Towards Estimating Collective Motor Behavior: Aware of Self vs. Aware of the Other

Lisa E. Rombout, Martin Atzmueller & Marie Postma-Nilsenová

Department of Cognitive Science & Artificial Intelligence, Tilburg University, The Netherlands
{l.e.rombout, m.atzmuller, marie.postma}@uvt.nl

Abstract. Many social activities involve motor-coordination between groups of people. Especially collective synchronous motor behavior is a complex phenomenon that has been associated with social bonding and the blurring of self-other boundaries. In order to coordinate movement in a group, people have to divide their attentional resources between the self and others. A group moving in synchrony can then be viewed as one network or a complex organism, where the behavior of the network is determined by the individual traits of its nodes and their interaction. In this study, we examine methodological and theoretical approaches towards measuring both individual traits and group interaction in the context of a group dance.

Keywords: collective behavior; position sensors; automatic movement tracking; interoception; proprioception; exteroception

1 Introduction

In the performing arts, there are several formal as well as informal theories about what makes a collaborative performance 'work'. Many of them touch upon the division of attentional resources, describing the ideal state of a performer as balanced, aware of their surroundings, and alert. The concept of 'flow' appears to be related to this ideal, as does the concept of the 'zéro' from physical theater [13]. Zéro describes the body as a tabula rasa, a resting point with the potential of movement. It exists in space and moves according to the constraints and affordances of the body itself, the space it is in, and the other bodies around it.

Compared to models of collective animal behavior, we know relatively little about the processes governing coordinated collective motor behavior in human agents. In order to coordinate successfully, each individual needs to be able to process in a rapid succession information about the expected position of one's own body in relation to the expected position of others. From a modeling perspective, this process can be seen as a complex network through which the behavior propagates. In order to describe properties of the network, it is necessary to measure and estimate various behavioral and relational aspects that may be governed by different sensory and executive mechanisms. The purpose of our study is to develop and test a range of instruments that can be used to measure individual dispositional tendencies to perceive certain internal and external signals and to relate the measures to actual collective performance.

1.1 Interoception, Exteroception and Proprioception

Several studies on embodiment illusions have identified individual differences in how different categories of sensory input are handled. In general, the distinction is made between interoceptive, exteroceptive and proprioceptive feedback [12]. For a majority of people, exteroceptive feedback and specifically vision is the most important information used to guide body ownership and agency; a reliance that does not appear to be very malleable [16, 28]. However, some individuals have a higher interoceptive sensitivity, which means that they can sense the internal physiological state of their body relatively well [20]. The classical rubber hand illusion approach (using external signals) [8] does not elicit the embodiment illusion in these individuals [32]. However, an altered illusion that provides synchronous heart-rate feedback instead (an internal signal) does work [30].

Interoceptive sensitivity and affect are closely related. Dating back to the James-Lange theory of emotion [15, 19], the peripheral autonomic changes that accompany emotional experience can be viewed as an integral part of it, regardless of precise cause and effect. The occurrence of this physiological affective feedback and an individuals sensitivity to it have both been shown to affect emotional experience [6, 34]. We therefore theorize that individual interoceptive sensitivity might also influence the social affect experience in a group. Synchronized behavior is present in several human social practices, such as chanting, marching, dancing, praying, clapping or singing [35]. This behavior has been shown to influence social bonding in several contexts. For example, making music and dancing together has an immediate positive effect on the pro-social behavior of four-year olds [18].

Despite the recent interest in interoception, exteroception, and proprioception as measures of dispositional tendencies towards certain types of sensory information, few instruments exist to estimate these properties beyond traditional self-reports. Therefore, little is known about the effects of, for example, interoceptive disposition on the ability to coordinate one's motor behavior with others. In the experiment described below, we tested a range of newly developed instruments in the context of a group dance. In addition to measuring the movement of the dancers, we also compared their performance in three different experimental conditions.

2 Methods

The participants in the study were dance students (N=11) at a dance academy in the Netherlands. Additionally, the choreographer of the dance was enlisted as the expert evaluator of the quality of the performed dances (N=1). Participation was voluntary and informed consent was obtained prior to the collection of all measurements. The dance students did not receive any form of reimbursement for their participation.

2.1 Pre-pilot practice sessions

Two practice sessions were organized with the dancers to test out the different approaches to data collection. One of the tested approaches was based on the use of micro-controllers specifically designed for creating wearables, such as the Arduino Lilypad [10]. These can be integrated into clothing relatively easily. We examined the potential of stretch, pressure and accelerometer sensors to gather data from the dancers, using both Bluetooth and Xbee (radio) shields to send real-time data from the dancers to a computer (since storage on the Lilypad itself was insufficient). These protocols proved to be problematic in terms of timing or in terms of reliably tracking more than 6 data-streams at the same time.

