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Optimal Cooperation In Joint Action Tasks

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by

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ABSTRACT

Joint action can be succinctly defined as an action in which two or more individuals work together for a common outcome. There have been numerous studies on the mechanisms behind joint action, but none have focused on the existence of optimal cooperators. The present study investigated if optimal cooperators, individuals who are better partners in joint action tasks, exist in the population. Individuals completed a virtual bar balancing task in dyads in which four hands were used to control the bar. Based on success rate, significant differences in performance variables were found. This study provides empirical evidence that some individuals are better partners in joint action tasks, and that optimal cooperators exist in the population. Further research should be conducted to confirm these results and explore the implication of these finding in rehabilitation techniques and robotic programming.

Table of Contents

List of Tables

CHAPTER 1: INTRODUCTION

1.1 JOINT ACTION DEFINED

The foundations of all human societies are built on collaborative activities and joint action is an indispensable part of everyday life. Joint action has been defined as a "social interaction whereby two or more individuals coordinate their actions in space and time to bring about a change in the environment" (1). Actions ranging from high fives to band performances are considered forms of joint action. In these activities it is impossible to understand an individuals' action independently of the actions of others (2). Working together has been an essential part of the evolution of man and the study of joint action is gaining attention because much of human information processing and behavior occurs in social situations. The performance of successful joint action requires the abilities to share representations, predict actions and to integrate predicted effects of own and others' actions (3).

Cooperation in humans begins shortly after birth with human infants interacting with other people in coordinated, turn-taking sequences (4). Warneken et al. (5) found that human children ages 18 to 24 months could successfully participate in cooperative problem solving activities and social games with the help of an adult partner. While there has been a lot of research done recently on joint action and the mechanisms underlying it, there has not been any research done to determine if "optimal cooperators", i.e. individuals who are better at completing joint tasks than others, exist, and if they do, what makes them successful in specific joint action engagements or in joint action engagements in general.

1.2 Models of Joint Action

Current research on joint action has focused on the perception, action and cognitive control necessary to perform such tasks. The mechanisms required to perform a joint action depend on the task. Joint-action tasks can be divided into either planned coordination or emergent coordination. In emergent coordination, action is independent of any joint plans or common knowledge. Two separate individuals may start to act in a single coordinated effort because common processes in the individuals are driven by the same cues and motor routines (6). Emergent coordination can occur between individuals who do not plan to perform actions together such as pedestrians falling into the same walking patterns or mimicking one another's mannerisms during conversation.

In planned coordination, the individual's behavior is caused by representations that specify the desired outcomes of joint action and the individual's own part in achieving this outcome. The individual may consider others' motives, thoughts and perspectives (7). For example, two people lifting a heavy piece of lumber might pay particular attention to when to begin the initial liftoff the lumber, the force and height required to complete the lift and how the other individual plans to hold the lumber.

Prediction relies on motor simulations whereby internal models specify the immediate consequence of one's actions. Internal predictive models are used for individual motor control and are continuously updated by comparing the actual and predicted consequences of ones actions (8). It has been demonstrated that people are able to anticipate the future course of others' actions based on their own motor experiences

(9). Findings from these studies suggest that joint action coordination should be better the more accurately interacting partners can predict the timing of each other's actions.

1.3 Brain Networks Involved in Joint Action

fMRI studies have investigated which brain areas are activated during the execution of joint-action tasks (10). There appears to be a clear distinction in the brain activity and performance of healthy children and children with autism spectrum disorders in being able to complete joint tasks (11). An assumption can be made that these results also translate to adults, however there have not been studies conducted on the differences of healthy individuals in completing joint actions.

The neurological basis for joint action has been explored in different ways with similar results. A study used fNIRS to measure brain activation in real life tasks in which participants performed table setting tasks either alone or with a partner (12). When comparing brain activation of the joint task to the solo task, results showed a greater activation of the left bilateral inferior parietal lobe (IPL), the orbitofrontal cortex, the medial and superior temporal gyrus, and the occipital cortex in the joint task. Of these areas, the difference in IPL activation was the strongest due to the IPL being used for the processing of observed and executed actions (12)

These results support an fMRI study which investigated the difference in brain activity in a virtual ball balancing task between participants acting alone or with the help of partner (13). They found that in the joint condition there was a higher activation of the human mirror system (MNS), specifically the bilateral IFG and the IPL.

