CogSci 2012 Workshop

Teleoperated Android as a Tool for Cognitive Studies, Communication and Art

August 1, 2012

Sapporo, Japan

The aim of this full-day workshop is to introduce and discuss on current insights and future usage of teleoperated androids.

Teleoperated androids, robots owning humanlike appearance equipped with semi-autonomous teleoperation facility, was first introduce to the world in 2007 with the public release of Geminoid HI-1. Geminoid is a teleoperated android robot that resembles existing human being. While androids were designed for studying human nature in general, geminoids was made to study individual aspects as presence or personality traits, tracing their origins and implementation into robots. Both its appearance that resembles the source person and its teleoperation functionality serves in making Geminoid as a research tool. After the release of Geminoid HI-1, several types of teleoperated androids has been produced: Geminoid F, Geminoid DK, Telenoid R1/R2 and Elfoid P1. While the Geminoids are after real existing persons, Telenoid and Elfoid are attempts to represent human beings in their minimalistic forms; a challenge to see to what extent elements that forms us can be omitted but still able to transfer presence of the teleoperating person.

Since their birth, Geminoids and Telenoids have been used in a variety of domains throughout the world, from studies in various fields such as in cognitive psychology / neuroscience, social psychiatry, developmental psychology, robotics, and human-machine interface to philosophy and art. One example is the android drama which showed new possibilities on not only on usage for teleoperated android robots but for artistic representations as well as seeking purity in the natures of human beings.

The past workshops that concentrated on autonomous humanlike robots and androids laid a foundation for android science research, a field that integrates the synthetic approach from robotics with the empirical methodologies of the social sciences. Participants, coming from engineering and the social, cognitive, and biological sciences sought fundamental principles underlying cognition and communication between individuals.

In this workshop, we will focus on the further enhanced and broadened usage of teleoperated androids that can provide new means for cognitive science studies, and can bridge the gap between cognitive neuroscience and the behavioral sciences, as well as philosophy, social science and arts, leading to a new way of understanding human beings.

Morning Session

09:30-09:40
Hiroshi Ishiguro (Osaka University)
Opening remarks

09:40-10:20
Kazuo Hiraki (University of Tokyo)
Can Humanoids be our Friends I: Yet another approach in cognitive science

10:20-11:00
Shuichi Nishio (ATR)
Transmitting human presence with teleoperated androids: From proprioceptive transfer to elderly care

--- *Break* ---

11:10-11:40
Ayse Pinar Saygin
(University of California, San Diego)
What can the brain tell us about interactions with artificial agents, and vice versa?

11:40-12:20
Shoji Itakura (Kyoto University)
Perception of non-human agents by human infants

--- *Lunch break* ---

Afternoon Session

13:30-14:30 **Invited Talk**
Gerd Gigerenzer
(Max Planck Institute for Human Development)
Less-is-more: Simple solutions for complex problems

--- *Break* ---

14:40-15:10
Tsutomu Fujinami (JAIST)
Enabling bodily communication between schoolchildren using a tele-operated humanoid

15:10-15:50
Hiroshi Ishiguro (Osaka University)
Representation of humanlike presence with robotics avatars

15:50-16:20
Antonio Chella (University of Palermo)
Sing with the Telenoid

--- *Break* ---

16:30-17:10
Round-table discussion

COGSCI 2012 WORKSHOP

TELEOPERATED ANDROID AS A TOOL FOR COGNITIVE STUDIES, COMMUNICATION AND ART

Organizers

Shuichi Nishio (nishio@ieee.org)
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Kazuo Hiraki
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Can Humanoids be our Friends I: Yet another approach in cognitive science

Abstract:
Progress in cognitive science requires the balance between divergence and convergence of approaches. As an interdisciplinary and integrated field for scientific understanding of human mind, cognitive science has incorporated diversified approaches such as computer modeling and brain imaging. These approaches brought us not only new findings but also new problem where the findings of different approaches are sometime conflicting each other. To resolve the problem, we need another new approach to converge the conflicting findings. In this talk I would like to introduce a new approach to investigate human mind. Using humanoids we have conducted a series of studies. Here I will focus on the merit of "real" robots to study human mind.

Shuichi Nishio
Advanced Telecommunications Research Institute International (ATR)

Transmitting Human Presence with Teleoperated Androids: From proprioceptive transfer to elderly care

Abstract:

Teleoperated androids, robots owning humanlike appearance equipped with semi-autonomous teleoperation facility, was first introduce in 2007 with the public release of Geminoid HI-1. Both its appearance that resembles the source person and its teleoperation functionality serves in making Geminoid as a research tool for seeking the nature of human presence and personality traits, tracing their origins and implementing into robots. Since the development of the first teleoperated android, we have been using them in a variety of domains, from studies on basic human natures to practical applications such as elderly care. In this talk, I will introduce some of our findings and ongoing projects.

Ayşe Pınar Saygin
University of California, San Diego

What can the Brain Tell us about Interactions with Artificial Agents, and Vice Versa?

Abstract:
No longer encountered only in science fiction, artificial agents such as humanoid robots and interactive animated characters are rapidly becoming participants in many aspects of social and cultural life. Artificial agents have a range of biomedical, educational and entertainment applications. In particular, they can enable telepresence, opening a range of new possibilities for human interaction. For these technologies to succeed however, we need to understand human factors guiding our interactions with these agents.
In our research we use methods from cognitive neuroscience and neuroimaging to explore how humans perceive, respond to, and interact with others, including artificial agents. Not only can we inform the design of new agents by studying human brain responses in interactions with artificial agents, but studies with artificial agents can improve our understanding of how the human brain enables some of our most important skills such as action understanding, social cognition, empathy, and communication. We suggest interdisciplinary collaboration is the most fruitful way to proceed in advancing robotics and animation on one hand, and cognitive science and neuroscience on the other.

What can the Brain Tell us about Interactions with Artificial Agents and Vice Versa?

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Abstract

No longer encountered only in science fiction, artificial agents such as humanoid robots and interactive animated characters are rapidly becoming participants in many aspects of social and cultural life. Artificial agents have a range of biomedical, educational and entertainment applications. In particular, they can enable telepresence, opening a range of new possibilities for human interaction. For these technologies to succeed however, we need to understand human factors guiding our interactions with these agents. In our research we use methods from cognitive neuroscience and neuroimaging to explore how humans perceive, respond to, and interact with others, including artificial agents. Not only can we inform the design of new agents by studying human brain responses in interactions with artificial agents, but studies with artificial agents can improve our understanding of how the human brain enables some of our most important skills such as action understanding, social cognition, empathy, and communication. We suggest interdisciplinary collaboration is the most fruitful way to proceed in advancing robotics and animation on one hand, and cognitive science and neuroscience on the other.

