*, 519–533.

Navarro, D., & Lee, M. (2001). Clustering using the contrast model. In Proceedings of the 23rd Annual Conference of the Cognitive Science Society (pp. 686–691). California Digital Library.

Ni, N., Gathercole, S. E., Norris, D., & Saito, S. (2023). Asymmetric negative transfer effects of working memory training. *Memory & Cognition*, *51*, 1654–1669.

Nosofsky, R. M. (1984). Choice, similarity, and the context theory of classification. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *10*, 104–114.

Parlow, S. E., & Kinsbourne, M. (1989). Asymmetrical transfer of training between hands: Implications for interhemispheric communication in normal brain. *Brain and Cognition*, *11*, 98–113.

Pothos, E. M., & Busemeyer, J. R. (2013). Can quantum probability provide a new direction for cognitive modeling? *Behavioral and Brain Sciences*, *36*, 255–327.

Pothos, E. M., Busemeyer, J. R., & Trueblood, J. R. (2013). A quantum geometric model of similarity. *Psychological Review*, *120*, 679–696.

Proctor, R. W., & Lu, C.-H. (1999). Processing irrelevant location information: Practice and transfer effects in choice-reaction tasks. *Memory & Cognition*, *27*, 63–77.

Proctor, R. W., Yamaguchi, M., & Vu, K.-P. L. (2007). Transfer of noncorresponding spatial associations to the auditory Simon task. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *33*, 245–253.

Proctor, R. W., Yamaguchi, M., Zhang, Y., & Vu, K. P.-L. (2009). Influence of visual stimulus mode on transfer of acquired spatial associations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *35*, 434–445.

R Core Team. (2021). *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. https://www.R-project.org/

Rorissa, A. (2004). Relationships between perceived features and similarity of images: A test of Tversky's contrast model. *Journal of the American Society for Information Science and Technology*, *58*, 1401–1418.

Ross, B. H. (1984). Remindings and their effects in learning a cognitive skill. *Cognitive Psychology*, *16*, 371–416.

Sainburg, R. L., & Wang, J. (2002). Interlimb transfer of visuomotor rotations: Independence of direction and final position information. *Experimental Brain Research*, *145*, 437–447.

Sala, G., & Gobet, F. (2016). Do the benefits of chess instruction transfer to academic and cognitive skills? A meta-analysis. *Educational Research Review*, *18*, 46–57.

Shannon, B. (1988). On the similarity of features. *New Ideas in Psychology*, *6*, 307–321.

Shepard, R. N. (1957). Stimulus and response generalization: A stochastic model relating generalization to distance in psychological space. *Psychometrika*, *22*, 325–345.

Siegel, L. L., & Kahana, M. J. (2014). A retrieved context account of spacing and repetition effects in free recall. *Journal of Experimental Psychology: Learning, Memory, &* Cognition, *40*, 755–764.

Simon, J. R., & Rudell, A. P. (1967). Auditory SR compatibility: The effect of an irrelevant cue on information processing. *Journal of Applied Psychology*, *51*, 300–304.

Singmann, H., Bolker, B., Westfall, J., Aust, F., & Ben-Shachar, M. S. (2023). *afex: Analysis of Factorial Experiments* (R Package Version 1.3-0). https://CRAN.R-project.org/package=afex

Tagliabue, M., Zorzi, M., & Umiltà, C. (2002). Cross-modal re-mapping influences the Simon effect. *Memory and Cognition*, *30*, 18–23.

Tagliabue, M., Zorzi, M., Umiltà, C., & Bassignani, F. (2000). The role of LTM links and STM links in the Simon effect. *Journal of Experimental Psychology: Human Perception and Performance*, *26*, 648–670.

Taylor, H. G., & Heilman, K. M. (1980). Left-hemisphere motor dominance in right handers. *Cortex*, *16*, 587–607.

Thorndike, E. L. (1914). *Educational psychology, brief course*. Columbia University.

Thorndike, E. L., & Woodworth, R. S. (1901). The influence of improvement in one mental function upon the efficiency of other functions: II. The estimation of magnitudes. *Psychological Review*, *8*, 384–395.

Tulving, E., & Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, *80*, 352–373.

Tversky, A. (1977). Features of similarity. *Psychological Review*, *84*, 327–352.

Vu, K.-P. L. (2007). Influences on the Simon effect of prior practice with spatially incompatible mappings: Transfer within and between horizontal and vertical dimensions. *Memory and Cognition*, *35*, 1463–1471.

Vu, K.-P. L., Proctor, R. W., & Urcuioli, P. (2003). Effects of practice with an incompatible location-relevant mapping on the Simon effect in a transfer task. *Memory & Cognition*, *31*, 1146–1152.

Wang, D. Y. D., Proctor, R. W., & Pick, D. F. (2007). Coding controlled and triggered cursor movements as action effects: Influences on the auditory Simon effect for wheel-rotation responses. *Journal of Experimental Psychology: Human Perception and Performance*, *33*, 657–669.

Wickham, H., Averick, M., Bryan, J., Chang, W., McGowan, L. D., François, R., Grolemund, G., Hayes, A., Henry, L., Hester, J., Kuhn, M., Pedersen, T. L., Miller, E., Bache, S.

M., Müller, K., Ooms, J., Robinson, D., Seidel, D. P., Spinu, V., & . . .Yutani, H. (2019). Welcome to the Tidyverse. *Journal of Open Source Software*, *4*, 1686.

Wittgenstein, L. (1953). *Philosophical investigations*. Basil Blackwell.

Yamaguchi, M., Chen, J., & Proctor, R. W. (2015). Transfer of learning in choice reactions: The roles of stimulus type, response mode, and set-level compatibility. *Memory & Cognition*, *43*, 825–836. https://doi.org/10.3758/s13421-015-0518-2

Yamaguchi, M., & Proctor, R. W. (2009). Transfer of learning in choice-reactions: Contributions of specific and general components of manual responses. *Acta Psychologica*, *130*, 1–10.

Yamaguchi, M., & Proctor, R. W. (2012). Multidimensional vector model of stimulus-response compatibility. *Psychological Review*, *119*, 272–303. https://doi.org/10.1037/a0026620

Yang, Y., Zhuo, Y., Zuo, Z., Zhuo, T., & Chen, L. (2024). The asymmetric transfers of visual perceptual learning determined by the stability of geometrical invariants. *eLife*, *13*, RP93959.