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Temporal and Spatial Parameters in Interpersonal Coordination of Jumping Rope Elite Boys

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Keywords

Kinematics Parameters
Prediction
Joint Action

Abstract

Background: Coordination depends on online performance, and online feedback supports the successful coordination of individuals in joint implementations.
Objective: The purpose of the research was to investigate temporal and spatial parameters in interpersonal coordination.
Methods: A single study was applied with 14 jumping rope elite boys (13-18 years). The subjects performed the jumping rope activity for 8 months so that they could do them properly and without online visual feedback. A Vicon motion analysis system with six infrared cameras was used to record three-dimensional movements of the legs and rope whirling.
Results: The results of the one-way ANOVA showed that with enough practice, even in the absence of feedback, landing position (spatial parameter) and hand-foot time deviation, timing variation in rope whirling, and landing time (temporal parameter) of joint groups will reach to equal level while a significant difference was observed in jump height (spatial parameter) and movement time (temporal parameter) between individuals ($P \leq 0.05$).
Conclusion: So, increasing task difficulty, amount and sustainability of inter-personal coordination will increase. according to individual and joint tasks constraints following cases can be occurred: i) increasing joint task demands, ii) increasing amount and sustainability of interpersonal coordination, iii) change in joining individual's power.

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Introduction

In order to be able to perform all the different activities properly, we must coordinate the performance of different muscles and joints. In other words, for a special movement, the muscles and joints in a certain direction or compensation movement must be involved, and this is the definition of coordination. In fact, the coordination of body and organs is associated with environmental objects and events (Magill & Lee, 1998). Supporters of dynamic systems believe that expert action is accomplished when the nervous system practically limits the muscles and joints cooperation to a joint action so that one can act according to the requirements of the position. One may develop this functional cooperation called "coordinative structure" which can be existed naturally, during training or experience. In addition to making coordinated mathematical models, supporters of dynamic systems theory put emphasis on the interaction with perceptual and motor variables. Important perceptual information includes invariability and uniformity of the environment that determines the probable behaviors. Dynamic positions of motion-control system interact with perceptual and motor variables to produce proper motion patterns, and also lead to achieve the purpose of the action in those situations