Keywords: action perception; uncanny valley; mirror neurons; biological motion

Introduction

With advances in technology, artificial agents such as robots are quickly becoming parts of our daily lives (Coradeschi et al., 2006; Ishiguro & Nishio, 2007). These technologies can enable telepresence, opening up new possibilities in human interaction that can reduce costs and travel (and associated carbon emissions), as well as increase diversity of participation. Thus, research on how humans perceive, respond to and interact with these agents is increasingly important (MacDorman & Kahn Jr, 2007; Sanchez-Vives & Slater, 2005; Saygin, Chaminade, Urgen, & Ishiguro, 2011). In particular, neuroscience and psychology research exploring human robot interaction (HRI) and telepresence can make valuable contributions to the development of future applications (Chaminade & Cheng, 2009; Chaminade & Hodgins, 2006; Saygin et al., 2011). An interdisciplinary perspective on human-agent interaction is especially important, since this field will impact issues of public concern in the near future, for example in domains such as education and healthcare (e.g., Billard, Robins, Nadel, & Dautenhahn, 2007; Kanda, Ishiguro, Imai, & Ono, 2004; Mataric, Tapus, Winstein, & Eriksson, 2009).

Conversely, experiments on the perception of artificial agents and telepresence can help advance neuroscience, since they can help us explore the functional properties of brain areas that subserve social cognition (e.g., Chaminade et al., 2010; Cross et al., 2011; Gazzola, Rizzolatti, Wicker, & Keysers, 2007; Saygin, Chaminade, Ishiguro, Driver, & Frith, 2012). Using artificial agents and telepresence we can control stimulus properties precisely, or create entities or environtments that violate physical realities of the world. Such manipuations can allow us to test whether particular neural systems or perceptual processes are selective or sensitive to natural (biological) stimuli or might also generalize to non-biological (artificial) stimuli.

The goal of our research program is to both improve our understanding of how the human brain enables social cognition, and to help engineers and designers in developing interactive agents that are well-suited to their application domains, as well as to the brains of their creators. In this paper, I will give an example of a neuroimaging study in which we have used artificial agents (humanoid robots) to study the human brain. Such interdisciplinary work that can allow us to answer questions about both artificial agents and about the brain are important as we face a future that includes interactions with such agents and telepresence.

Action Perception

In primates, the perception of body movements and actions is supported by network of lateral superior temporal, inferior parietal and inferior frontal brain areas. Here, we refer to this network as the action perception system, or APS (Fig. 1). Two of the areas within the APS, (PMC and IPL) contain mirror neurons in the macaque brain (Rizzolatti & Craighero, 2004). Mirror neurons respond not only when a monkey executes a particular action, but also when it observes another individual perform the action. For instance a mirror neuron that fires as the monkey cracks a peanut, can also fire as the monkey observes someone else crack a peanut. It is thought that a similar system underlies action perception in the human brain (e.g., Grafton, 2009; Iacoboni & Dapretto, 2006; Saygin, 2007; Saygin, Wilson, Hagler,

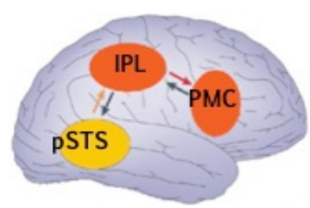

Figure 1: Schematic of the Action Perception System (APS): Superior Temporal Sulcus (pSTS), Inferior Parietal Lobule (IPL), Premotor Cortex (PMC). Adapted from Iacoboni & Dapretto, 2006.

Bates, & Sereno, 2004). Some researchers have argued that in addition to subserving action processing, the APS helps in linking "self" and "other", and thus may constitute a basis for social cognition (Rizzolatti & Craighero, 2004).

The finding that the visual perception of another entity automatically engages the observers' own motor system indicates that at some levels of the nervous system, simply seeing another agent automatically engages interaction.

The APS has received intense interest from neuroscientists in the last decade and a half, and we can now use the accumulated knowledge in this field to study how the human brain supports interactions with artificial agents and telepresence. Conversely research on artificial agent perception and telepresence can help research on the human brain by allowing us to test functional properties of the APS and other brain areas.

Due to the presence of mirror neurons, the neural activity in PMC and IPL regions during action perception is often interpreted within the framework of "simulation": A visually perceived body movement is mapped onto the perceiving agent's sensorimotor neural representations and "an action is understood when its observation causes the motor system of the observer to 'resonate" (Rizzolatti, Fogassi, & Gallese, 2001). But what are the boundary conditions for 'resonance'? What kinds of agents or actions lead to the simulation process? Is human-like appearance important? Is human-like motion?

On the one hand, we might expect the closer the match between observed action and observers' own sensorimotor representations, the more efficient the simulation will be. In support for this, the APS is modulated by whether the observer can in fact perform the seen movement (e.g., Calvo-Merino, Grezes, Glaser, Passingham, & Haggard, 2006). The appearance of the observed agent may also be important (e.g., Chaminade, Hodgins, & Kawato, 2007).

On the other hand, human resemblance is not necessarily always a positive feature in artificial agents. The "uncanny valley" hypothesis suggests that as a robot is made more human-like, the reaction to it becomes more and more positive, until a point is reached at which the robot becomes oddly repulsive (Mori, 1970). While this phenomenon is well known to roboticists and animators, there is only a small (but growing) body of experimental evidence in favor of or against it (e.g., Cheetham, Suter, & Jancke, 2011; Ho, MacDorman, & Dwi Pramono, 2008; Lewkowicz & Ghazanfar, 2012; MacDorman & Ishiguro, 2006; Saygin et al., 2012; Seyama & Nagayama, 2007; Steckenfinger & Ghazanfar, 2009; Thompson, Trafton, & McKnight, 2011; Tinwell, Grimshaw, Nabi, & Williams, 2011). The uncanny valley not only constitutes a practical challenge for robotics and telepresence, but also is a puzzling phenomenon to study from a perceptual and cognitive standpoint.

Robots can have nonbiological appearance and movement patterns – but at the same time, they can be perceived as carrying out recognizable actions. Is biological appearance or biological movement necessary for engaging the human Action Perception System (APS)? Robots can allow us to ask such questions and to test whether particular brain areas are selective or sensitive to the presence of a human, or an agent with a humanlike form, or respond regardless of the agent performing the action.

Neuroimaging Study: Perception of Robot and Android Actions

There is a small neuroscience literature on the perception of artificial agents, including robots (e.g., Gazzola et al., 2007; Oberman, McCleery, Ramachandran, & Pineda, 2007; Tai, Scherfler, Brooks, Sawamoto, & Castiello, 2004). Unfortunately, the results are highly inconsistent. Furthermore, many studies had used toy robots or very rudimentary industrial robot arms, so the results were not informative regarding state-of-the-art humanoid robots or telepresence. Furthermore, the roles of humanlike appearance or motion were not explored in previous work. We used neuroimaging (functional Magnetic Resonance Imaging (fMRI)) along with a method called Repetition Suppression (RS) to overcome limitations of previous work, and studied this question with well-controlled stimuli developed in by an interdisciplinary team (Saygin, Chaminade, & Ishiguro, 2010; Saygin et al., 2012).