Newman-Norlund et al. (11) provide further evidence that the MNS is an integral part to joint action by studying the differences in joint action between healthy children and children with autism spectrum disorder (ASD). Children with ASD have an inability to internally model actions. This ability allows individuals to simulate the actions of others in their own sensory-motor system (14). This makes it difficult for ASD children to predict the actions of others over time. Children with ASD are impaired in predicting their partner's response and they do not delay the timing of initiating the task to synchronize with their partner.

1.4 STUDY AIMS

The study on planned coordination was approved by University of South Carolina's IRB. In joint action tasks it is necessary for people to represent the goal and the tasks needed to perform these goals. In the joint task of picking up and moving a bench, both individuals must represent their task of lifting one side of the bench in such a way that the other person can synchronize with them.

In this study subjects participated in a virtual bar balancing task in which two people, lifting cooperatively, lift a ball into a specified target area. This study was designed to test the hypothesis that some people are inherently better than others at performing joint action tasks.

CHAPTER 2: METHODS

2.1 PARTICIPANTS

Ten healthy adults between the ages of 18 and 30 with normal or corrected to normal vision participated in the experiment (*M*= 18.4; SD = 0.517). Subjects were randomly assigned into two groups of five. Participants were required to fill out a form that screens for common signs of unknown neurological conditions and were excluded if they suffered from neurological abnormalities (epilepsy, motor disability).

2.2 APPARATUS AND SETUP

A version of the virtual bar-balancing task exploited by Newman-Norlund et al. (12) was used. The task was programmed in Presentation 9.90 (Neurobehavioral Systems, USA). To complete the task, subjects used an analog joystick (Logitech F310 GamePad) to control the vertical movement of a bar on the computer screen (2005 13” Apple MacBook).

Participants were seated next to each other on adjustable chairs approximately two feet in front of a table in which a computer screen was placed at eye level (figure 2.1 A). Participants were able to control the bar by moving the left and right analog joysticks forward in the sagittal plane. Lateral movements of the joystick did not affect the position of the bar.

2.3 TASK/PROCEDURE

Before the experiment, participants received instructions about the purpose of the task, i.e. to lift the bar into a target area consisting of two horizontal lines in the upper part of the screen (figure 2.1 B). It was explained that, in order for the trail to be successful, the bar had to be lifted to the target area, while keeping the ball in the middle of the bar on the target. The bar had to be held in the target area for 2 seconds continuously, without dropping the ball. Participants received feedback when the bar was positioned correctly in the target area (bar turned bright white). After the bar remained in the target area for 2 s the trial would finish. Participants were not allowed to talk during the task. Participants jointly lifted the bar with four hands, with the left hands of both subjects controlling the left end of the bar with the left joystick and the right hands of both subjects control the right end of the bar with the right joystick. Each pair performed 15 trails together. At the start of each trial a visual countdown of 3 seconds is displayed on the screen in the center of the bar counting down to one. In cases where the joysticks were moved before the countdown was finished, a message indicating the detection of a 'false start' was presented on the screen and the trial was restarted. A trial would finish when subjects managed to keep the bar inside the target area for 2 s or when the ball dropped off of the bar.

2.4 DATA COLLECTION

All dependent variable values were recorded using Presentation (Neurobehavioral Systems, USA). Reaction time was measured by calculating the time elapsed between the go signal and the joystick rotation exceeded a baseline measurement that was taken before the countdown. Reaction times were calculated per trial for each participant separately as the first movement of either the left or the right joystick. Bar rotation was assessed by calculating the absolute bar rotation angle in degrees relative to horizontal from the time of movement onset until trial end. The ball error was determined by calculating the average absolute distance between the middle of the ball and the middle of the bar. Furthermore, for each trial the total time was calculated during which the stimulus bar was positioned correctly in the target area, (time in target area). Success-rate was determined by calculating the number of successful trials as a percentage of the total number of trials administered and the trial time was calculated from the time elapsed from the go signal until either successful completion of the task or when the ball was dropped.