(Magill & Lee, 1998). However, in many situations, the goal is not only coordination between different organs, but also, two or more individuals must come together to achieve a joint goal (Knoblich, Butterfill, & Sebanz, 2011). Individuals coordinate their actions with another person in a range of everyday activities and skill domains. Optimum common performance needs the continuous anticipation of an adaptation to each other's actions, especially when movements are spontaneous rather than preplanned movements (Varlet, Nozaradan, Nijhuis, & Keller, 2020). Humans work together to achieve common goals (Buccino et al., 2001; Sebanz, Bekkering, & Knoblich, 2006) and the Successful joint actions requires exact temporal and spatial coordination. Joint tasks require two or more people for (intentionally or spontaneously) coordination to reach the joint goal (D. C. Richardson & Dale, 2005; D. C. Richardson, Dale, & Kirkham, 2007; Sebanz et al., 2006). For example, in joint tasks, the performance of one is entirely linked to the other person's operation, and often, successful implementation of every one ability depends on his ability to recognize and respond to the behavior of the other person. The ability to engage in bilateral relationship and its maintenance is adjusted by cognitive (Wilson & Knoblich, 2005) and perceptual-motor (Shockley, Santana, & Fowler, 2003; Stoffregen, Giveans, Villard, Yank, & Shockley, 2009) processes. Thus, the performance of two independent individuals and thus, two independent motor systems should become coordinated for the joint actions (Wolpert, Doya, & Kawato, 2003). The studies showed that two key mechanisms are used in temporal coordination. First, the tendency to the temporal pairing of interpersonal movements which is called "Entrainment" (M. J. Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; M. J. Richardson, Marsh, & Schmidt, 2005; Schmidt, Bienvenu, Fitzpatrick, & Amazeen, 1998; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). Second, motion synchronicity allows individuals to predict their partners' action based on predictive models in their own motor system (Keller, Knoblich, & Repp, 2007; Knoblich & Jordan, 2003; Ramnani & Miall, 2004; Sebanz & Knoblich, 2009; Wolpert et al., 2003). Experimental studies show that interactions between humans have a great deal in common with coordinated behaviors between limbs. Coordination and motor synchrony are essential features of many human movements in joint tasks such as clapping, walking in the crowded, playing music, group exercising or dancing (Ellamil, Berson, Wong, Buckley, & Margulies, 2016). Interpersonal coordination is based on similar processes in which the internal models of the person are used by simulating the other person's action (as if the person does it himself) to predict others' performance (Wolpert et al., 2003). In fact, there are many empirical evidences that the individual's motion system is activated when observing motion and motion execution (Brennan & Clark, 1996; Cross, Hamilton, & Grafton, 2006; Cross, Kraemer, Hamilton, Kelley, & Grafton, 2009) and imaging the other person's action (Grezes & Decety, 2001; Ramnani & Miall, 2004). The strength of this motor resonance is adjusted by the individual’s familiarity with the action (Casile & Giese, 2006; Knoblich & Flach, 2001), his expertise (Aglioti, Cesari, Romani, & Urgesi, 2008; Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005) and social relation to the executive person (Kourtis, Sebanz, & Knoblich, 2010b). In other hands, when two or more people want to achieve a joint goal, they often have to plan their performance exactly based on their partner's performance, which is particularly important in team disciplines (Della Gatta et al., 2017) Empirical pieces of evidence for collaborative actions has been provided for action mimicry. Tsai et al. (2011) showed that compatibility relations between observation and performance in teamwork can overrule compatibility relations at the level of individual contributions to a joint action (Kourtis, Woźniak, Sebanz, & Knoblich, 2019). Subsequent studies have corroborated the role of We-Representations for achieving successful interpersonal synchronization (Sacheli, Arcangeli, & Paulesu, 2018) and examining the level of individual engagement and common control in joint actions (van der Wel, 2015). How individuals coordinate joint actions while they have no direct information about the time and the way of their partner’s performance? A strong coordination strategy is "predictability" as much as possible because it allows individuals to rely on and build common ground (Brennan & Clark, 1996; Carston, 1999). So far, most pieces of evidence for the "predictability" of individuals come from those tasks that do not require close temporal coordination. Since, the temporal and movement coordination is of the success factors in rhythmic and team skills such as jumping rope, the following question can be mentioned; can we minimize the temporal and spatial parameters of individuals in two-person and group activities by enough practice and removal of feedback, to achieve "predictability" and the success in rhythmic implementations?

Method

This study was an applied and descriptive analytical study based on objective. The research project was a single-stage case study (Light & Warner, 1983).

Subjects

Fourteen rope elite boys (13-18 years) participated in pairs of two. They had at least 3 years of experience in the field of jumping rope (Temprado, Swinnen, Carson, Tourment, & Laurent, 2003) and could perform skills on different levels (1, 2, 3, 4 and 5). They were selected among available boys and, filled the Edinburg laterality inventory, to determine a dominant right foot. The two participants of each pair were familiar with each other. Each subject practiced with his exercise partner in all the trails. All subjects gave prior informed consent for participation in the project. The experiment was conducted to conform the standards of the Helsinki declaration and in accordance with local ethical committee guidelines.

Data Gathering Tool

Six synchronized infrared cameras were placed circumferentially around subjects, and since both subjects did the tasks back-to-back, the Three-Dimensional filming was performed by three cameras on each side. In order to record the trajectory of the rope, three reflective labels were stuck at the distal ends and on the middle of the rope. A reflective marker (diameter 9.5 mm) was applied on the toe to help judge the takeoff and landing phase during jumping rope (Chen et al., 2013). The experimental setup consisted of a ground designed with specific areas for the beginning and end of the different jumping rope tasks. These marked positions included five rectangles (30×50 cm) on each side of a row. One end was marked as the starting area, where the participants stood before each experiment. Two headphones were applied to remove the rope noise and announce the start alarm to the subjects.