We performed fMRI as participants viewed video clips of human and robotic agents carrying out recognizable actions. fMRI is a powerful method that allows imaging the activity of the live human brain non-invasively and has revolutionized neuroscience, though as with any method, there are limitations (e.g., no ferromagnetic materials, limited interactivity).

We used Repliee Q2, an android developed at Osaka University in collaboration with Kokoro Ltd (Ishiguro, 2006; Ishiguro & Nishio, 2007). Repliee Q2 has a very human-like appearance (Fig. 2, Android (A)); the robot's face was modeled after an adult Japanese female who also participated in our stimulus development (Fig. 2, Human (H)). Repliee Q2 can make facial expressions, as well as eye, head, upper limb, and torso movements. It has 42 degrees of freedom (d.o.f.) in its movements, with 16 d.o.f. in the head. With very brief exposure times, Repliee Q2 is often mistaken for a human being, but more prolonged exposure and interaction can lead to an uncanny valley experience (Ishiguro, 2006).

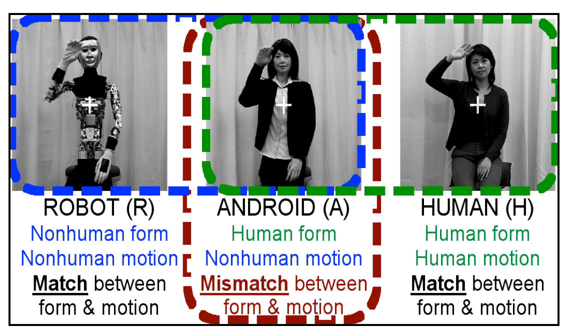

Figure 2: Stills from the videos depicting the three agents (R, A, H) and the experimental conditions (form and motion) they represent.

Repliee Q2 was videotaped both in its original human-like appearance (A) and in a modified, more mechanical appearance (Fig. 2, Robot (R)). For this, we removed as many of the surface elements as possible in order to reveal the electronics and mechanics underneath. The silicone covering the face and hands could not be removed, so we used a custom mask and gloves to cover these areas. The end result was that the robot's appearance became mechanical and nonhuman. However, since the A and R are in fact the same robot, the motion dynamics and kinematics are the same for these two conditions.

There were thus three agents: human (H), robot with human form (A), and robot with nonhuman form (R). H and A are very close to each other in form, both with humanlike form, whereas R has nonhuman form. In terms of the movement, H represents truly biological motion and A and R are identical, both with mechanical kinematics. Using fMRI and RS, we explored whether the human brain would display specialization for human form (similar responses for A and H, and different for R) or motion (similar responses for R and A, and differential responses for H). Another possibility was for RS responses not to reflect biological form or motion per se, but instead pattern with the uncanny valley. In this scenario, responses to H and R would be similar to each other, even though these two agents are divergent from each other in both form and movement.

The articulators of Repliee Q2 were programmed over several weeks at Osaka University. The same movements were videotaped in both appearance conditions (R and A). The human, the same female adult to whom Repliee Q2 was designed to resemble, was asked to perform the same actions as she naturally would. All agents were videotaped in the same room and with the same background. A total of 8 actions per actor were used in the experiment (e.g., drinking water from a cup, waving hand). 20 adults participated in the fMRI experiment. Participants had no experience working with robots. Each was given exactly the same introduction to the study and the same exposure to the videos prior to scanning since prior knowledge can affect attitudes to artificial agents differentially (Saygin & Cicekli, 2002). Before the experiment, subjects were told that they would see short video clips of actions by a person, or by two robots with different appearances and were shown all the movies in the experiment. By the time scanning started, participants were not uncertain about the robotic identity of the android.

Scanning was conducted at the Wellcome Trust Centre for Neuroimaging, in London, UK using a 3T Siemens Allegra scanner and a standard T2* weighted gradient echo pulse sequence. During fMRI, subjects viewed the stimuli projected on a screen in the back of the scanner bore through a mirror placed inside the head coil. There were blocks of 12 videos, each preceded by the same video (Repeat) or a different video (Non-repeat), which allowed us to compute the RS contrast (Non-repeat > Repeat). Every 30-seconds, they were presented with a statement about which they would have to make a True/False judgment (e.g., "I did not see her wiping the table"). Since the statements could refer to any video, subjects had to be attentive throughout the block. Data were analyzed with SPM software (http://www.fil.ion.ucl.ac.uk/spm).

RS differed considerably between the agents (Fig. 3). All agents showed RS in temporal cortex near the pSTS. For A, extensive RS was found in additional regions of temporal, parietal and frontal cortex (Fig. 3b).

In the left hemisphere, lateral temporal cortex responded to H and A, but not to R. The specific location of this activation corresponds to extrastriate body area (EBA), a region that responds strongly during the visual perception of the body and body parts (Peelen, Wiggett, & Downing, 2006). Our data showed that robotic appearance can weaken the RS response in the EBA.

Aside from the EBA, we did not find evidence selective coding for human form or motion. Instead, for A, whose form is humanlike, but its motion mechanical, increased responses were found in a network of cortical areas. This was most pronounced (and statistically significant) in the IPL, one of the nodes of the APS (Fig. 3b, circled areas).

But why would there be an area of the brain highly selective for androids? This response pattern brings to mind the uncanny valley – except, rather than valleys, we measured "hills" in the neural responses, in the form of increased RS. A framework within which to interpret these data is the predictive coding account of cortical computation (Friston & Kiebel, 2009; Friston, Mattout, & Kilner, 2011; Kilner, Friston, & Frith, 2007). Predictive coding is based on minimizing prediction error among the levels of a cortical hierarchy (e.g. the APS). More specifically, during the perception of H and R, there is no conflict between form and motion of the agent. H appears human and moves like a human. R appears mechanical and moves mechanically. For A on the other hand the agent's form is humanlike, which may result in a conflict when the brain attempts to process