All statistical analyses were conducted in Excel (Microsoft Office, 2011).

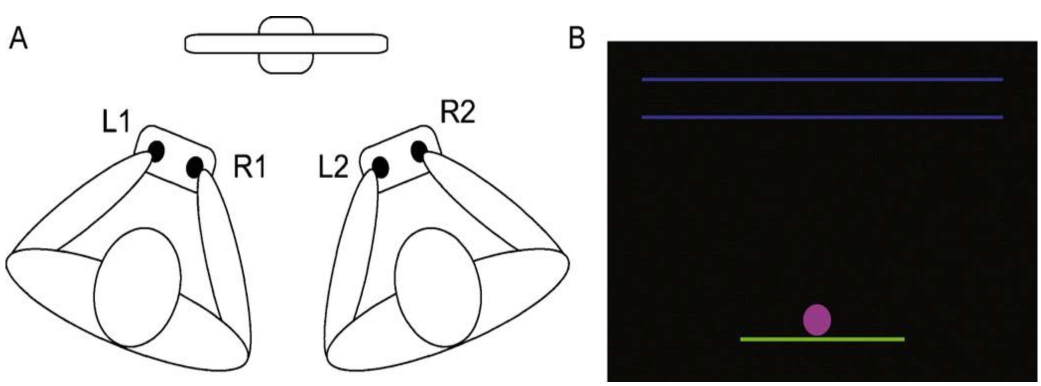

Figure 2.1 – *(A) Shows the experimental setup. Both subjects could control the lift of either side of a virtual bar. (B) A picture of the ball-balancing task. Subjects were asked to keep the ball in the middle of the bar and lift into the target area that is signified by the two horizontal lines at the top of the screen.*

CHAPTER 3: RESULTS

3.1 STATISTICAL ANALYSIS

For Statistical analysis, the participants were ranked by success rate and the participants with the top five rates were grouped together (the optimal cooperators) and the five with the lowest success rates were grouped together. For each variable a one-tailed t test was run in excel (Microsoft Word 2011) with a significance level of 0.05.

Analysis shows there is a significant difference in the scores for time in target area between the top 5 group (M=1.67, SD=0.71) and the bottom 5 group (M=1.31, SD=1.01); $t(588)=3.31$, $p < 0.001$.There are also significant differences for trial time duration scores[top 5 (M=8.50, SD=5.89),bottom 5 (M=9.48, SD=5.60); $t(588)=2.35$, $p = 0.02$], reaction time scores [top 5 (M=0.78, SD=0.90), bottom 5 (M=1.50,SD=3.86); $t(588)=3.31$, $p = 0.001$], success rate [top 5 (M=0.86, SD=0.35), bottom 5 (M=0.64,SD=0.48); $t(588)=3.31$, $p < 0.001$], bar rotation error [top 5 (M=8.94, SD=6.71), bottom 5 (M=10.73,SD=8.64); $t(588)=3.10$, $p = 0.003$].

There was not a significant difference in the scores for ball error for the top 5 (M=1.09, SD=5.61) and the bottom 5 (M=1.11, SD=6.98) groups; $t(588)=0.70$, $p = 0.49$.

3.2 DATA

A summary of the results for all participants can be seen in table 3.1. The participants were ranked based on their success rate and then placed into two groups based on their success rate. The participants with the top five success rates were grouped together to make comparisons to the bottom five. Table 3.2 shows the means and standard deviations for the two groups.

