Short Report

Haptically Linked Dyads

Are Two Motor-Control Systems Better Than One?

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We report performance of haptically linked dyads on a target-acquisition task, comparing it with that of the same individuals when they performed the task individually. In the dyad condition, a subject's limb motion responds to the output of two motor-control systems—the subject's own and his or her partner's—which might be expected to complicate motor planning and efficient task execution. However, task completion times indicated that dyads performed significantly faster than individuals, even though dyad members exerted large task-irrelevant forces in opposition to one another, and despite many participants' perceptions that their partner was an impediment.

A much earlier study of teams using a pursuit rotor (Wegner & Zeaman, 1956) found a similar performance increment. Since that study, there has been little research on physically coupled dyads (Sallnas & Zhai, 2003; Shergill, Bays, Frith, & Wolpert, 2003), which we find surprising because performance of motor tasks requiring the physical coordination of two or more people must be an ancient human ability. Bimanual coordination has some similarities to dyadic coordination, but controlling two arms with a single nervous system admits different strategies and constraints (Swinnen & Wenderoth, 2004).

METHOD

Thirty students (10 men; 2 left-handed; ages 18–24) from Northwestern University's psychology participant pool participated with informed consent. In each session, 2 randomly selected subjects stood on opposite ends of a two-handled rigid crank (Fig. 1), separated by a curtain. They were asked not to speak but were aware of each other's presence. An overhead LCD projector displayed targets and messages for each subject onto a white circular disk affixed to the crank; the messages instructed one or both subjects to grasp their handles. The task was to move a mark on the disk (a black line aligned with the position of the handle) into the target as quickly as possible and hold it there until a new target appeared (a random delay of 700–1,700 ms). In the dyad condition, the projector displayed corresponding targets for the 2 subjects, so that they were presented with the targets simultaneously and (because of their mechanical coupling) completed the task simultaneously. The target changed color when the handle was properly within it. Each target subtended 6° of the disk, which had a diameter of 50.5 cm, so that the target corresponded to 2.6 cm at the perimeter of the disk. The distance between consecutive targets was $70^\circ \pm 10^\circ$ (30.9 ± 4.4 cm). Five sixths of the trials required a reversal of handle rotation from the previous trial; in one sixth of the trials, handle motion in the same direction as on the previous trial was required (catch trials). The catch trials, the variation of the target position, and the variation of the delay before a new target appeared were included to prevent subjects from adapting to a predictable pattern. We discarded catch trials and the trials immediately following them from our analyses. To encourage subjects to move as quickly as possible, we displayed a motivating performance measure after each trial.

Each block of trials (consisting of 120 target acquisitions) could be performed by an individual or by a dyad. In the individual condition, the nonparticipating subject could see the apparatus move, but could not see the other person or the target. Pairs of subjects were selected randomly from the participant pool, and members of the same pair were given the same appointment time for the session. Half of the pairs completed a block of trials first as a dyad and then one block each as individuals (AB, A, B), whereas the other pairs completed blocks of trials first as individuals (A, B, AB). For all pairs, the sequence was repeated (e.g., A, B, AB, A, B, AB). The physical apparatus was identical in the individual and dyad conditions, except that the small rotational inertia of the crank ($0.113\ kg{*}m^2$) was doubled in the dyad condition. Each subject's force and the

