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Journal

Proceedings of the Annual Meeting of the Cognitive Science Society, 22(22)

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Publication Date

2000

Peer reviewed

Constraints of Embodiment on Action Coordination

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Abstract

One consequence of the embodiment of cognition is that a single cognitive system may use fast internal mechanisms to coordinate conflicting actions in real time performance. In contrast, two different cognitive systems engaged in joint action have to resolve similiar conflicts via the environment. A tracking paradigm was used to investigate the coordination of conflicting actions in individuals and groups. The main question was whether and how persons engaged in joint action would exploit the perceivable environmental outcomes of their partner´s actions to adjust their own actions with respect to a jointly desired state. Groups performed worse than individuals, initially, but they achieved the same level of performance after some training. Groups improved because conflicting results of the partner´s actions were taken into account when members of the pair produced their own actions. This led to the emergence of an agreed-upon environmental location, around which, group members coordinated their action effects. The results are consistent with the view that the special requirements of social interaction may have fostered the development of higher cognitive functions.

Varieties of Embodiment

During the past decade, more and more researchers have become interested in the notion of embodied cognition (A. Clark, 1997; Port & van Gelder, 1995; Varela, Thompson, & Rosch, 1991). This approach has arisen largely out of dissatisfaction with the earlier notion of a central, disembodied symbol-manipulation system that is buffered from the environment via sensorimotor systems. In contrast, the Embodied approach stresses both, the importance of sensorimotor processes in cognitive functioning, and the close, dynamically supportive couplings that exist at all times between organisms and their environments.

Despite their common ground, different versions of the Embodied approach take issue with different aspects of the symbolic approach. In its most radical form, which is advocated by proponents of Dynamical Systems Theory (Port & van Gelder, 1995; Thelen & Smith, 1994), embodied cognition constitutes a rejection of representationalism as a whole, and conceptualizes cognition in terms of dynamic organism-environment couplings, exclusively. Less radical versions also stress the dynamic, organism-environment couplings, yet retain the notion of internal representation in order to account for the fact that certain biological systems are able to produce actions that are directed toward objects not currently present in the immediate environment (Ballard, Hayhoe, Pook, & Rao, 1997; A. Clark, 1997). Given that these representing systems are assumed to have emerged due to the possibilities they afforded action production, proponents of this version often claim cognitive functioning to be constrained in one way or another, by the functioning of the sensorimotor system (e.g. the formation of concepts, (Barsalou, 1999; Lakoff & Johnson, 1999)).

The present research takes this notion as its starting point, and addresses its implications for action coordination. This is because, to date, embodiment has focused primarily on the individual cognitive system and its continuous environmental couplings. Members of many species, however, especially humans, often engage in joint action with other members of their species. Though some may consider social interaction just another example of environmental interaction, it may be the case that special requirements of joint action placed certain constraints on action production. Such constraints may have served, historically, to shape the structures and processes that came to be embodied in evolving cognitive systems (Mead, 1934; Vygotsky, 1978). The present research addresses these constraints.

Individual and Joint Coordination of Conflicting Actions

A major function of action control in an individual organism is to select proper actions to obtain a desired impact on the environment (Prinz, 1997). If there are conflicting action alternatives, some internal mechanism may resolve the conflict (Anderson, 1990) and the motor system can be adjusted according to the action selected.

The situation is quite different when the action alternatives are distributed across two different cognitive systems that are engaged in joint action. Following a definition by H. H. Clark (1996), by a joint action we denote an action "that is carried out by an ensemble of people acting in coordination with each other" (p. 3). This implies that the individuals in the ensemble try to achieve a common goal. However, the intention to achieve a common goal does not protect the ensemble from encountering conflicts, especially when each system has only one of many action alternatives at its disposal.