Next, we employed a Kinect depth sensor, which uses an infrared laser projector and a monochrome CMOS sensor to map the environment in 3D. Similarly to the wearables, the Kinect was only able to recognize up to six bodies simultaneously. Post-processing did not provide a solution, as there were many instances of occlusion and the field-of-view of the Kinect was not large enough to capture the entire dance. For movement in more enclosed spaces, the Kinect might be interesting if the sensor is installed at a high angle and body-tracking is performed via post-processing.

Lastly, we provided every dancer with wrist- and ankle bands in bright colors with the intention to use color tracking on the video footage. This proved to be quite effective for up to four dancers, after which occlusion again became a problem. For our actual experiment, we therefore focused on proximity tags and hand-analyzed video footage.

2.2 Design

We used a within-participants design, where the subjects danced three times under different conditions. Because all dancers had to participate in the same dance, it was not possible to counterbalance the conditions. The dance used in this study had been practiced by the subjects for several weeks at the time of measurement. The subjects rehearsed the dance for performances unrelated to this study. The measurements were collected during an extra practice-session one week before the first performance.

2.3 Measurements

Interoceptive sensitivity Interoceptive sensitivity can be divided into interoceptive sensibility (self-assessment), interoceptive accuracy (performance on objective tests), and interoceptive awareness (meta-cognitive - correspondence between accuracy and confidence) [14]. All of these measures were assessed before dancing started. The subjective measurement was the short form of the Body Perception Questionnaire [25], the body awareness part only (26 items, 5 point scale). The objective measurement was a heart-rate detection and a heart rate distinction task. Subjects were asked to count along with their own heart rate for an unknown period of time, after which their count and their real heart rate were compared. For the distinction task, subjects watched a flashing red circle on a screen and had to indicated whether the flashing was synchronous with their heart rate or not. For both tests, subjects were also asked to indicate their confidence on a 10-point scale. The actual heart rate was measured using a Grove/Seeedstudio ear-clip sensor (see figure 2).

Fig. 1. Proprioception test

Fig. 2. Heart rate test

Exteroceptive sensitivity We used a subjective measure of exteroceptive sensitivity applying a newly developed questionnaire, based on the Body Perception Questionnaire but focused on awareness of surroundings and other people (5 items, 5-point scale).

Proprioceptive sensitivity To measure proprioceptive sensitivity, a few different approaches were used. The subjective measurements were based on the Body Perception Questionnaire and parental report questionnaires when assessing proprioceptive sensitivity in children [7, 23]. We developed two short questionnaires, one based on awareness of bodily position (5 items, 5-point scale), and one on behavior (5 items, 5-point scale). The two-part objective measurement was developed specifically for this study. Subjects were seated and blindfolded, and given a pen to place on a paper in front of them. They were then asked to raise their hand as high as it would go, and place it back on the paper in one quick movement, as close to the original spot as possible. For the second part, they were asked to place the pointer finger of their non-dominant hand on the paper, and place a dot with the pen in their dominant hand as close to the tip of the finger as possible, again starting with their hand high up (see figure 1).

During the Dance While the subjects were dancing, they were filmed from three angles with Sony Cyber-Shot DSC-HX5V cameras. Synchronicity scores were extracted from this footage by hand, by selecting the frames in which individual dancers began and ended certain movements. The last movement of the dance, a sudden head-movement to the side (see figure 3, duration of movement was < 500 ms), was transcribed in this way to establish a preliminary 'synchronicity score' for the different dances.
In addition, Sociopattern proximity tags [5][1] were applied in order to detect close-range proximity (1-1.5 meters) of the individuals wearing them. Accelerometer data was also collected using these sensors, for each proximity contact. This infrastructure has been deployed in various environments for studying the dynamics of human contacts, e. g.,

[1] `http://www.sociopatterns.org`

Fig. 3. Mid head-turn, last movement of the dance

at conferences [4, 11, 21]. Postprocessing and analysis is then supported by the Ubicon software platform [3].