Implementation Method

The experiment consisted of two parts, as follows:

1. Each subject performed the jumping rope task with the right foot.
2. Both subjects had to perform the task of "jumping rope with two feet", simultaneously.

The individual jumping rope task was performed to understand the basic level of subjects' jumping and their familiarity with the task (Vesper, van der Wel, Knoblich, & Sebanz, 2013). Before testing, the agenda was given to the subjects, and simultaneous landing (simultaneous landing of two individuals in the joint action task) was taught. There was no additional training for the individual groups. The same procedure was followed for efforts in each of two parts; in all two parts, subjects stood out of jumping rope zone in the starting area, and they then jumped 30 cm forward (the first rectangle). In the joint task, each individual knew the landing area of his partner beforehand, so he could plan for the start time and jump height. After a random fore-period of 1.7, 2, or 2.3 seconds, a short sound (440 Hz, 100ms) was broadcast as a starting signal, and the subject started jumping rope. After the jump, subjects returned to the starting position and waited for the next task.

During the experiments, after providing the necessary explanations to participants in connection with the research and wearing appropriate clothing, the reflective markers were positioned on the target points by double-sided bonding tape. Marking a Three-Dimensional system was used. Six infrared cameras (Vicon Mxt40s, Oxford Metrics Ltd, Oxford, UK). They were capable of 120 frames per second acquisition. All data were then low-pass filtered (fourth-order, zero-phase lag, Butterworth, 10 Hz cut-off frequency) (winter, 2009). Then, critical data points for each person's/leg's trajectory were determined by a customized semiautomatic Matlab (R2008b). Finally, the numerical data were transferred to Microsoft Excel for formatting and subsequently for analysis in SPSS program.

Statistical tests

Shapiro-Wilk test was used to determine the normality of data; and parametric tests were used based on the normality of data distribution. Levene's test was used to assess the equality of variance, and finally, one-way ANOVA was used for data comparison and evaluation of interpersonal coordination in different distances, and Tukey's post hoc test was used to determine statistically significant differences among groups. The significance level was considered $p < 0.05$. Data were analyzed using SPSS version 19 software (SPSS Inc., Chicago, IL, USA). These data points were the time of trial start, the time of takeoff for jumping and, the time of landing on the ground after the jump. From these data points, five dependent variables were calculated. First, "movement time" (MT) or "foot jumping cycle" is the time from takeoff to landing. Second, "jump height" (Varlet et al.) is the maximum value of the vertical dimension in the height between takeoff and landing. Third, the absolute value of "Hand-Foot time deviation" is calculated by subtracting the timing variation in whirling from the MT value. Fourth, the "timing variation in whirling" is calculated as the absolute value of the difference between 60 and rope whirling cycle (Rope whirling cycle is the rope marker reaching the ground). Fifth, "landing position" (POS) is the longitudinal position at the point of landing. Finally, asynchrony is the absolute difference between the landing times of the two subjects in a pair (joint tasks). From all six dependent variables, difference scores were computed as described above.

Results

In this study, the spatial parameters (landing position and jump height of individuals during joint jumping rope at the same time) and temporal parameters (movement time, Hand-Foot time deviation, timing variation in rope whirling, and landing time difference between two individuals) were analyzed for interpersonal coordination. After enough practice and without feedback, the one-way ANOVA showed that there was a significant difference between the movement times of individuals at different distances. ($P \leq 0.05$) (Table 1).

Table 1. Movement time at different distances (30, 60 and 90 cm).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.042	8	0.005	2.962	0.005
Within Groups	0.205	116	0.002		
Total	0.247	124			

Tukey's post hoc test results showed significant relationships. There was a significant difference between the movement times of individuals in jumping rope task with a distance of 30 cm for both subjects compared with performing the same task with distances of 30 and 90 cm ($P \leq 0.05$), while there was no significant difference compared to other tasks condition ($P > 0.05$).

There was a significant difference in the movement times of individuals in jumping rope task with a distance of 60 cm for both subjects compared to performing the same task with a distance of 30 cm for one subject, and 90 cm for the second subject ($P \leq 0.05$), while there was no significant difference compared to other tasks ($P > 0.05$).