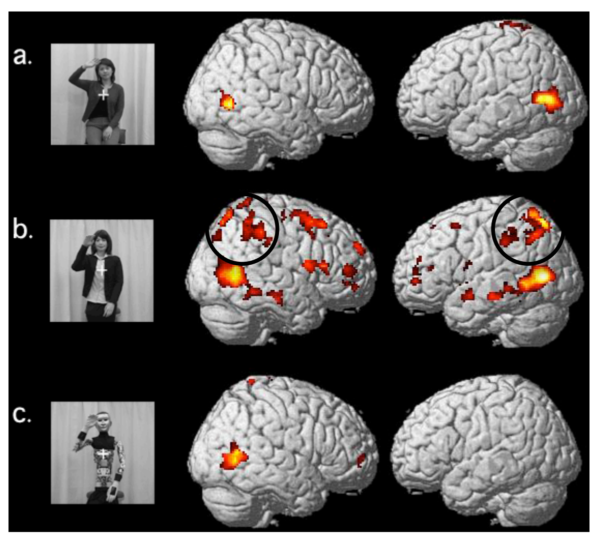

Figure 3. Repetition suppression (RS) results for the Human (a), Android (b), and Robot (c). (Non-repeat > Repeat at t>=8.86, p<0.05 with False Discovery Rate (FDR) correction for multiple comparisons, cluster size of at least 30 voxels). Adapted from Saygin et al., 2012.

and integrate the movement of the agent with its form. This conflict leads to the generation of a prediction error, which is propagated in the network until the predictions of each node are minimized. During this process, we can measure the prediction error in the fMRI responses. It is not possible from the current data to know the exact neural sources, the directionality, and the time course of error propagation, but it is clear that the cortical network is engaged more strongly during the perception of A compared with the agents that lead to less prediction error (R and H). Furthermore, the effect is largest in parietal cortex, the node of the network that links the posterior, visual components of the APS and the frontal, motor components (Matelli & Luppino, 2001).

In summary, in this interdisciplinary study, we found that a robot with highly humanlike form is processed differentially compared with a robot with a mechanical form, or with an actual human. These differences are found in a network of brain areas, most prominently in parietal cortex (Saygin et al., 2012). We propose these "hills" in the brain activity reflect the prediction error that is propagated in the system. The uncanny valley may thus arise from processing conflicts in the APS, and the resultant error signals, which can in turn be measured using fMRI.

The study described above constitute only a beginning. In future work, we can utilize animation in order to modulate form and motion parameters more precisely (although this is likely to lead to a decrease in presence (Sanchez-Vives & Slater, 2005)). We will also use other neuroimaging and psychological methods in addition to, or in conjunction with fMRI. More time-resolved behavioral and neuroimaging methods are also important to study the temporal dynamics of action processing (Saygin & Stadler, 2012; Urgen, Plank, Ishiguro, Poizner, & Saygin, 2012).

Discussion

Using cognitive neuroscience, we have been able to suggest an interpretation for the classic anecdotal reports of the uncanny valley hypothesis. While our experiment was not designed to explain the uncanny valley, the results suggest an intriguing link between the phenomenon, and brain responses in the APS. As shown in Figure 2, the android condition features a mismatch between form and motion. In a predictive coding, the android is not predictable: an agent with that form (human) would typically not move mechanically as Repliee Q2 does. When the nervous system is presented with this unexpected combination, a propagation of prediction error may occur in the APS. We suggest this framework may contribute to an explanation for the uncanny valley and future experiments will test this hypothesis.

Using robotics, we were able to answer questions regarding the neural basis of action perception. We were able to test functional properties of human action perception system (APS), helping shed light on how our brains enable social cognition.

Collaboration between cognitive neuroscience and robotics and telepresence research can be a win-win for both sides. Understanding both the computational and the human side of human-agent interaction is necessary for developing successful assistive artificial agents and telepresence systems.

Acknowledgments

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References

Billard, A., Robins, B., Nadel, J., & Dautenhahn, K. (2007). Building Robota, a mini-humanoid robot for the rehabilitation of children with autism. *Assistive Technologies, 19*(1), 37-49.

Calvo-Merino, B., Grezes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology, 16*(19), 1905-1910.

Chaminade, T., & Cheng, G. (2009). Social cognitive neuroscience and humanoid robotics. *Journal of Physiology Paris, 103*(3-5), 286-295.

Chaminade, T., Hodgins, J., & Kawato, M. (2007). Anthropomorphism influences perception of computer-animated characters' actions. *Social Cognitive and Affective Neuroscience, 2*(3), 206-216.

Chaminade, T., & Hodgins, J. K. (2006). Artificial agents in social cognitive sciences. *Interaction Studies, 7*(3), 347-353.

Chaminade, T., Zecca, M., Blakemore, S. J., Takanishi, A., Frith, C. D., Micera, S., . . . Umilta, M. A. (2010). Brain response to a humanoid robot in areas implicated in the perception of human emotional gestures. *PLoS ONE, 5*(7), e11577.

Cheetham, M., Suter, P., & Jancke, L. (2011). The human likeness dimension of the "uncanny valley hypothesis": behavioral and functional MRI findings. *Frontiers in Human Neuroscience, 5*, 126.

Coradeschi, S., Ishiguro, H., Asada, M., Shapiro, S. C., Thielscher, M., Breazeal, C., . . . Ishida, H. (2006). Human-inspired robots *IEEE Intelligent Systems, 21*(4), 74-85.

Cross, E. S., Liepelt, R., de, C. H. A. F., Parkinson, J., Ramsey, R., Stadler, W., & Prinz, W. (2011). Robotic movement preferentially engages the action observation network. *Human Brain Mapping*.

Friston, K., & Kiebel, S. (2009). Predictive coding under the free-energy principle. *Philosophical Transactions of the Royal Society London B, 364*(1521), 1211-1221.

Friston, K., Mattout, J., & Kilner, J. (2011). Action understanding and active inference. *Bioligical Cybernetics, 104*(1-2), 137-160.

Gazzola, V., Rizzolatti, G., Wicker, B., & Keysers, C. (2007). The anthropomorphic brain: the mirror neuron system responds to human and robotic actions. *Neuroimage, 35*(4), 1674-1684.

Grafton, S. T. (2009). Embodied cognition and the simulation of action to understand others. *Annual NY Academy of Sciences, 1156*, 97-117.

Ho, C.-C., MacDorman, K. F., & Dwi Pramono, Z. A. D. (2008). *Human emotion and the uncanny valley: a GLM, MDS, and Isomap analysis of robot video ratings*. 3rd ACM/IEEE international conference on Human robot interaction, Amsterdam, Netherlands.

Iacoboni, M., & Dapretto, M. (2006). The mirror neuron system and the consequences of its dysfunction. *Nature Reviews Neuroscience, 7*(12), 942-951.

Ishiguro, H. (2006). Android science: conscious and subconscious recognition. *Connection Science, 18*(4), 319-332.

Ishiguro, H., & Nishio, S. (2007). Building artificial humans to understand humans. *Journal of Artifical Organs, 10*(3), 133-142.

Kanda, T., Ishiguro, H., Imai, M., & Ono, T. (2004). Development and evaluation of interactive humanoid robots. *Proceedings of the IEEE 92*(11), 1839-1850.

Kilner, J. M., Friston, K. J., & Frith, C. D. (2007). The mirror-neuron system: a Bayesian perspective. *Neuroreport, 18*(6), 619-623.