3.3 Lift Distribution

To examine the lift distribution, the relative contributions of each actor's inner and outer hands during the joint task were examined. This was done to determine if participants favored lifting one side of the bar. Figure 3.1 shows the typical lift distribution pattern that occurred during the trials. As the trials progressed, two general trends emerged between the partners completing the joint task. As seen in table 3.3, the participants used significantly more force on the joystick located on the same side the computer screen they were sitting on (dominant hand M=54.35, SD=11.00; opposite hand M = 45.65, SD=11.00, $t(588)=3.10$, $p=0.008$). This pattern is seen in figure 3.1 where player one was sitting on the left side and player 2 on the right. This is evidence of the social Simon effect described in the study conducted by Simon and Rudell (15) and confirmed by Sebanz, Knoblich et al. (16) and Stoit, van Schie et al. (11).

The second trend that can be seen in table 3.3 is one player on average tended to significantly account for a greater percentage of the combined force than the other (player 1 M=41.45, SD=0.21; player 2 M=58.55, SD=0.21, $p < 0.001$). Figure 3.1 clearly shows player 1 using more total force than player 2. Interestingly it appears what made the participants with the highest success rates so successful were that they used more or less force depending on their partner. This is evidence that optimal cooperators are more willing to adapt their strategy to accomplish the joint task successfully. This is consistent the findings of Bosga et al. (17) where dyads adopted a leader-follower strategy in an interpersonal task.

3.4 Qualitative Pairwise Comparison

Tables 3.4 and 3.5 show the dyad success rates for each group. On average, dyads were able to complete the task 75% of the time. The group 1 dyads that contained participants who were both in the top five in success rate had rates above 75% except for one. The dyad consisting of participants B and D had a success rate of 73%. Since each dyad only completed 15 trails, we would expect 11 or 12 successful trails on average so this dyad is right around the average.

Three of the four group 1 dyads containing participant C, who is in the bottom 5 of success rate, had much lower success rates than average. The exception was the dyad consisting of participants C and A, which had a 100% success rate. Interestingly, this is the only dyad involving participant C in which participant C did not have the lowest reaction time. Participant C would wait for A to do the most of the lifting and then C would come in to provide the last force needed to reach the target area. Since this dyad was the last trail for participant C, This may be attributed to the subject learning a new strategy based on previous trials that could be considered a threat to the internal validity of the experiment.

Looking at group two, only participant I was in the top 5 for success rate. When comparing dyads of participants that consisted of the two players grouped in the bottom 5, we find average dyad success rates well below the average of 75%. The highest success rate of these dyads was 66% by participants F and H. When we compare the dyads containing participant I, we find success rates well above the average with the lowest success rate of 86%. The drastic difference in these dyad success rates is the strongest evidence of the existence of an optimal cooperator. This data also confirms previous findings that some people, such as participant I, are better able to adapt their strategy to complete a joint task.

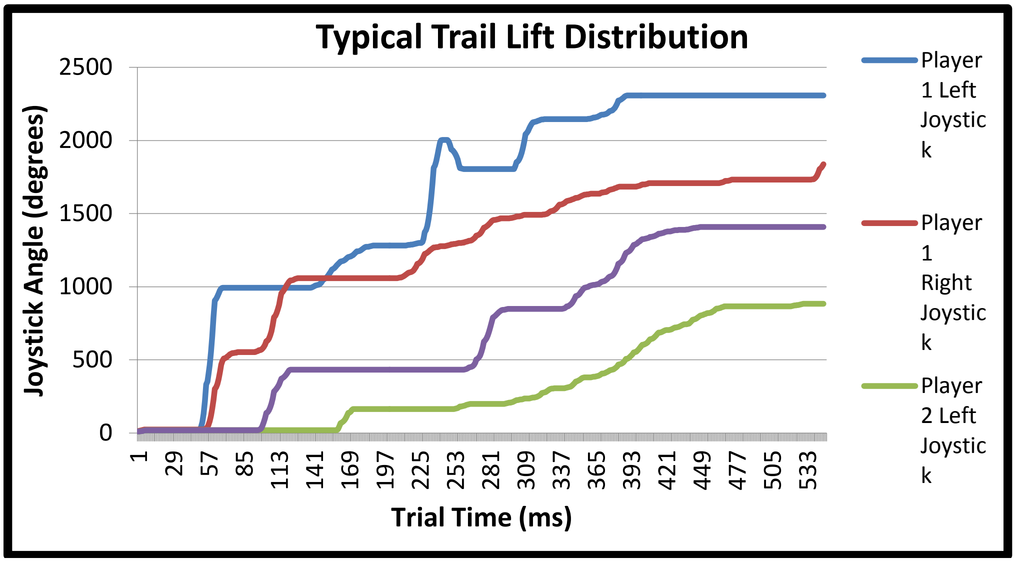

Figure 3.1 - *A comparison of the lift distribution between two participants completing the virtual bar balancing task. Each player favors the side they are sitting on and it can be seen that player one uses more total lift than player 2.*