There was a significant difference between the movement times of individuals in jumping rope task with a distance of 90 cm for both subjects compared to performing the same task with a distance of 30 cm for one subject, and 90 cm for the second subject ($P \leq 0.05$), while there was no significant difference compared to other tasks ($P > 0.05$). There was a significant difference between the movement times of individuals in jumping rope task with a distance of 30 cm for one subject and 60 cm for another one compared to performing the same task with a distance of 30 cm for one subject, and 90 cm for the second subject ($P \leq 0.05$), while there was no significant difference compared to other tasks ($P > 0.05$).

There was a significant difference between the movement times of individuals in jumping rope task with a distance of 30 cm for one subject and 90 cm for another one compared to performing the same task with a distance of 30 cm for one subject, and 60 cm for the second subject ($P \leq 0.05$), while there was no significant difference compared to other tasks ($P > 0.05$).

Also, according to the results of one-way ANOVA, there was a significant difference between jump heights in different distances ($P \leq 0.05$ (Table 2).

Table 2. Jump height at different distances (30, 60 and 90 cm).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	13480.089	8	1685.011	2.034	0.048
Within Groups	96110.868	116	828.542		
Total	109590.957	124			

In the meantime, the results of LSD post hoc test showed that to investigate the significance of relations, there was a significant difference between the jump heights of individuals in jumping rope task with a distance of 30 cm for both subjects compared to 30-90 and 30-60 cm task performance ($P \leq 0.05$), while there was no significant difference compared to other tasks ($P > 0.05$).

There was a significant difference between the jump heights of individuals in jumping rope task with a distance of 60 cm for both subjects compared to performing the same task with a distance of 30 cm for one subject, and 90 cm for the second subject, and also, for 60 cm for one subject, and 90 cm for the second subject ($P \leq 0.05$) while, there was no significant difference compared to other tasks ($P > 0.05$).

There was no significant difference between the jump heights of individuals in jumping rope task with a distance of 90 cm for both subjects compared to other tasks ($P > 0.05$).

There was a significant difference between the movement times of individuals in jumping rope task with a distance of 30 cm for one subject and 60 cm for another one compared to performing the same task with a distance of 30 cm for one subject, and 90 cm for the second one, and also, with a distance of 60 cm for one subject, and 90 cm for the second one ($P \leq 0.05$) while there was no significant difference compared to other tasks ($P > 0.05$).

There was a significant difference between the movement times of individuals in jumping rope task with a distance of 30 cm for one subject and 90 cm for another one compared to performing the same task with a distance of 90 cm for one subject, and 30 cm for the second one, and also, with a distance of 60 cm for one subject, and 90 cm for the second one ($P \leq 0.05$) while, there was no significant difference compared to other tasks ($P>0.05$).

The results of one-way ANOVA showed that there was no significant difference between Hand-Foot time deviations of individuals in different distances (Table 3), ($P>0.05$).

Table 3. Hand-Foot time deviation at different distances (30, 60 and 90 cm).

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.101	8	0.013	1.229	0.288
Within Groups	1.197	116	0.010		
Total	1.299	124			

It was also observed that there was no significant difference between timing variations in rope whirling of individuals in different distances (Table 4) ($P>0.05$).

Table 4. Timing variation in rope whirling at different distances (30, 60 and 90 cm).

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.075	8	0.009	1.186	0.314
Within Groups	0.915	116	0.008		
Total	0.990	124			

Table 5. Jump length at different distances (30, 60 and 90 cm).

	Sum of Squares	DF	Mean Square	F	Sig.
Between Groups	3834.376	8	479.297	1.501	0.164
Within Groups	37033.912	116	319.258		
Total	40868.288	124			

Then, a significant difference was observed between the jump lengths of individuals in different distances (Table 5) ($P \leq 0.05$).

And finally, it was observed that there was no significant difference between the times of landing at different distances ($P > 0.05$).