To illustrate, imagine a situation in which two people drive a car together on a straight road. They can neither see

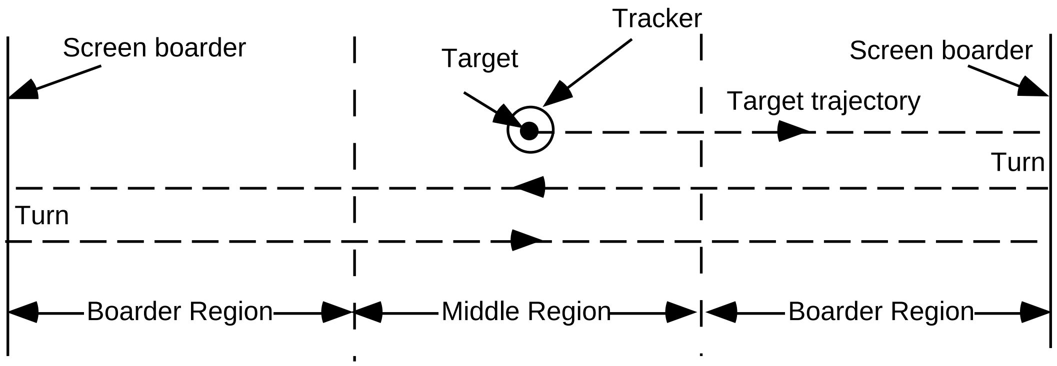


Figure 1: Illustration of experimental paradigm (vertical positions of target and tracker do not change in the actual task).

nor speak to one another. Person G controls the gas and person B, the brakes. As long as the car does not need to stop, there is no conflict, G acts and B does nothing. Now imagine a situation in which the ensemble encounters a traffic light. If the traffic light is green, no change is needed. If the traffic light is red, G has to stop acting and B has to start acting. Hence, this situation requires G and B to coordinate their actions according to an anticipated point at which they want to bring the car to a full stop. Conflicts may arise with respect to the point in time at which G stops and B starts acting, and as a consequence the ensemble may give gas and brake at the same time during a certain time interval. Hence, the car may well stop at a point that was intended neither by G, nor by B.

It is very unlikely that an individual in the same situation would carry out both actions at the same time even if different feet were used for giving gas and braking. An internal mechanism would select between the action alternatives in advance, instead of carrying out two conflicting actions at the same time. In the joint action example, conflict resolution is necessarily linked to noticeable changes in the environment, at least initially. Hence, if the situation requires braking, and B decides to start braking early, G will only know of that decision after perceiving that B has started to brake.

The aim of our research is to investigate how individuals and groups optimize their performance when conflicts arise in real time action coordination. Our main hypothesis is that persons engaged in joint action will use perceivable outcomes of the other´s actions to dynamically adjust their own actions with respect to a commonly desired future state. Individual performance can be used as baseline to determine how the same conflict is dealt with within a single cognitive system.

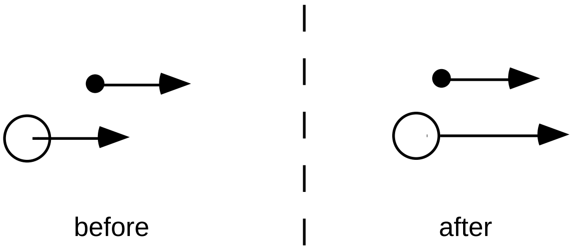
Experimental paradigm

We use a tracking paradigm for our studies. Generally, in tracking tasks one has to control a tracker so as to minimize the distance between the tracker and the target. The tracker is controlled by means of simple and clearly defined actions, e.g. hand movements or keypresses. The standard task requires minimal anticipation of future events and no conflict arises between alternative actions. For our study, we developped a different type of tracking task. In this task, anticipation of future events is crucial, and conflicts between two different action alternatives arise in a clearly defined manner. Figure 1 illustrates this task.

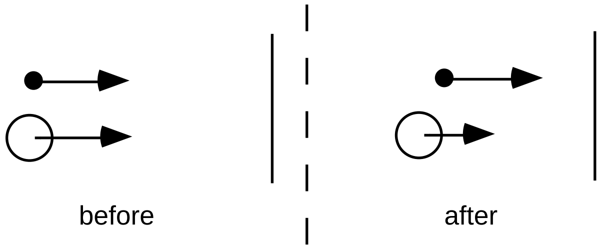
A target moves across the computer screen horizontally with constant velocity. As soon as it reaches a border of the screen, it changes its direction abruptly and moves back towards the other border, changes its direction again, and so on. The task is to keep a tracker on the target by controlling its velocity with two keys. When the tracker is moving to the right, hitting the right key accelerates it by a constant amount and hitting the left key decelerates it by the same amount. When the tracker is moving to the left, hitting the left key accelerates it and hitting the right key decelerates it. To illustrate, if the right key has been pressed five times, the left key will have to be pressed five times to bring the tracker to a full stop. Within the middle region, tracking performance can be optimized by decreasing the immediate error, as in most tracking paradigms. For instance, if the target is moving to the right and the tracker is left of the target, accelerating the tracker by a right keypress is the only reasonable action to be carried out (see panel a, in Figure 2).