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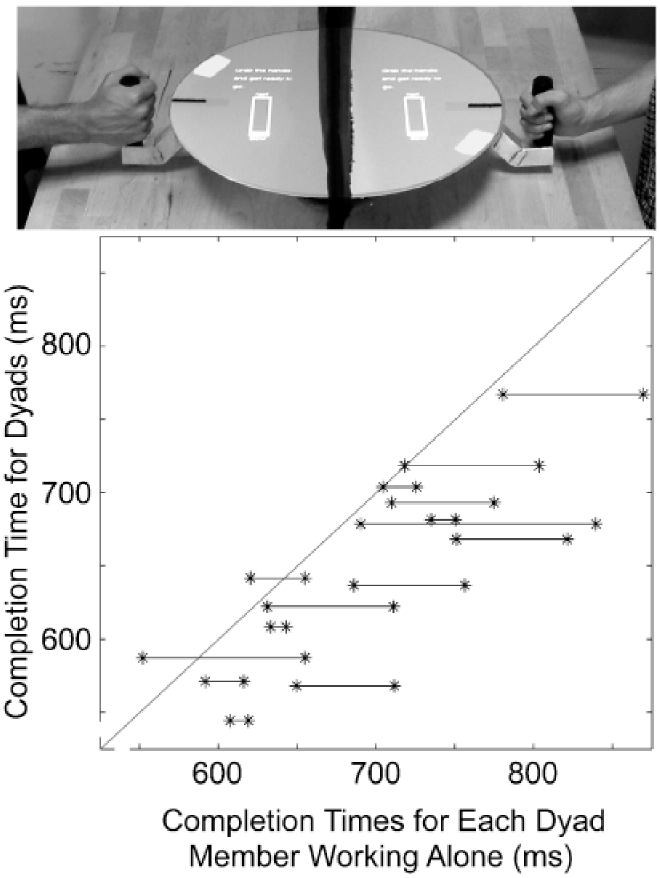

Fig. 1. The experimental setup and results. As illustrated in the photograph, 2 subjects shared a single rigid crank so that their limb motions resulted from their partner's actions as well as their own. In the dyad condition, the subjects were simultaneously presented with equivalent targets and attained their target simultaneously because their motions were physically linked. In the individual condition (not shown), 1 subject performed the same target-acquisition task, while the other subject stood by. Subjects were aware of each other's presence despite the curtain, in both individual and dyad trials. The graph shows the average completion time for each dyad and the average completion times for the same 2 individuals performing alone (the asterisks). A horizontal line connects the values for the 2 members of each dyad. Symbols to the left of the diagonal thus represent individuals who outperformed their dyad (only 2 of 30).

crank's motion were recorded at 1000 Hz. Each session took less than 30 min and included a total of 720 trials (480 involving each subject). After completing the session, the subjects were asked if they noticed any difference between the blocks of trials and, if so, what was different.

RESULTS AND DISCUSSION

Two people in repetitive physical contact tend to escalate their force levels (Shergill et al., 2003). Perhaps similarly, the subjects in this study exerted a greater force in the dyad condition than in the individual condition: Force magnitude averaged 2.1 times larger in the dyad condition, with most of this additional force being expended in opposition to the partner, rather than contributing to accelerating the crank.

Despite increased force levels, the average completion time for dyads was 54.5 ms less than the average of the completion times for the same individuals working alone, paired-samples $t(15) = 5.95$, $p_{rep} > .99$, $d = 0.81$. The average completion time for individuals was 680 ms. Figure 1 shows the average completion time for each dyad, and the average completion times for the constituent members of each dyad when working alone. Improved dyad performance was established quickly when a dyad began to work together (within 20 trials), for both the A, B, AB sequence and the AB, A, B sequence. The increased forces we observed in the dyad condition might suggest a faster subject pulling along a slower one. However, the average completion time for dyads was 24.8 ms less than the average completion time of the faster members of each dyad working alone, paired-samples $t(15) = 2.76$, $p_{rep} = .96$, $d = 0.39$. The expressed perception of some subjects that they found a partner to be an impediment was not justified by the actual performance measure.

The force profiles recorded show that when working together, many dyads developed a new strategy that was not available to the members when they were working alone: Dyads specialized such that one member contributed more to acceleration and the other to deceleration. Because the only interaction between subjects was haptic, they must have used this channel to develop a cooperative strategy. We speculate that haptic interaction between individuals is a form of communication that may be used to develop a cooperative strategy for motor tasks requiring coordination with another person.

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