Post-dance Questionnaires After each dance, subjects were asked to fill out a self-assessment manikin (measures of valence, arousal and dominance, 9-point scale) to indicate their affective state during the dance [9]. Additionally they were asked to rate the awareness of their own body, the other dancers, and their surroundings during the dance (3 items, 9-point scale). They were also asked to indicate their closeness to the other dancers using an inclusion of others in the self scale (IOS, 7-point scale) [1]. Lastly, they were asked to rate the quality of their own dancing and the quality of the dance as a whole. The expert was also asked after each dance to rate the quality of the dance as a whole (9-point scale).

2.4 Procedure

After providing informed consent, each subject went through the baseline interoceptive, proprioceptive and exteroceptive measurements. Then they were given 'secret personal instructions' for the first dance, and performed the dance. After the dance, they filled out the post-dance questionnaires, and the expert gave their rating of dance quality. This procedure of instructions-dance-questionnaire was then repeated two more times.

The instruction for the first dance was to dance as usual. For the second dance, the participants were instructed to focus mainly on their own body (with the incentive that there would be questions about that after the dance), and the third dance on their surroundings and the other dancers. Subjects were not told that everyone received the exact same instructions. Some post-dance questions were added specific to the instructions to maintain the motivation to follow them. The expert was not aware of the content of the instructions.

3 Results

In order to explore the relation between different types of measurements for interoceptive, exteroceptive, and proprioceptive sensitivity, as well as the actual performance during the dance, we conducted a series of correlation analyses. Performance synchronicity was operationalized in terms of the interval (in frames) between the start of the head movement of the first dancer and the start of the head movement of all other dancers. Higher interval meant a lower performance synchronicity. The head movement analyzed occurred towards the end of the short dance and was perceptually the most prominent synchronous group action performed. The size of the participant group did not allow for a factor analysis. As can be seen in Figure 4, there was a strong relation between proprioceptive predispositions measured with the questionnaire (Proprioception-Q) and the baseline performance of the dancers: higher proprioception was negatively linked to a higher delay, i.e., positively related to synchronicity. There was also a strong relation between proprioception measured with an actual behavioral task (Proprioception-T) and delay in synchronicity in the condition where dancers were instructed to focus on others. Next to the weak relation between Proprioception-Q and Proprioception-T, these results suggest that the two types of measurements possibly capture different components of proprioceptive sensitivity. Finally, there was a relatively strong negative relation between interoceptive sensitivity and delay in synchronicity in the condition where dancers were focusing on their own body. Interestingly, this led to a higher coordination with other dancers. In fact, the results indicate that interoceptive dancers - those who are successful in monitoring the internal processes of their own body - may be more equipped to coordinate with others in general.

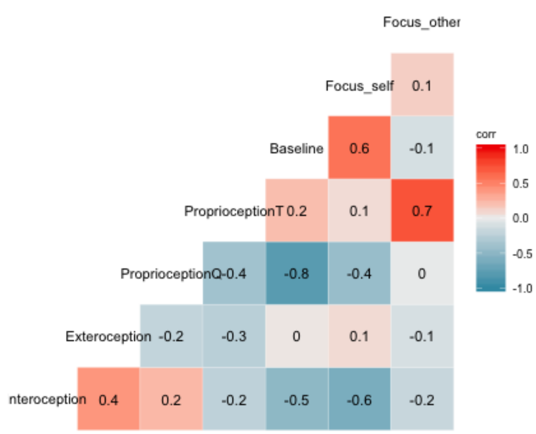

Fig. 4. Correlation between dispositional measures and dance performance.

In line with this observation, the expert, unaware of the instructions, was most surprised by the third dance ('focus on other'), noting that 'the dancers seemed to have more fun, but the dance was not good'. This impression is confirmed by the overall synchronicity scores which were the lowest in the focus-on-other condition (calculated in terms of the delay from first dancer movement Mean_Baseline = 3.5 frames, Mean_Focus-self = 4.9 frames, and Mean_Focus-other = 10.9 frames). This outcome again suggests that awareness of one's own body is an important precondition for synchronizing with others.

4 Conclusion and Discussion

The setup of this pilot study and its first results indicate findings that may be of interest for network modeling of the captured relations. Modeling group behavior as complex networks is an important research direction, e. g., [2, 24] regarding methods from complex network analysis [29, 33]. Analyzing the individual measures of interoceptive, exteroceptive and proprioceptive sensitivity and relating that to each participants' synchronicity performance, we could presumably describe a network of interactions where some participants are more in sync with each-other than others. Sub-networks may develop, where dancers who react similarly to the different conditions synchronize their behavior.