The situation is different within the border regions. In these regions, a conflict arises between two alternative strategies. The first alternative, i.e., trying to stay on target as long as possible, will minimize the immediate error up until the point at which the target changes its direction. Afterwards, a large error will arise because tracker velocity can only be changed gradually. Several keypresses will be needed to stop the tracker and more will be needed to gain velocity in the opposite direction. During this interval, the target will continue moving in the opposite direction, constantly increasing the distance between itself and the tracker. Thus, trying to minimize immediate error will create an extremly large future error.

The second alternative is to slow down the tracker before the target turns. In this case, the immediate error will be *increased* to prevent future error. This is the case because the target continues to move toward the border as the tracker decelerates with each keypress. Using the latter strategy is the only way to improve performance within the border region, especially when the target moves fast and the impact of each keypress on the velocity of the tracker is low. Within this context, we refer to keypresses that decrease immediate error as compensatory presses, and those that that increase immediate error in order to reduce future error, as anticipatory brakes (see panel a, and b, in Figure 2).



a) Effect of a compensatory button press.



b) Effect of an anticipatory button press.

Figure 2: Illustration of the effects of compensatory and anticipatory keypresses (in the actual task target and tracker are horizontally aligned).

To investigate conflict resolution in individuals and groups we used two versions of the task that differed in one single aspect. In the individual condition each person controlled both keys, in the group condition each person controlled only one key. Hence, in the individual condition, the conflict between minimizing immediate vs. future error arises within *one* cognitive system, while in the group condition it arises between *two* cognitive systems. As a consequence, individuals may solve the conflict by use of fast internal mechanisms, while groups have to use certain aspects of the environment to act out the conflict overtly. Thus, in the group condition, the only way to better coordinate conflicting actions and thereby improve performance is to focus on changes in certains aspects of the environment that result from the other person´s actions. Regularities in these changes can then be used to adjust one´s own actions with respect to the commonly desired future state.

Predicitions

The nature of the present paradigm affords the measurement of several dependent variables that characterize performance, the extent and timing of the anticipatory strategy, and certain environmental anchors to which coordination can be linked. In the following, we will describe the rationale for using each of these variables, and derive predictions for the individual and group condition, in turn.

Performance

To characterize performance, we use the absolute distance between tracker and target at the time of each button press as an error measure. Our prediction is that the error should be lower for individuals, initially, because individuals coordinate conflicting actions by using fast internal mechanisms, whereas groups can only use perceivable changes in the environment, in their attempt to coordinate conflicting actions. Hence, groups should need more time to coordinate, which in turn should deteriorate real time performance, initially. However, if persons in a group are able to integrate some aspect of the environment that characterizes their partner´s actions into their individual planning, the difference in error between individuals and groups should largely decrease.

Extent and timing of anticipatory strategy

Anticipatory brakes. The extent to which the anticipatory strategy is employed within the boundary regions can be defined as the proportion of anticipatory brakes (see Figure 2, panel b) occurring in that region. We predict that the anticipatory brake rate will be greater for individuals than for groups, because once individuals have decided to prevent future error, they will be less likely to switch back to the conflicting action that reduces immediate error. In contrast, coordination requires overt action within groups. Therefore, the person who is responsible for reducing immediate error will quite likely produce actions that interfere with the anticipatory actions of the other person. The anticipatory brake rate should increase in both, individuals and groups, as they become more familiar with the task, because employing an anticipatory strategy is the only way to reduce overall error.

Decision point. One way in which the person responsible for anticipatory braking in a group can compensate for conflicting actions of the other is to take them into account, when timing her or his own actions. This should lead to earlier initiation of anticipatory braking in the group condition. The decision point, by which we denote the position of the tracker at the time of the first anticipatory brake, can be used to test this hypothesis. It should be further removed from the border in the group condition than in the individual condition.