Table 3.1 – Participant Performance Variables

Participant	Success Rate (%)	Time in Target Area (s)	Bar Rotation (degrees)	Ball Error (degrees)	Trial Time (s)	Reaction Time (s)
A	93	1.70	1.38	8.94	8.48	0.79
B	79	1.63	0.58	5.29	9.95	2.46
C	66	1.26	1.33	9.11	12.15	2.11
D	77	1.49	0.63	7.79	10.96	1.44
E	86	1.61	0.55	9.73	9.22	0.51
F	65	1.44	3.13	11.54	8.32	0.36
G	64	1.25	1.13	9.44	10.35	0.83
H	64	1.33	1.43	9.54	10.68	1.13
I	95	1.91	0.76	10.69	6.13	0.29
J	62	1.29	0.50	7.74	12.20	1.14

Table 3.2 - Performance Variable Means by Success Rate

Performance Variable	Success Rate Top 5		Success Rate Bottom 5	
	M	SD	M	SD
Success Rate (%)	86	35	64	48
Reaction Time (s)	0.78	0.90	1.50	3.86
Bar Rotation (degrees)	8.99	6.71	10.74	8.64
Ball Error (degrees)	1.10	5.61	1.11	6.98
Time in Target Area (s)	1.67	0.71	1.31	1.01
Trial Time (s)	8.49	5.89	9.47	5.60

Table 3.3 – Average Lift Distribution of Dyads

DYAD	Player 1 Left Hand Percentage	Player 2 Right Hand Percentage	Player 1 Total Force Percentage	Player 2 Total Force Percentage
A B	58	63	59	41
A C	51	51	73	27
A D	56	49	24	76
A E	55	54	32	68
B C	49	49	75	25
B D	51	54	70	30
B E	46	49	12	88
C D	40	45	25	75
C E	57	58	58	42
D E	76	66	40	60
F G	76	63	35	65
F H	38	44	35	65
F I	71	54	18	82
F J	29	69	46	54
G H	71	59	35	65
G I	61	57	40	60
G J	69	70	50	50
H I	44	47	34	66
H J	41	47	30	70
I J	42	45	38	62
AVERAGE	54.05	54.65	-	-

Table 3.4 – Group 1 Dyad Means for Performance Variables

Dyad	Time in Target Area (s)	Total Trial Duration (s)	Success Rate (%)	Bar Rotation Error (degrees)	Ball Error (degrees)	Reaction Time (1) (s)	Reaction Time (2) (s)
A B	1.63	8.63	80	11.18	48.30	1.06	1.06
D E	1.88	11.85	100	7.52	0.36	0.54	0.16
A D	1.74	5.25	93	10.56	0.73	0.31	1.11
A E	1.72	10.95	100	5.87	0.18	1.00	2.29
B D	1.61	4.37	73	10.60	2.73	0.52	0.71
B E	1.75	3.72	80	6.96	0.97	0.03	0.29
C D	0.71	9.68	40	15.16	1.95	2.07	0.96
C E	1.09	11.59	53	16.21	2.61	0.63	0.94
A C	1.72	11.38	100	6.15	0.70	1.12	3.09
B C	1.54	4.22	73	10.65	4.40	0.33	0.28