In order to analyze group cohesion and synchronicity dynamics in groups of individuals, those individuals, e. g., dancers, can then be modeled as actors in a (complex) network. Modeled as a graph, the actors correspond to nodes where the edges (links) between those are given by connectivity or cohesion metrics. For example, these can relate to spatial proximity (as measured by the applied proximity tags), gaze (line-of-sight) or synchronicity relationships between the actors.

The predictive coding account of embodiment states that body ownership is a process of error reduction between the predicted bodily state and the sensory feedback from body and environment [17]. The cerebral body is constructed by multi-sensory integration and sensory input is weighted according to its perceived importance [31]. In this context, attention can be re-interpreted as an optimization of precision weighting [28]. Attention is (re)directed towards those sensory elements that minimize prediction errors. Recently, efforts have been made to model these mechanisms on the scale of the individual [27]. We propose that similar but expanded computational models could be developed for collective movement due to the flexible self-other boundaries experienced by the participants [22].

We see two possible approaches to expand further on the current pilot study. The first is to focus on dyadic interactions, simplifying the network approach and allowing for more precise automated measurement through the Kinect or other sensors. One advantage of this approach is that participants can be paired according to their interoceptive, exteroceptive or proprioceptive sensitivity, allowing a closer look at these different styles of approaching embodied social interaction. The second approach would be to focus on very large groups of people and choose measurements based on proximity or large overall movement. For example, when a group of people is performing a 'wave' as seen in sporting events, their synchronicity can likely be measured quite well by a pressure-sensor in the chair, recording only the moment of rising and the moment of sitting down again.

Several of the measurements can be improved upon. Most importantly, heart rate distinction and detection tasks suffer under the drawback that they are susceptible to false successes if the subject has reasonable knowledge about healthy heart-rates and a well-developed sense of timing [14]. Additionally, subjects who have a high interoceptive sensitivity but feel their heart-rate on a different delay then the sensor used are at a disadvantage in the detection task. An altered version of the detection task, where the heart-rate is presented at a range of different delays, could be more precise [26].

In conclusion, our study is the first to explore the contribution of individual dispositional tendencies to perceive certain internal and external signals towards measuring and describing synchronous collective motor behavior. This type of behavior has links to social bonding and affect, embodiment, and self-other boundaries, and as such is a complex phenomenon of which the dimensions are as yet relatively unknown.

References

1. Aron, A., Aron, E.N., Smollan, D.: Inclusion of other in the self scale and the structure of interpersonal closeness. Journal of personality and social psychology 63(4), 596 (1992)
2. Arrow, H., McGrath, J.E., Berdahl, J.L.: Small Groups as Complex Systems: Formation, Coordination, Development, and Adaptation. Sage Publications (2000)
3. Atzmueller, M., Becker, M., Kibanov, M., Scholz, C., Doerfel, S., Hotho, A., Macek, B.E., Mitzlaff, F., Mueller, J., Stumme, G.: Ubicon and its Applications for Ubiquitous Social Computing. New Review of Hypermedia and Multimedia 20(1), 53–77 (2014)
4. Atzmueller, M., Doerfel, S., Hotho, A., Mitzlaff, F., Stumme, G.: Face-to-Face Contacts at a Conference: Dynamics of Communities and Roles. In: Modeling and Mining Ubiquitous Social Media, LNAI, vol. 7472 (2012)
5. Barrat, A., Cattuto, C., Colizza, V., Pinton, J.F., den Broeck, W.V., Vespignani, A.: High Resolution Dynamical Mapping of Social Interactions with Active RFID. PLoS ONE 5(7) (2008)
6. Barrett, L.F., Quigley, K.S., Bliss-Moreau, E., Aronson, K.R.: Interoceptive sensitivity and self-reports of emotional experience. Journal of personality and social psychology 87(5), 684 (2004)
7. Blanche, E.I., Reinoso, G., Chang, M.C., Bodison, S.: Proprioceptive processing difficulties among children with autism spectrum disorders and developmental disabilities. American Journal of Occupational Therapy 66(5), 621–624 (2012)
8. Botvinick, M., Cohen, J.: Rubber hands 'feel'touch that eyes see. Nature 391(6669), 756 (1998)
9. Bradley, M.M., Lang, P.J.: Measuring emotion: the self-assessment manikin and the semantic differential. Journal of behavior therapy and experimental psychiatry 25(1), 49–59 (1994)
10. Buechley, L., Eisenberg, M.: The lilypad arduino: Toward wearable engineering for everyone. IEEE Pervasive Computing 7(2) (2008)
11. Cattuto, C., Van den Broeck, W., Barrat, A., Colizza, V., Pinton, J.F., Vespignani, A.: Dynamics of Person-to-Person Interactions from Distributed RFID Sensor Networks. PLoS ONE 5(7) (2010)
12. Craig, A.D.: How do you feel? interoception: the sense of the physiological condition of the body. Nature reviews neuroscience 3(8), 655 (2002)
13. Decroux, E.: Words on mime. Pomona College Theatre Department (1977)
14. Garfinkel, S.N., Seth, A.K., Barrett, A.B., Suzuki, K., Critchley, H.D.: Knowing your own heart: distinguishing interoceptive accuracy from interoceptive awareness. Biological psychology 104, 65–74 (2015)