Lewkowicz, D. J., & Ghazanfar, A. A. (2012). The development of the uncanny valley in infants. *Developmental Psychobiology, 54*(2), 124-132.

MacDorman, K. F., & Ishiguro, H. (2006). The uncanny advantage of using androids in cognitive and social science research. *Interaction Studies, 7*(3), 297-337.

MacDorman, K. F., & Kahn Jr, P. H. (2007). Introduction to the special issue on psychological benchmarks of human-robot interaction. *Interaction Studies, 8*(3), 359-362.

Mataric, M., Tapus, A., Winstein, C., & Eriksson, J. (2009). Socially assistive robotics for stroke and mild TBI rehabilitation. *Studies in Health Technology Informatics, 145*, 249-262.

Matelli, M., & Luppino, G. (2001). Parietofrontal circuits for action and space perception in the macaque monkey. *Neuroimage, 14*(1 Pt 2), S27-32.

Mori, M. (1970). The uncanny valley. *Energy, 7*(4), 33-35.

Oberman, L. M., McCleery, J. P., Ramachandran, V. S., & Pineda, J. A. (2007). EEG evidence for mirror neuron activity during the observation of human and robot actions: Toward an analysis of the human qualities of interactive robots. *Neurocomputing, 70*, 2194-2203.

Peelen, M. V., Wiggett, A. J., & Downing, P. E. (2006). Patterns of fMRI activity dissociate overlapping functional brain areas that respond to biological motion. *Neuron, 49*(6), 815-822.

Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience, 27*, 169-192.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Neurophysiological mechanisms underlying the understanding and imitation of action. *Nature Reviews Neuroscience, 2*(9), 661-670.

Sanchez-Vives, M. V., & Slater, M. (2005). From presence to consciousness through virtual reality. *Nature Reviews Neuroscience, 6*(4), 332-339.

Saygin, A. P. (2007). Superior temporal and premotor brain areas necessary for biological motion perception. *Brain, 130*(Pt 9), 2452-2461.

Saygin, A. P., Chaminade, T., & Ishiguro, H. (2010). *The perception of humans and robots: Uncanny hills in parietal cortex*. Proceedings of the 32nd Annual Conference of the Cognitive Science Society, Portland, OR.

Saygin, A. P., Chaminade, T., Ishiguro, H., Driver, J., & Frith, C. (2012). The thing that should not be: predictive coding and the uncanny valley in perceiving human and humanoid robot actions. *Social Cognitive and Affective Neuroscience, 7*(4), 413-422.

Saygin, A. P., Chaminade, T., Urgen, B. A., & Ishiguro, H. (2011). *Cognitive neuroscience and robotics: A mutually beneficial joining of forces.* Robotics: Systems and Science, Los Angeles, CA.

Saygin, A. P., & Cicekli, I. (2002). Pragmatics in human-computer conversations. *Journal of Pragmatics, 34*(3), 227-258.

Saygin, A. P., & Stadler, W. (2012). The role of appearance and motion in action prediction. *Psychological Research, 76*(4), 388-394.

Saygin, A. P., Wilson, S. M., Hagler, D. J., Jr., Bates, E., & Sereno, M. I. (2004). Point-light biological motion perception activates human premotor cortex. *Journal of Neuroscience, 24*(27), 6181-6188.

Seyama, J., & Nagayama, R. (2007). The uncanny valley: Effect of realism on the impression of artificial human faces. *Presence: Teleoperators and Virtual Environments, 16*, 337-351.

Steckenfinger, S. A., & Ghazanfar, A. A. (2009). Monkey visual behavior falls into the uncanny valley. *Proceedings of the National Academy of Sciences of the United States of America, 106*(43), 18362-18366.

Tai, Y. F., Scherfler, C., Brooks, D. J., Sawamoto, N., & Castiello, U. (2004). The human premotor cortex is 'mirror' only for biological actions. *Current Biology, 14*(2), 117-120.

Thompson, J. C., Trafton, J. G., & McKnight, P. (2011). The perception of humanness from the movements of synthetic agents. *Perception, 40*, 695–705.

Tinwell, A., Grimshaw, M., Nabi, D. A., & Williams, A. (2011). Facial expression of emotion and perception of the Uncanny Valley in virtual characters. *Computers in Human Behavior, 21*, 741–749.

Urgen, B. A., Plank, M., Ishiguro, H., Poizner, H., & Saygin, A. P. (2012). *Temporal dynamics of action perception: The role of biological appearance and motion kinematics*. 34rd Annual Conference of the Cognitive Science Society, Sapporo, Japan.

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Yuko Okumura

Perception of Non-Human Agents by Human Infants

Abstract:
How do human infants perceive the nonhuman agents? We report two studies here concerns to this issue. In study 1, infants faced to the android in the context of still-face paradigm. In this paradigm, infants' reactions to a sudden 1 min still face adopted by a social partner in a face-to-face interaction were recorded. Previous studies had shown that infants demonstrated attempts to re-engage the experimenter during the still-face episode with human tester. In the case with android, however, infants did not show such re-engage action. In study 2, twelve-month-old infants were shown videos in which a human or a robot gazed at an object. The results demonstrated that the infants followed the gaze direction of both agents, but only human gaze facilitated their object learning: Infants showed enhanced processing of, and preferences for, the target object gazed at by the human but not by the robot. Importantly, an extended fixation on a target object without the orientation of human gaze did not produce these effects. Together, these findings show the importance of humanness in the gazer, suggesting that infants may be predisposed to treat humans as privileged sources of information for learning.

Gerd Gigerenzer
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Invited Talk
Less-is-More: Simple solutions for complex problems

Abstract:
In worlds of known risks, probability theory typically provides the optimal course of action. In uncertain worlds, however, simple heuristics can result in smart solutions by focusing only on a few cues and ignoring the rest. I illustrate such less-is-more effects through the recognition heuristic, the gaze heuristic, and lexicographic heuristics. The heuristics in the “adaptive toolbox” are anchored in the mind and the environment. They are embodied in the sense that they can exploit capacities of the human mind (such as recognition memory), which allow judgments to be quick. They are anchored in the environment in the sense that they can exploit statistical or social structures (such as signal-to-noise ratio). The study of the ecological rationality of heuristics and the bias-variance dilemma provides a general account to understand why and when less can be more.

