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How Much for Joint Action? Assessing the Cost of Moving Together

Riley Mayr[1], Tehran Davis[1], Michael A. Riley[1], Tamara Lorenz[123]

[1]Department of Psychology, University of Cincinnati
[2]Department of Mechanical and Materials Engineering, University of Cincinnati
[3]Department of Electrical Engineering and Computer Science, University of Cincinnati

When performing an action, humans must expend energy. Every individual has their own most mechanically and energetically efficient movement frequency, often called their natural frequency (Holt, Hamill, & Andres, 1991; Turvey, Schmidt, Rosenblum, & Kugler, 1988). However, when moving together in coordination with another person, which is often beneficial because a dyad can achieve more than what is possible on the individual level (Isenhower, Richardson, Carello, Baron, & Marsh, 2010), people "detune" from their natural frequency and tune to each other's in order to adapt to each other's movements (Lorenz, Vlaskamp, Kasparbauer, Mörtl, & Hirche, 2014; Richardson, Campbell, & Schmidt, 2009). This detuning also happens when people walk with each other. Wagnild and Wall-Scheffler (2013) showed that when individuals with different preferred walking speeds walk next to each other, they do not only adjust their walking frequency, but also their walking speed, which was hypothesized to lead to an increased level of energy expenditure due to the deviation from their natural frequency. In contrast, when people slow down their movements, their actions may actually be less costly (Berret & Jean, 2016). Joint action, therefore, could entail a group to expend more, or less, energy while working together to accomplish a range of tasks. Surprisingly, the cost of interpersonal detuning, and hence the energetic cost of joint action, has never actually been measured. Therefore, the purpose of this study was to determine energy consumption during joint action, and to determine if joint action comes at a cost of expending more energy than individual action, or in contrast if detuning to each other may actually reduce the individual's energy consumption and hence provide another added benefit for the individual.

Method

In order to address these questions, we recruited twelve students (6 females and 6 males, age 18-41 years) at the University of Cincinnati. Participants were paired to create six dyads. All participants were healthy and right-handed, reporting no physical limitations.

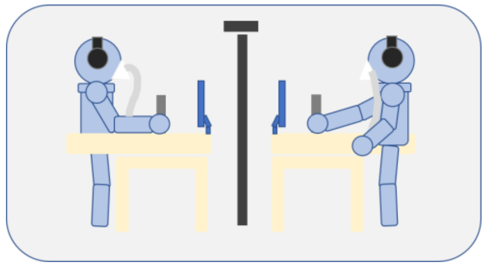

Figure 1. Experimental Setup

To test whether being engaged in joint action alters energy consumption, an apparatus simulating a two-person crosscut saw was crafted. The "saw" used throughout the entire experiment consisted of two physically decoupled sleds that utilized spring-induced resistance on both the push and pull actions, simulating the friction caused from using a real saw (see *Figure 1*). A custom program was written in the Unity Creation Engine to guide participant actions and run the experiment. The movement over time of each participant's "saw"-handle was tracked using an IR-based passive motion tracking system (Motion Analysis Corporation Kestrel system). Individual saw-movements were then used to drive the progress made in sawing a virtual (Unity-rendered) log, which was shown to each participant individually on a screen.

We measured energy consumption by comparing the Respiratory Exchange Ratio (RER) between different actions (Lighton, 2008). RER is a continuous measurement that compares the amount of carbon dioxide produced in metabolism relative to the oxygen used and is a common measure of energy expenditure. To collect energy expenditure data, each participant was connected to an expired gas analysis system set from BIOPAC that continuously calculated their respective RER throughout each trial.

Three different action scenarios were created to induce three different levels of jointness. First, in the Single Action (SA) condition each person sawed alone. They viewed a single log and a saw with a single handle moving vertically down the log, showing task progress. In the Pseudo Joint Action (PJA) condition, participants worked together to saw one log, twice the size as the SA log, without any ability to see or hear their partner—only a shared log and a bigger saw with two handles alerted them of their partner's actions. For both the SA and PJA conditions, a blackout curtain shielded participants from visually exchanging information and noise cancelling headphones playing white noise kept them from hearing each other move. Finally, in the Factual Joint Action (FJA) condition, participants sawed together as in PJA, but the curtain and headphones were removed to grant participants informational access to their partners—participants could see and hear one another's movements.