Table 3.5 – Group 2 Dyad Means for Performance Variables

Dyad	Time in Target Area (s)	Total Trial Duration (s)	Success Rate (%)	Bar Rotation Error (degrees)	Ball Error (degrees)	Reaction Time (1) (s)	Reaction Time (2) (S)
F G	1.00	12.64	47	9.43	0.94	1.97	2.16
F H	1.31	8.07	67	7.21	0.69	2.83	1.69
F I	2.10	16.08	93	4.99	0.08	7.74	0.63
F J	1.36	9.35	53	11.67	1.26	0.56	0.68
G H	1.24	8.70	53	13.80	1.94	1.14	0.83
G I	1.82	7.19	100	5.41	0.28	0.69	0.23
G J	0.95	9.20	53	12.99	0.79	0.53	0.42
H I	1.83	14.16	87	6.00	1.16	2.32	2.00
H J	0.91	7.01	40	16.30	2.24	0.71	0.51
I J	1.90	5.33	100	8.12	0.36	0.18	0.40

CHAPTER 4: DISCUSSION

4.1 IMPLICATIONS

While there has been no previous research on the human population to determine the existence of optimal cooperators, there is some evidence that they exist in the chimpanzee population. Chimpanzees are our closest evolutionary relatives, sharing 99.4% of our DNA (18). While it is clear that human collaborative skills are more evolved than that of the chimpanzee, they have the cognitive ability to participate in human like cooperative tasks and have shown collaborative behavior (19). Melis et al. (20) has demonstrated that chimpanzees not only recruit partners to complete certain tasks, but also appear to choose the more effective of two partners.

The purpose of this study was to determine if such optimal cooperators exist in the human population or if individuals exist whose performance is always poor compared to others. The analysis of this study shows evidence that optimal cooperators do exist as all but one performance variable was deemed significant.

To be successful in joint tasks, it is helpful for each agent to represent the other individual's task as well. Although it is not necessary for carrying out a joint task, it can improve the performance. It is worth investigating this area further in the human population due to evidence of representation found in a study conducted on chimpanzees (20). The subjects were presented with a food shelf that they could only access if two chimpanzees pulled on either end of a rope at approximately the same time. The Chimpanzees were able to do this but it is possible that the chimpanzee did not represent the other's task but instead realized they needed to inhibit pulling on the rope except when it was tensing, which occurred when the other was starting a pull. However by co-representing, it enables one to predict what others will do next.

If it can be further established that there are individual differences in healthy people performing joint tasks, research can focus on investigating the neural processes that cause these discrepancies, and how to improve the performance of individuals performing joint tasks. This information can also help with an important goal of engineers in the 21st century, the creation of robot control architectures capable of supporting joint action both with other humans and with other robots (21).

4.2 LIMITATIONS

One of the major limitations of this study was the population used. Participants were recruited from a university campus and all participants were either 18 or 19 years old. Also, there were only 10 participants and each pairing only completed 15 trials.

The results may also be affected by previous joystick experience. It could be that the participants who performed the best may be more skilled with using a joystick than those who had no experience. Since there were no baseline measurements of solo participant lifting performance, the possibility cannot be ruled out. Future studies might include a 'solo lifting condition' to eliminate this possible confound.

CHAPTER 5: GENERAL CONCLUSIONS

The present study found evidence that there is a difference in performance in joint action tasks between individuals, suggesting the existence of optimal cooperators. There were significant differences in most performance variables such as success rate, reaction time, time in target area, bar rotation and trial time. Qualitative analysis of lift distribution revealed that those who were most successful in completing the task were better able to adapt their lifting strategy to their partners. Although the study focused on a narrow portion of the general population, it is worth continuing research in joint action performance to help further rehabilitation techniques and provide advancements in robotic programming.

REFERENCES

1. Bekkering, H., Cuijpers, R., de Bruijn, E., Newman-Norlund, R.D., van Schie, H.T., & Meulenbroek, R.G.J. (2009), *Neurocognitive mechanisms supporting human interactions.* Topics in Cognitive Science.**1**, 340-352.

2. Marsh, K. L., Richardson, M. J., Baron, R. M., & Schmidt, R. C. (2006). *Contrasting approaches to perceiving and acting with others*. Ecological Psychology, 18, 1-37.