Discussion and Conclusion

The purpose of the research was to investigate temporal and spatial parameters in interpersonal coordination. The results indicated that with enough practice, landing position (spatial parameter) and Hand-Foot time deviation, timing variation in rope whirling, and landing time (temporal parameter) of joint groups reached an equal level while a significant difference was observed in jump height (spatial parameter) and movement time (temporal parameter) between individuals. Distance affected some performance parameters. People who jumped shorter distances coordinated with their partners by jumping longer and slower. Also, those who jumped for a longer period of time did not show any particular adjustment with their partner. The results show that people, who perform the easier part, are involved in movement simulating of their partner's jump (such as designing their own movement). This philosophy of jump adjustment has been derived and programmed based on the theories of "common assumption" of illustrated actions (Prinz, 1997). Correlation analysis showed that variability was less caused by increased intrapersonal coordination. The relationship was observed between low variability and high coordination when partners did independent tasks together and without the intention to coordinate.

In fact, these findings support the claim that the low variability is used as a coordination strategy to achieve the ability for prediction; these results were consistent with the findings of Vesper et al. (2011) (Vesper, van der Wel, Knoblich, & Sebanz, 2011). Following the previous evidence of motor simulation during action prediction (Kilner, Vargas, Duval, Blakemore, & Sirigu, 2004; Kourtis, Sebanz, & Knoblich, 2010a) and imaging (Grezes & Decety, 2001; Ramnani & Miall, 2004), our findings suggest that motor simulation during joint action planning is a temporal predictive service. Participants knew exactly how far their peers had to jump, so they began to simulate their peers' movements, allowing them to land at the same time. This result is consistent with the findings of some researchers (Song & Nakayama, 2009))Knoblich & Jordan, 2003). (Welsh & Elliott, 2004). The effects observed in the performance phase were occurred due to active simulation of partners jumping during motor programming, meaning that individuals could integrate simulation of different parts of a common action, and this is consistent with Wesper et al.'s findings (2014) (Vesper, Knoblich, & Sebanz, 2014). Also, increasing task difficulty, amount and sustainability of interpersonal coordination will increase. Increasing demand for joint tasks, amount and sustainability of interpersonal coordination will increase, and the pairing power of individuals will be changed according to constraints of individual and joint tasks. Interpersonal coordination is influenced by the nature of the task and the constraints imposed from data (Ramenzoni, Davis, Riley, Shockley, & Baker, 2011).

it is necessary to know the other's performance for the development of programs effectively and this is what researchers (Knoblich & Jordan, 2003) achieved in their study. Duch et al. (2017) and Wesper et al. (2017) showed that awareness of others performance is an essential condition for group work to anticipate each other's performance and thus, do optimal performance (Dötsch, Vesper, & Schubö, 2017; Vesper et al., 2017). These results are also consistent with the results obtained by (Sebanz & Knoblich, 2009) on the prediction in the joint action: What? Who? And where? The researchers were trying to know how people manage the prediction of the others performance (which is a basis for joint action tasks). They found out that how a joint coding of perceived and performed actions may allow a performer to predict the type, time, and place of action. The aspect of "What" refers to the prediction of the type of action and the intention of the action by the others. The aspect of "Who" is vital for all joint actions that need close temporal coordination. The aspect of "Where" is important for the simultaneous coordination of actions because performers must distribute a joint space effectively. We argue that although a joint coding of actions was performed and perceived alone, but it is not enough to engage in joint action, it provides an identification policy to consolidate its action with others.

The results of this study are important both theoretically and practically. Theoretically, the results of the research increase the little information in the literature on strengthening interpersonal coordination in the absence of any feedback. Also, it investigates the involvement of each person based on spatial parameters (jump height and landing position) and temporal parameters (movement time, Hand-Foot time deviation, timing variation in rope whirling). Also, due to the various results in the literature, this research could remove the ambiguity in prediction research, and become a beginning point of such investigations. Practically, the possible positive results of this research can be used in education (physical education in schools, sports centers) and the Organization of Physical Education, which are the main custodians of sport in the country, in preparation of athletes at different levels from beginner to championship.

Thus, regarding the importance of interpersonal coordination in rhythmic activities, and optimal planning, and tightening the exercises by removing online feedback, individuals can predict the movements of the teammate(s) and success in the group activities.

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