Tsutomu Fujinami
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Ryuji Yamazaki, Masaru Nishikawa, Shuichi Nishio

Enabling Bodily Communication between Schoolchildren using a Tele-Operated Humanoid

Abstract:
Tele-operated humanoids open a new field of communication within which participants interact with each other through body movements in addition to voices. Such a new medium poses a challenge to participants in that they are forced to incorporate humanoids into their communication. They have to find out what they are and how they can be used for communication. We need to establish a humanoid literacy just as the Internet literacy was required for everyone to communicate with each other through the Internet. As the first attempt to look for an appropriate use of humanoids in communication, we brought in the telenoid, a tele-operated humanoid, to a primary school to test it in a classroom setting. We recruited a professional dancer, with whom we designed a course of bodily communication using telenoid. In the classroom, students were first instructed to touch it to feel it as if it were an existence akin to human being. They were then asked to name it and were induced to dance to animate it. These steps helped them to attribute a sort of personality to the telenoid. Establishing a communication channel in which the telenoid was involved was, however, another matter and required further trainings to them. The way they communicate with each other was restricted to hand-clapping and singing. All these instructions and trainings had finally led them to a usage in which the telenoid functioned as a medium to convey bodily expressions between them. We report the process in detail and discuss its implication.

Hiroshi Ishiguro
Osaka University

Representation of Humanlike Presence with Robotics Avatars

Abstract:
Geminoid that is an tele-operated android of an existing person can transmit the presence of the operator to the distant place. The operator recognizes the android body as his/her own body after talking with someone through the geminoid and has virtual feeling to be touched when someone touches to the geminoid. However, the geminoid is not the ideal medium for everybody. For example, elderly people hesitate to talk with adult humans and adult androids. A question is what is the ideal medium for everybody. In order to investigate the ideal medium, we are proposing the minimum design of interactive humanoids. It is called Telenoid. The geminoid is the perfect copy of an existing person and it is the maximum design of interactive humanoids. On the other hand, the minimum design looks like a human but we cannot know the age and gender. Elderly people like to talk with the telenoid. In this talk, we discuss the design principles and the effect to the conversation.

Antonio Chella
University of Palermo

Haris Dindo, Rosario Sorbello, Shuichi Nishio, Hiroshi Ishiguro

Sing with the Telenoid

Abstract:
We introduce a novel research proposal project aimed to build a robotic setup in which the Telenoid learns to improvise jazz singing in a duet with a human singer. In the proposed application, the Telenoid acts in teleoperated mode during the learning phase, while it becomes more and more autonomous during the working phase. A goal of the research is to investigate the essence of human communication which is based on gestures and prosody. We will employ an architecture for imitation learning that incrementally learns from demonstrations sequences of internal model activations, based on the idea of coupled forward-inverse internal models for representing musical phrases and the body sequences of singer movements. Possible applications are in the field of entertainment, where the Telenoid setup system acts as a musical game like Guitar Hero or Rock Band; in the field of music learning; for the analysis of mental disorders as Autism, and to build a new generation of companion robots for elderly care.

Sing with the Telenoid

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Keywords: Computer Music; Embodiment; Emotions; Imitation learning; Creativity; Human-robot Interaction.

Introduction

We introduce a novel research proposal project at the RoboticLab of the University of Palermo, aimed to build a robotic setup in which the Telenoid learns to improvise jazz singing in a duet with a human singer. In the proposed application, the Telenoid acts in teleoperated mode during the learning phase, while it becomes more and more autonomous during the working phase.

A main goal of the research is to investigate the essence of human communication which is based on *gestures* and *prosody*. This essential interaction is at the basis of music and of conversation (see Donald 1991).

The adopted setup is based on the Telenoid as a jazz singer able to improvise in a duet with a human singer (see Figure 1). This setup is highly challenging: it takes into account the gestural movements of the singer together with the Telenoid, the expressions of emotions of the Telenoid and the singer during music production, and the creative aspects of music improvisation. It is to be stressed that these aspects are not predefined by the system designer, but they are learned according to the framework of imitation learning.

The software architecture controlling the Telenoid is able to acquire and to learn the gesture movements of a singer teacher during music production and to associate them a suitable emotional state. Therefore, the architecture will learn to associate jazz phrases with suitable gestures and emotional states. During the imitation learning step, the human jazz singer will start to move and to improvise on a fixed musical base with fixed tempo and chords sequences. Then, the Telenoid acting in a teleoperated mode, will begin to learn to mimic the human singer in order to learn the association of gestures, emotions and sound.

During successive steps, the Telenoid will become more and more autonomous and will be able to generalize from the learned music phrases and to improvise by responding in an appropriate way to the partner singer.

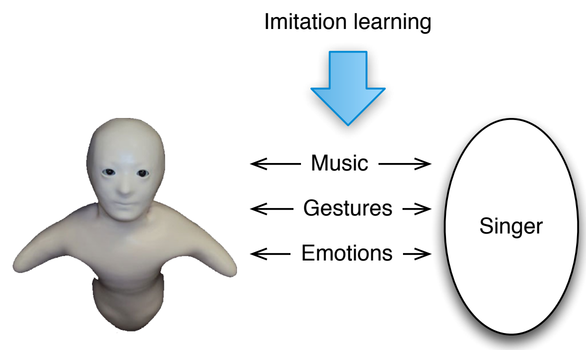

Figure 1: The Telenoid setup.

Embodied systems performing music currently at the state of the art are the *Haile* robot (Weinberg & Driscoll 2006) and the *Waseda Flautist* Robot (Solis *et al.* 2006). However, these systems, through effective, do not take into account the complex interactions between the two partners of a musical duet and based on gestures, emotional states and production of musical phrases.

The Telenoid is an effectively physically embodied agent and it is perceived as a physical agent by the duet partner. It is able to sing, to move, and to receive audio and visual feedbacks by the cameras and the microphones, therefore it is an ideal robot candidate to study the essential basis of human robot interactions (Nishio & Ishiguro 2011).

Jazz Improvisation

Jazz improvisation is an interesting case of study in relation to creativity: creativity during improvisation is different from other typical models of creativity. In fact, the creativity process is often studied with regards to the production of new abstract ideas, as new mathematical or physical idea after periods of great concentration (Boden 2004). Jazz improvisation is instead a form of immediate and continuous lively creation process closely connected with the external world, made up of musical instruments, people, moving bodies, environments, audience and other musicians.

Moreover, jazz improvisation has peculiar features that set it apart from the traditional classic improvisation (Pressing, 1988): as part of Western classical music, improvisation is a kind of *real time* composition with the same rules and patterns of classic composition. On the other side, improvisation is based on a specific set of patterns and elements. The melody, the rhythm (the *swing*), the chord progressions are some of the issues that need to be analyzed and studied with stylistic and aesthetic criteria different from those of Western classical music.

The classical view, often theorized in textbooks of jazz improvisation (see e.g., Coker, 1964), suggests that during a session, the improviser follows his own musical path largely made up by a suitable musical sequence of previously learned patterns. This is a partial view of an effective improvisation. Undoubtedly, the musician has a repertoire of musical patterns, but is also able to deviate from its path depending on the feedback he receives from other musicians or the audience, for example from the rhythm section or due to signals of appreciation from the listeners or due to the movements of the other singers.