The only differences between the SA and both joint action conditions (PJA, FJA) were the instructions and the visual feedback participants received on the computer screen during each trial. In the SA condition, participants had their own progress meter and were told they were sawing their own log. In the PJA and FJA conditions, they shared a progress meter with their partner and were told that they were sawing each log together.

To start the experiment, participants approached the tables with the "saws" on them and were given a platform to stand on if they were not tall enough to comfortably reach the handle. Breathing masks were put in place and adjusted for comfort. The experiment consisted of a total of 30 trials, 10 in each condition (SA, PJA, and FJA). The first 10 trials were always SA, allowing for participants to establish their own comfortable working pace. In each condition, participants had to fully saw the log in two halves, which was controlled by total distance moved on the saws. The trials ended when each individual moved the required distance of 35 m. Next were two 10 trial blocks (trials 11-20 & 21-30) counterbalanced per pair in either PJA followed by FJA or vice versa. Since the participants worked together in these trials, the trials ended when the sum of the pair's movements exceeded the required distance of double the SA trials, 70 m. Time between trials in each block was minimized to keep the participants' heart rates up, and breaks of 5-7 minutes were taken between blocks to allow RER values to return to the recorded resting rate.

Results and Discussion

To prepare the data for analysis, all trials within each condition for each pair were averaged to determine an average RER per condition per participant. A mixed-design repeated measures ANOVA was calculated on RER with the within-subject factor joint action condition (SA, PJA, FJA), and the between-subject factor person. There was a significant main effect for joint action condition, $F(1.27,13.88) = 20.42$, $p < .001$ (Greenhouse-Geisser corrected) (see *Figure 2*). Bonferroni-corrected post-hoc analyses revealed a significant decrease in energy expended in PJA conditions compared to SA conditions ($p = .005$). Participants used significantly less energy in FJA conditions compared to SA conditions ($p = .001$). FJA required significantly less energy than PJA ($p = .009$). This result demonstrates hat RER differs depending on the level of jointness of an activity in that less energy is necessary when one is truly engaged in a joint activity (FJA compared to PJA). It seems that the benefit of joint action goes beyond seeking out help or seeking support from others to complete a task beyond what one could accomplish alone. In fact, joint action seems to be beneficial for managing one's own energetic resources. There was also a significant main effect between persons, $F(1,10) = 6.52$, $p = 0.29$, pointing towards a systematic difference in the setup. No significant interaction effect was found.

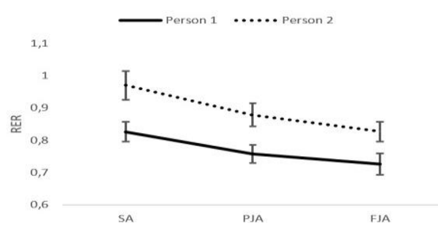

Figure 2. RER per condition; Error bar is standard error of the mean.

These results are preliminary, and more research must be done in order to understand the reasons for the energetic benefits of joint action, especially whether or not interpersonal synchrony has beneficial effects on energy expenditure. Furthermore, it needs to be investigated if the systemic difference between people is an effect of the small sample size, the very sensitive hardware calibration, or if there is in fact an effect of task sharing, i.e. a leader-follower dynamic that can explain the difference in metabolic cost between persons. Keep in mind that the total amount of physical work each person performed per trial remained constant throughout the entire experiment, but there was a significant reduction in overall expenditure in the JA conditions compared to the solo condition. Additionally, since the energy consumption in FJA is significantly reduced beyond that of PJA, the informational exchange between partners must be supporting this effect. Thus, it can be speculated that the information-induced coupling and resulting potential rhythmicity of the action is a causal factor for reduced energy consumption in joint action.

In conclusion, our work shows that there are significant differences in energy expenditure between levels of jointness during a joint activity. We showed that it matters energetically if people are truly engaged in joint action, i.e., if the joint action is based on information exchange that allows for mutual adaptation, or if the activity is a pseudo joint action, i.e. an activity that is only performed conjointly at the same time, but without mutual information exchange and potential co-adaptation between the agents.

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