Environmental anchors

Location of turn-around points. By the turn-around point we denote the most extreme tracker location during each run of the target from one side of the screen to the other. If the target turns at the right border, the turn-around point is the maximal screen position of the tracker, if the target turns at the left border the turn-around point is the minimal screen position of the tracker (see Figure 1). To make turn-around points on both sides of the screen comparable they are expressed in terms of the absolute distance to the respective border. At the turn-around point the tracker comes to a full stop and is accelerated towards the other direction by the following keypresses. The turn-around point is functionally important because it can be used as an environmental anchor to which the goal of minimizing overall error can be tied. The reason is that, given a certain velocity of the target and a certain impact of each keypress, the optimal turn-around point will be relatively invariant.

If, as predicted, groups pick a decision point that is further removed from the boarder, groups may achieve a turn-around point that is as equally removed from the border as the one achieved by individuals. Otherwise, it should be less removed from the border in the group condition. In the individual and the group condition as well, the turn-around point should become further removed from the border in later trials because overall error can be decreased by turning the tracker earlier.

Homogeneity of turn-around points. In the individual condition the turn-around points at the left and the right border are the result of actions taken by the same person. The situation is different in the group condition. Whenever the target approaches the right border, the person who is in charge of the left key is responsible for anticipatory braking and the person who is in charge of the right key is responsible for compensating immediate error. Whenever the target approaches the left border, each group member must assume the opposite role (the compensator becomes the anticipatory braker, the anticipatory braker becomes the compensator).

Hence, the prediction for individuals is that they will pick similiar turn-around points at both borders. Therefore, the absolute difference between the left and the right turn-around point in a trial should be relatively small and not change substantially across consecutive blocks. In contrast, two persons in a group should pick more heterogeneous turn-around points initially. However, in later trials they may coordinate their actions by „agreeing“ on a certain turn-around point. Therefore, we predict a huge initial difference that substantially decreases in later blocks.

Method

Participants Forty-five paid participants took part in the experiment. Fifteen participants were assigned to the individual condition. Thirty participants were assigned to the group condition.

Material and Procedure Upon entering the lab, participants were informed of the nature of the task. They were instructed individually in the group condition. Afterwards, they were seated in front of a computer monitor at a distance of 80 cm and were asked to put on a set of headphones. Participants in the group condition were divided by a partition. They could neither see one nor talk to one another. However, each was provided with a separate computer monitor, and all events taking place during the experiment (e.g. the movements of the tracker and the movements of the target) were presented simultaneously on both monitors. Thus, the only information shared was the task display and the acoustic feedback accompanying each keypress.

At the beginning of each trial target and tracker were displayed in the middle of the screen for 500 ms, the tracker being superimposed on the target. Thereafter, the target started moving either to the left or to the right with constant velocity. After reaching the border, it abruptly began travelling back in the opposite direction. There were three such target turns during each trial. The initial velocity of the tracker was zero. Each left keypress accelerated the tracker to the left and each right keypress accelerated it to the right. Right presses triggered a 600 Hz tone and left presses triggered a 200 Hz tone. Participants in the individual condition controlled both keys. In the group condition, each member was given an individual control panel consisting of one key. Keypresses of the individual on the left side of the partition resulted in tracker acceleration to the left, while those of the other individual produced tracker-acceleration to the right. The experiment consisted of 3 blocks of 40 trials each.