3. Sebanz, N., Bekkering, H., &Knoblich, G. (2006). *Joint action: Bodies and minds moving together.* Trends in Cognitive Science, 10, 70–76.

4. Trevarthen, C. (1979). Instincts for human understanding and for cultural cooperation: Their development in infancy. In M.von Cranach, K. Foppa, W. Lepenies, & D. Ploog (Eds.), *Human ethology: Claims and limits of a new discipline* (pp. 530–571).

5. Warneken, F., Chen, F., and Tomasello, M. (2006). *Cooperative activities in young children and chimpanzees*. Child Dev, 77, 640–663.

6. Marsh, K. L., Richardson, M. J., & Schmidt, R. C. (2009). *Social connection through joint action and interpersonal coordination*. Topics in Cognitive Science, 1(2), 320–339.

7. Vesper, C., Butterfill, S., Knoblich, G., &Sebanz, N. (2010). *A minimal architecture for joint action.* Neural Networks, 23, 998-1003

8Wolpert, D. M., Doya, K., &Kawato, M. (2003). *A unifying computational framework for motor control and interaction*. Philosophical Transactions of the Royal Society of London B, 358, 593–602.

9. Aglioti, S. M., Cesari, P., Romani, M, &Urgesi, C. (2008). *Action anticipation and motor resonance in elite basketball players*. Nature Neuroscience, 11(9), 1109–1116.

10. Newman-Norlund, R.D., et al. (2007).*Exploring the brain basis of joint action: co-ordination of actions, goals and intentions.* SocNeurosci, .**2**(1): p. 48-65.

11. Stoit A., van Schie H., Riem M., Meulenbroek R., Newman-Norlund R., Slatts-Willemse D., Bekkering H., &Buitelaar J. (2011). *Internal model deficits impair joint action in children and adolescents with autism spectrum disorders*. Research in Autism Spectrum Disorders 5 (2011) 1526-1537.

12. Egetemier J, Stenneken P, Koehler S, Fallgatter AJ, Herrmann MJ. (2011).*Exploring the Neural Basis of Real-Life Joint Action: Measuring Brain Activation during Joint Table Setting with Functional Near-Infrared Spectroscopy***.** Front Hum Neurosci, 5:95,Epub 2011 Sep 8.

13. Newman-Norlund, R.D., Bosga, J., Meulenbroek, R.G., Bekkering, H.(2008). *Anatomical substrates of cooperative joint-action in a continuous motor task: virtual lifting and balancing*. NeuroImage, 41, 169–177.

14. Blakemore, S. J., Tavassoli, T., Calo, S., Thomas, R. M., Catmur, C., Frith, U., et al. (2006). *Tactile sensitivity in Asperger syndrome*. Brain and Cognition, 61(1), 5–13.

15, Simon, J. R., &Rudell, A. P. (1967).*Auditory S–R Compatibility – Effect of an irrelevant cue on information processing*. Journal of Applied Psychology, 51(3), 300–304.

16. Sebanz N, Knoblich G, Prinz W (2003) *Representing others' actions: just like one's own?* Cognition, 88, B11–B21.

17. Bosga, J., Meulenbroaek R., Cuijpers R. (2010*) Intra- and Interpersonal Movement Coordination in Jointly Moving a Rocking Board*. Motor Control, 2010, 14, 440-459.

18. Wildman, D., Uddin M., Liu G., Grossman L, Goodman M. (2003). *Implications of natural selection in shaping 99.4% nonsynonmous DNA identity between humans and chimpanzees: Enlarging Genus Homo.* PNAS, 100(12), 7181-7188.

19. Muller, M.N., and Mitani, J.C. (2005). *Conflict and Cooperation in Wild Chimpanzees*. In Adv. Study Behav, 35, 275–331.

20. Melis A. et al. (2006). *Chimpanzees Recruit the Best Collaborators*. Science,311, 1297-1298.

21. Dautenhahn, K. (2007). *Socially intelligent robots: dimensions of human-robot interaction.* Philos Trans R SocLond B BiolSci, 362(1480), 679-704.