Cognitive scientists typically model jazz improvisation processes by means of formal grammars (see Johnson-Laird 1991). This model appears to be problematic because it does not explain the complexity of the interaction between the player, the rest of the group and the audience.

López-González & Limb (2012) in a recent review discuss interesting results from neuroscience related with jazz improvisation. Limb & Braun (2008) pointed out that expert jazz players enter in a peculiar state of mind during improvisation, that is similar to dreaming or hypnosis states. This altered state of mind is in facts characterized by strong activation of sensorimotor areas and deactivation of motivation and emotional brain functions. Spontaneous musical performance therefore happens in absence of self-monitoring and volitional control.

According to Engen & Keller (2011), expert jazz players are quite good at recognizing a genuine jazz improvisation performance with respect to pure rehearsal. Amygdala and suitable motor areas are more activated during listening of improvised melodies than to imitated ones. The listener seems in facts to internally simulate the musical performance in order to evaluate its spontaneity.

These results suggest that a spontaneous jazz improvisation performance do not depends on voluntary actions but it strongly depends on the personal action-related musical experience.

Embodiment and gestures

Embodiment is fundamental to any kind of musical performance: according to Krueger (2009), making music is essentially a body activity. Instead, the current research on algorithmic composition mainly concentrated on expert systems (see Balaban, Ebcioglu & Laske 1992) or neural networks (see Todd & Loy 1991) in order to represent and to generate music.

Only recently, Leman (2008) discussed at length the main relevance of embodiment and gestures for computer music. Notably, Leman reports many evidence concerning the fact that listeners are typically able to associate and reproduce the main gestures of a player during performance by listening off line records of the player. Music is therefore tightly associated with gestures production.

Apart from the previously mentioned *Haile* and the *Waseda Flautist*, an example of embodied systems for music productions is *Roboser* (Manzolli & Verschure, 2005), a Khepera robot that can move autonomously in an environment and generate sound events in real time according to its internal state and to the sensory input it receives from the environment. *EyesWeb* (Camurri *et al.* 2000) is another system that analyzes body gestures with particular reference to emotional connotations in order to accordingly generate sound and music in real time and also to suitably control robots.

As previously stated, the mentioned systems take into account only partially the interactions between partner duets in the framework of imitation learning as in our proposed setup. In this respects, the Telenoid, is an ideal candidate to explore the role of embodiment and gestures in music production.

Emotions and Empathy

The relationships between emotions and music have been widely analyzed in the literature, suggesting computational models describing the main mechanisms underlying the evocation of emotions while listening to music (Juslin & Sloboda 2010).

In the case of a live performance as an improvisation, the link between music and emotions is a deep one: during a successful performance the player create a tight *empathic* relationship between herself and the listeners.

Gabrielsson & Juslin (1996) conducted an empirical analysis of the emotional relationship between a musician and the listeners. According to this analysis, a song arouses emotions on the basis of its structure: for example, a *sad* song is in a minor key, it has a slow rhythm and the dissonances are frequent, while an *exciting* song is fast, strong, with few dissonances.

The emotional intentions of a musician during a live performance can be felt by the listener with greater or lesser effectiveness depending on the song itself. The basic emotional connotations such as the joy or the sadness are easier to transmit, while more complex connotation such as *solemnity* are more difficult to convey. The particular musical instrument employed has a relevance in the communication of emotions, and of course the degree of achieved empathy depends on the skill of the performer. This analysis shows that an agent, to make an effective performance, must be able to convey emotions and to have a model (even implicit) of them.

The relationships between emotions and music also concern social aspects of music. Molnar-Szakacs & Overy (2006) among others, analyze data from neuroimaging suggesting that music, as language, may perform activations of hierarchical organized motor elements able to generate affective responses mediated by mirror neurons systems.

Panksepp (1998) speculates on the possible influences of music to the social motivation system of the brain which are in turns strictly linked with the thermoregulatory systems of the brain. Thus, a sad song may resemble to a cry of a lost child, it may evoke chills generating sensations of cold and thermoregulatory discomfort therefore promoting a desire of reunion.

Music has therefore a strong role in generating and maintaining social bonds; this is an active research field related with the studies on the origins of music that parallels the studies on the evolution of the human kind (Wallin *et al.* 2000).

In the Telenoid setup we will adopt a computational model of emotions that has been previously employed in Cicerobot (Barone *et al.* 2008), a mobile robot acting as a museum guide in indoor and outdoor museums. In particular, we refer to a neural network model of emotional learning developed by Balkenius & Moren (2001) able to summarize and classify the ongoing musical performance of the robot by means of six *basic emotions* proposed by (Ekman 1992): *Joy, Sad, Surprise, Anger, Fear* and *Disgust.*

Our model will give the Telenoid the ability to dynamically learn the emotional value for musical and gestures stimuli. In turns, this emotional state will drive the Telenoid gestures and singing.

The setup with the Telenoid will therefore allow the emotional system to associate emotional states with musical phrases and the body gestures during duet singing.

Imitation Learning

By imitation learning we mean the process of achieving the intention hidden in the observation of an action (Chella *et al.* 2006). In other words, it is not the means that should be imitated, as in a pure mimicking, but rather the final goals. Central to the modeling of such intentional actions is the idea that learning by imitation can be efficiently achieved by reenacting one's own internal models in simulation (Wolpert *et al.* 2003).

In the Telenoid setup we will employ an architecture for imitation learning that incrementally learns from demonstrations sequences of internal model activations (Dindo *et al.* 2011). It is based on the idea of coupled forward-inverse internal models for representing goal-directed behaviors and the body sequences of movements. A forward model is, in the musical context, a predictor that, given the state of the system and a command, produces a prediction of the future outcome of the given musical phrase and the associated gestures and emotional state.

An inverse model, known also as controller in control theory, produces commands necessary to reach a state as a musical phrase given the present state. Internal models are powerful constructs able to represent operational knowledge of an agent and to govern its interaction with the environment. While a single internal model is capable of solving a single task, it is their sequence that enables the system to hierarchically deal with complex task.

The overall behavior therefore emerges by the interaction of incrementally learned skills. Internal models encode behaviors of the system and an ad hoc module is responsible for coordinating the activation of the most significant internal models given the actual state of the system including its motivations and emotions. In a similar way, learning of complex skills is achieved by composing and coordinating simple ones.

Learning to sing is initially triggered by domain-dependent knowledge stored in a component called *Masterplan*. It stores a set of primitive musical phrases, body gestures and emotional states together with an initial ontology, goals and heuristics needed to monitor the learning progress. By directly interacting with the human singer the system generates hypotheses of new models. These will be stored in *Masterplan* and tested in order to assess their usefulness.