Results and Discussion

Performance

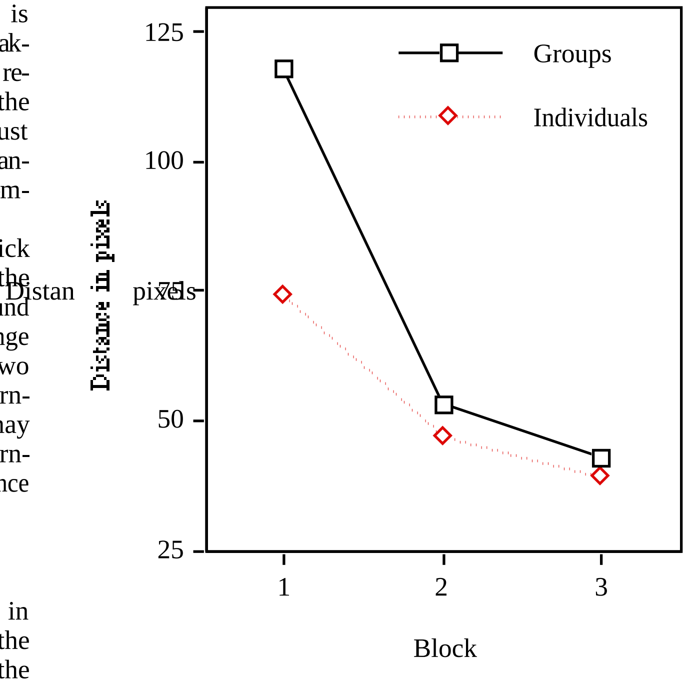


Figure 3: Individual and group performance across consecutive blocks

As can be seen in Figure 3, error decreased for individuals and groups across consecutive blocks. Hence, performance improved in individuals and groups. As expected, the error was much larger in the group condition during the first block. After the second block, group performance reached the level of individual performance. A 2 x 3 ANOVA with the factors Experimental Group (Individuals and Groups, between) and Block (1, 2, and 3, within) revealed a significant main effect for the Block factor, $F(2, 56) = 24.2$, $p < .001$, and a significant interaction between Experimental Group and Block, $F(2, 56) = 3.5$, $p < .05$

Anticipatory brakes

The anticipatory brake rate was computed as the number of anticipatory brakes in a border region divided by the overall number of button presses in that region. Figure 4 shows the results. The anticipatory brake rate increased over consecutive blocks for individuals and groups. As expected, the anticipatory brake rate was constantly lower in the group condition than in the individual condition.

A 2 x 3 ANOVA with the factors Experimental Group (Individuals and Groups, between) and Block (1, 2, and 3, within) revealed significant main effects for the Group factor, *F*(1, 28) = 9.4, *p* < .01, and the Block factor, *F*(2, 56) = 26.1, *p* < .001. There was no significant interaction.

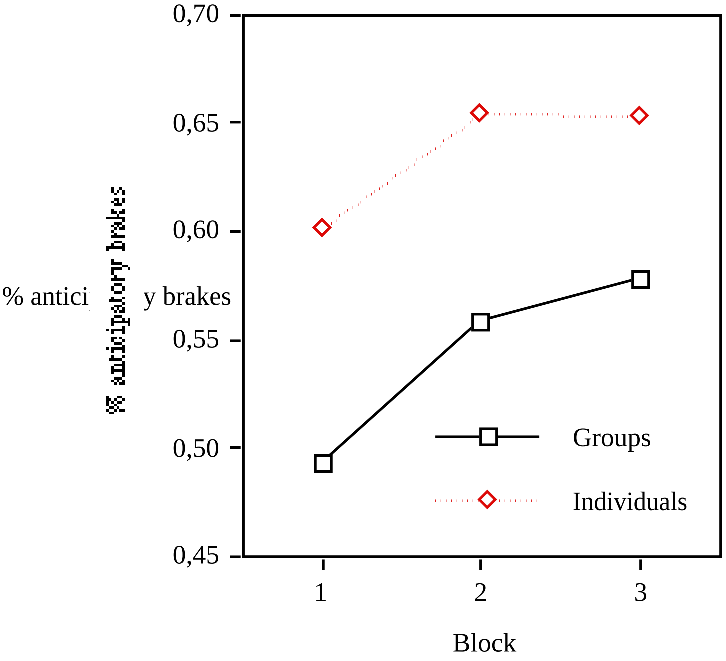


Figure 4: Anticipatory brake rate in individuals and groups across consecutive blocks