15. James, W.: What is an emotion? Mind 9(34), 188–205 (1884)
16. Khalsa, S.S., Rudrauf, D., Damasio, A.R., Davidson, R.J., Lutz, A., Tranel, D.: Interoceptive awareness in experienced meditators. Psychophysiology 45(4), 671–677 (2008)
17. Kilteni, K., Maselli, A., Kording, K.P., Slater, M.: Over my fake body: body ownership illusions for studying the multisensory basis of own-body perception. Frontiers in human neuroscience 9, 141 (2015)
18. Kirschner, S., Tomasello, M.: Joint music making promotes prosocial behavior in 4-year-old children. Evolution and Human Behavior 31(5), 354–364 (2010)
19. Lange, C.G.: The mechanism of the emotions. The classical psychologists pp. 672–684 (1885)
20. Ludwick-Rosenthal, R., Neufeld, R.W.: Heart beat interoception: a study of individual differences. International Journal of Psychophysiology 3(1), 57–65 (1985)
21. Macek, B.E., Scholz, C., Atzmueller, M., Stumme, G.: Anatomy of a Conference. In: Proc. ACM Hypertext. pp. 245–254. ACM, New York, NY, USA (2012)
22. Maister, L., Slater, M., Sanchez-Vives, M.V., Tsakiris, M.: Changing bodies changes minds: owning another body affects social cognition. Trends in cognitive sciences 19(1), 6–12 (2015)
23. Miller-Kuhaneck, H., Henry, D., Glennon, T., Parham, D., Ecker, C.: Sensory processing measure: home form, main classroom form, and school environments form. Los Angeles: Western Psychological Services (2007)
24. Passos, P., Davids, K., Araújo, D., Paz, N., Minguéns, J., Mendes, J.: Networks as a Novel Tool for Studying Team Ball Sports as Complex Social Systems. Journal of Science and Medicine in Sport 14(2), 170–176 (2011)
25. Porges, S.: Body perception questionnaire. Laboratory of Developmental Assessment, University of Maryland (1993)
26. Ring, C., Brener, J., Knapp, K., Mailloux, J.: Effects of heartbeat feedback on beliefs about heart rate and heartbeat counting: a cautionary tale about interoceptive awareness. Biological psychology 104, 193–198 (2015)
27. Samad, M., Chung, A.J., Shams, L.: Perception of body ownership is driven by bayesian sensory inference. PloS one 10(2), e0117178 (2015)
28. Seth, A.K.: Interoceptive inference, emotion, and the embodied self. Trends in cognitive sciences 17(11), 565–573 (2013)
29. Strogatz, S.H.: Exploring Complex Networks. nature 410(6825), 268 (2001)
30. Suzuki, K., Garfinkel, S.N., Critchley, H.D., Seth, A.K.: Multisensory integration across exteroceptive and interoceptive domains modulates self-experience in the rubber-hand illusion. Neuropsychologia 51(13), 2909–2917 (2013)
31. Tsakiris, M.: The multisensory basis of the self: from body to identity to others. The Quarterly Journal of Experimental Psychology 70(4), 597–609 (2017)
32. Tsakiris, M., Tajadura-Jiménez, A., Costantini, M.: Just a heartbeat away from one's body: interoceptive sensitivity predicts malleability of body-representations. Proceedings of the Royal Society of London B: Biological Sciences 278(1717), 2470–2476 (2011)
33. Wasserman, S., Faust, K.: Social Network Analysis: Methods and Applications. No. 8 in Structural Analysis in the Social Sciences, Cambridge University Press, 1 edn. (1994)
34. Wiens, S.: Interoception in emotional experience. Current opinion in neurology 18(4), 442–447 (2005)
35. Wiltermuth, S.S., Heath, C.: Synchrony and cooperation. Psychological science 20(1), 1–5 (2009)