The system learns new models of singing and gestures and the related emotional states by interacting with the human singer. The components of the system continuously analyze the perceptual data in order to acquire this new knowledge. Initially the system interacts with the human singer in a teleoperated way by singing casual phrases and executing random movements in order to learn simple causal relations of the entities of the world and of itself - a process common in newborns called babbling. More complex models, encoded as chains of simple models activations, are learned by interacting and observing the human singer during long time sessions.

When acting, the agent needs to decide what to do in a particular musical situation. It should be noticed that, as showed by the previous results from neuroscience, jazz improvisation is not a goal driven activity, but it is a sort of explorative activity without volition.

An explorative module is therefore responsible of selecting which internal models to execute given the current musical, emotional and body situation. Decisions are made reactively and in parallel by exploiting the available knowledge at present, by taking into account the emotional state too. Since multiple decisions can be made, we developed a module that anticipates possible choices and uses this information to decide the set of gestures and musical phrases to be executed in a particular emotional state.

Conclusions

An application field of the described system is the entertainment, where the system may act as a sort of musical game like *Guitar Hero* or *Rock Band*, in which the human player is engaged in singing in tune at the right tempo with the Telenoid. A related application is in the field of music learning: the system may be employed by jazz singers to learn and practice jazz songs and to experiment new musical ideas.

An interesting application field is the analysis of mental disorders. The described system may be employed in order to study Williams syndrome (Levitin & Bellugi 1998) or Autism disorders (Bhatara *et al.* 2010).

Finally, an application area may concern elderly care, when a senior person could have the possibility to teach and store by means of the Telenoid, all the popular songs learned through his whole life in order to save part of the popular music cultural heritage.

References

Balaban, M., Ebcioglu, K. & Laske, O. (Eds.) (1992). *Understanding Music with AI: Perspectives on Music Cognition*. AAAI Press/MIT Press, Menlo Park, CA.

Balkenius, C. & Morèn, J, (2000). Emotional learning: a computational model of the amygdala. *Cybernetics and System, 32,* 611-636.

Barone, R., Macaluso, I., Riano, L. & Chella, A. (2008). A Brain Inspired Architecture for an Outdoor Robot Guide. In: A. Samsonovich (Chair) (2008). Biologically Inspired Cognitive Architectures, Papers from the AAAI Fall Symposium. Technical Report FS-08-04, AAAI Press, Menlo Park, CA.

Bhatara A., Quintin, E.-M., Levy, B., Bellugi, U., Fombonne, E. & Levitin, D.J. (2010). Perception of Emotion in Musical Performance in Adolescents with Autism Spectrum Disorders, *Autism Research*, *3*, 214–225.

Boden, M. (2004). *The Creative Mind: Miths and Mechanisms - Second Edition.* Routledge, London.

Camurri, A., Hashimoto, S., Ricchetti, M., Ricci, A., Suzuki, K., Trocca, R. & Volpe, G. (2000). EyesWeb: Toward Gesture and Affect Recognition in Interactive Dance and Music Systems. *Computer Music Journal*, *24*, 57 – 69.

Chella, A., Dindo, H. & Infantino, I. (2006). A cognitive framework for imitation learning. *Robotics and Autonomous Systems*, *54*, 403–408.

Coker, J. (1964). *Improvising Jazz*. Simon & Schuster, New York, NY.

Demiris, Y. (2007). Prediction of intent in robotics and multi-agent systems. *Cognitive Processing*, *8*, 151–158.

Dindo, H., Chella, A., La Tona, G., Vitali, M., Nivel, E. & Thorisson, K.R. (2011). Learning Problem Solving Skills from Demonstration: An Architectural Approach. In J. Schmidhuber, K.R. Thorisson, & M. Looks (Eds.), *AGI 2011*, Lecture Notes in Artificial Intelligence 6830, 194-203, Springer-Verlag, Berlin, 2011.

Donald, M. (1991). *Origins of the Modern Mind.* Harvard University Press.

Ekman P, 1992. Are there basic emotions? *Psychological Review*, *99*, 550 – 553.

Engel, A., & Keller, P. E. (2011). The perception of musical spontaneity in improvised and imitated jazz performances. *Frontiers in Psychology*, *2*, 1-13.

Gabrielsson, A. & Juslin, P.N. (1996). Emotional Expression in Music Performance: Between the Performer's Intention and the Listener's Experience. *Psychology of Music*, *24*, 68 – 91.

Johnson-Laird, P.N. (1991). Jazz Improvisation: A Theory at the Computational Level. In: *Representing Musical Structure*. P. Howell, R. West & I. Cross (Eds.), Academic Press, London.

Juslin, P.N. & Sloboda, J.A. (Eds.) (2010). *Handbook of Music and Emotion, Theory, Research, Applications*. Oxford University Press, Oxford, UK.

Krueger, J.W. (2009). Enacting Musical Experience. *Journal of Consciousness Studies*, *16*, 98-123.

Leman, M. (2008). *Embodied Music Cognition and Mediation Technology.* MIT Press, Cambridge, MA.

Levitin, D.J., & Bellugi, U. (1998). Musical ability in individuals with Williams' Syndrome. *Music Perception*, *15*, 357–389.

Limb, C. J., & Braun, A. R. (2008). Neural substrates of spontaneous music performance: An fMRI study of jazz improvisation. *PLoS ONE*, *3*, e1679.

M. López-González, M. & Limb, C. (2012). Musical Creativity and the Brain. *Cerebrum*, February.

Manzolli, J. & Verschure, P.F.M.J. (2005). Roboser: A Real-World Composition System. *Computer Music Journal*, *29*, 55 – 74.

Molnar-Szakacs I. & Overy, K. (2006). Music and mirror neurons: from motion to 'e'motion. *SCAN*, 1, 235–241.

Nishio, S. & Ishiguro, H. (2011). Attitude Changes Induced by Different Appearances of Interaction Agents. *International Journal of Machine Consciousness*, *3*, 115 – 126.

Panksepp, J. (1998). *Affective Neuroscience: The Foundations of Human and Animal Emotions.* Oxford University Press, Oxford, UK.

Pressing, J. (1988). Improvisation: Methods and Models. In: *Generative Processes in Music: The Psychology of Performance, Improvisation, and Composition*. J. Sloboda (Ed.), Oxford University Press, Oxford, UK.

Solis, J., Chida, K., Taniguchi, K., Hashimoto, S.M., Suefuji, K. & Takanishi, A. (2006). The Waseda Flutist Robot WF-4RII in Comparison with a Professional Flutist. *Computer Music Journal*, *30*, 12 – 27.

Todd P.M. & Gareth Loy, D. (Eds.) (1991). *Music and Connectionism*. MIT Press, Cambridge, MA.

Wallin, N., Merker, B. & Brown, S. (Eds.) (2000). *The Origins of Music*. MIT Press, Bradford Books, Cambridge, MA.

Weinberg, G. & Driscoll, S. (2006). Toward Robotic Musicianship. *Computer Music Journal*, *30*, 28 – 45.

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