Decision points

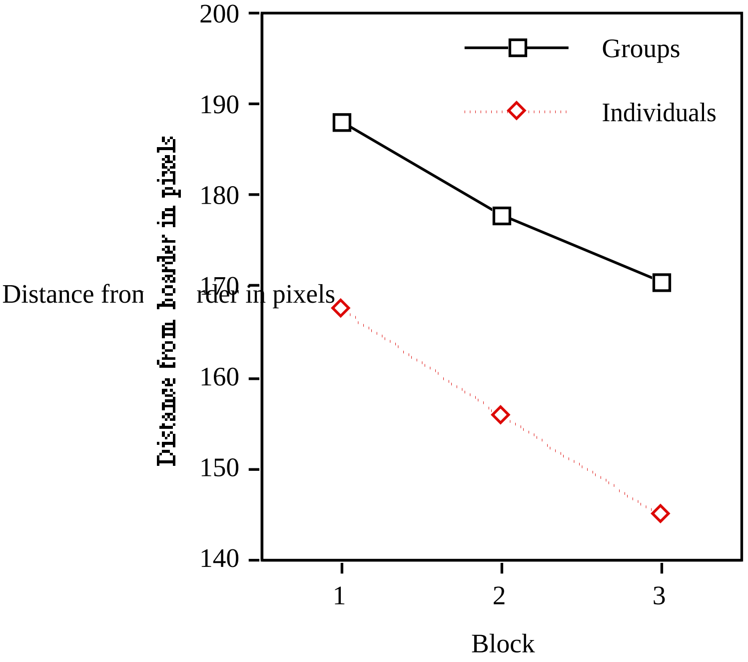


Figure 5: Decision point in individuals and groups across consecutive blocks.

Figure 5 shows the result of the analysis of decision points, i.e., the distance of the tracker from the border at the time of the first anticipatory brake.

As they became more familiar with the task, individuals and groups moved the tracker closer to the border before they initiated the first anticipatory brake. This result indicates that resolving the action conflict took less time in later trials. As expected, in the Group condition the tracker was always further from the border, when the first anticipatory brake occured. A 2 x 3 ANOVA with the factors Experimental Group (Individuals and Groups, between) and Block (1, 2, and 3) revealed a significant main effect for the Group factor, *F*(1, 28) = 4.6, *p* < .05, and the Block factor, *F*(2, 56) = 11.2, *p* < .001. There was no significant interaction.

Location of turn-around points

Figure 6 illustrates the results of the analysis of turn-around poins, i.e., the absolute distance between the border and the point at which the tracker stopped before changing its direction.

Distance fron rder in pixels

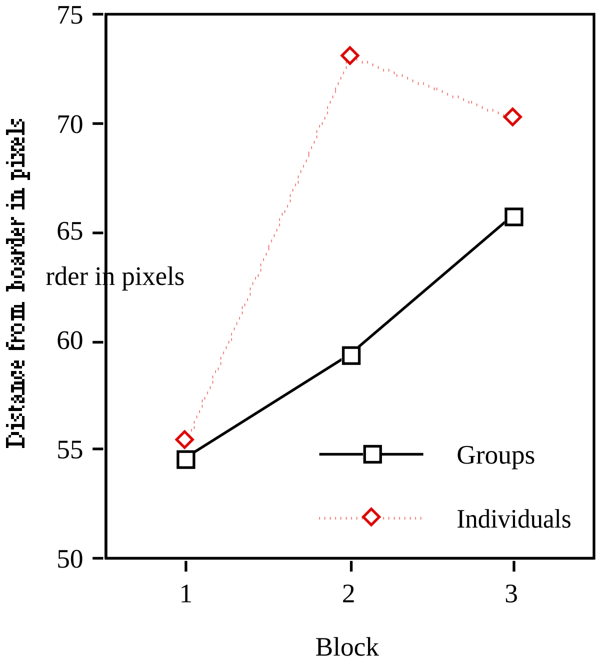


Figure 6: Turn-around point chosen by individuals and groups across consecutive blocks.

As expected, in later blocks, the turn-around point became further removed from the border in both experimental conditions. Individuals produced a sharper increase than groups from the first to the second block. A 2 x 3 ANOVA with the factors Experimental Group (Individuals and Groups, between) and Block (1, 2, and 3) revealed a significant main effect for the Block factor, *F*(2, 56) = 11.6, *p* < .001, and a marginally significant interaction, *F*(2, 56) = 2.62, *p* = .08. The difference between individuals and groups was highly significant during the second block, *t* = 4.21, *p* < .001. The main effect of experimental group was not significant.

Homogeneity of turn-around points.

Figure 7 depicts the results of the analysis of the homogeneity of turn-around points.

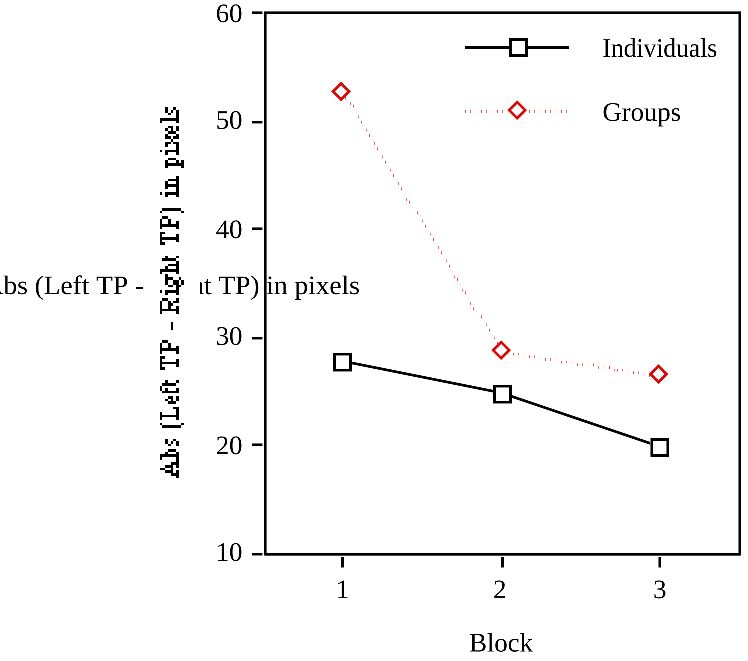


Figure 7. Homogeneity of turn-around points in individuals and groups across consecutive blocks.

Individuals turned the tracker at roughly the same point on both sides of the screen, i.e., there was only a small difference of about 30 pixels. The homogeneity of turn-around points increased only slightly across consecutive blocks. In contrast, persons in a group picked heterogeneous turn-around points, initially. In later trials, the selected turn-around points which were almost as homogeneous as those chosen by individuals. A 2 x 3 ANOVA with the factors Experimental Group (Individuals and Groups, between) and Block (1, 2, and 3) revealed a significant main effect for the Block factor, $F(2, 56) = 8.25$, $p < .001$, and a significant interaction, $F(2, 56) = 3.30$, $p < .05$. There was no significant main effect of experimental condition.

Discussion

Individuals as well as groups are able to learn to coordinate conflicting actions with respect to a common goal, in real time, but groups clearly perform worse initially. The results illustrate robustly the different constraints that groups must deal with as they attempt to coordinate conflicting actions. To be sure, both groups and individuals improve by employing the advantageous anticipatory strategy. This is reflected in the fact that both gave rise to increases in anticipatory braking, as well as increases in the distance of the turn-around point from the border. Within groups however, this anticipatory strategy had to be worked out via the environment. Thus, it seems that group members take into account the potentially interfering actions of their partner by starting to brake at a further distance from the border. In addition, they seem to "agree" on a certain point in space at which to turn the tracker, as is evidenced by increased homogeneity of the turn-around point. As soon as such an agreement has been reached, both the homogeneity of the turn-around points and the degree of error become almost indistinguishable from that produced by individuals.

The additional constraints on action coordination that arise within groups, as opposed to within an individual, are due to the fact that embodied cognitive systems have to make use of the environment to coordinate conflicting actions. This need to “lean” on the environment in group action, may constitute a selective pressure responsible for the phylogenetic emergence of cognitive systems capable of integrating the anticipated effects of another system’s actions, into the planning of their own. This capability, in turn, may have afforded the emergence of the ability to produce environmental effects whose intended outcome was not solely entailed in the effect itself, but rather, in the impact that effect was anticipated to have upon the planning abilities of other cognitive systems. In short, the group need to collaborate through the environment may have driven the embodiment and environmental projection of symbol systems. This is consistent with Clarks (1996) assertion that the essence of language is joint action.

Acknowledgements

We thank Rüdiger Flach for helpful comments, and Irmgard Hagen, Eva Seigerschmidt, and Patric Bach for their help in collecting the data.

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