Using Robot Assisted Therapy Tools in Rhythm and Locomotion Intervention Contexts with Typically Developing...


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Using Robots to Teach Musical Rhythms to Typically Developing Children and Children with Autism

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ABSTRACT

Robot assisted therapies offer promise as training and educational tools for facilitating learning in children. Music training or therapy is often provided to school-age children. We are using commercially available humanoid robots to systematize music training sessions by providing consistent repetitive training that is also spontaneous and interactive. We use an embodied approach to musical training wherein the robot progresses from whole body rhythmic actions to finer drumming actions. In order to minimize the amount of control and energy needed to create rich sounds we took advantage of the forces in the system. In this way the robot was able to produce complex dynamics with minimal control. We were able to create multiple themes as basic behaviors. 10 typically developing children interacted with Nao across 12 rhythm training sessions within a robot-child-child context. Pre-, mid- and posttest data have been collected to examine the child's motor patterns during whole body action and drumming. Preliminary analyses are currently ongoing. We hypothesize that the children will improve their intralimb

and interlimb coordination during rhythmic actions such as marching, clapping, and drumming following training. We also hypothesize that social interactions such as conversation bouts and rates of joint attention bids will increase across training sessions. Overall, we believe that the rhythm intervention context developed with a 23-inch tall humanoid robot called Nao (Aldebaran Robotics, Inc.) is a highly engaging context for children to facilitate social communication and motor skills. Robot child interaction based training shows promise as a modality for skills training and education.

Keywords: humanoid robotics, rhythm therapy, education, autism, music

1. INTRODUCTION

This work is based on a collaboration between several departments at the University of Connecticut and members of the community. We are looking at issues of human robotic interface and how it relates to real world applications in education and therapy. Our fundamental perspective is that communication and social interaction are embodied dynamical processes. [10,16,17] Aspects of perceptuo motor control are fundamental to attunement and interaction. Training that promotes motor control and awareness of the movements of others can improve basic social skills, communication, and quality of life. [5,11,12,13,14,17]

2. BACKGROUND

Robot assisted training offers promise as an educational and therapeutic tool to facilitate learning in children. [7,8,18,19,20,25] In robot assisted training the trainer works with a child using the robot as a tool to lead and motivate the child. The training contexts may involve one robot and one to two children. In all cases we have an adult mediate the interactions between the robot and the children. The trainer sets the mode of operation of the robot, the child and robot go through an activity. The activities address specific skill sets within motor, social, and communication domains. Kids are motivated to interact with robots. [20] Children in general find robots interesting and enjoyable to work with. This offers the opportunity to use robot interactions as a motivating context for repetitive activities. This is helpful in training regimens where part of the effort by the trainer is generally engaging the child to participate and then maintaining their engagement throughout the training session. Some time is often spent in re-engaging the child after they have been distracted from the task at hand. Robots are dynamically interactive and can participate in re-engaging the child and primary activity.

3. CAPABILTIES OF ROBOTS

In our research we are working to develop deployable systems that can be used in real-world clinical and educational environments. Commercial robotics has reached a level of maturity that has made available robust humanoid and mobile robots that could be used as training tools by clinicians and educators in the field. These robots have several capabilities that can be applied to robot assisted training. Robots have the ability to provide social interactions through the use of language and gestures [19,20]. The robot can be programmed to speak predetermined sentences. The phrases and sentences can be triggered as a response to speech recognition or initiated by the trainer. Various gestures can be programmed by these robots as part of their motor repertoire. Each of these actions can be modified in a systematic way so that the complexity of the interaction can be varied based on the level of training that is appropriate.

Currently available robots such as the Nao (Aldebaran Robotics, Inc.) can provide lifelike (real world?) interactions. The Nao has 25 degrees of freedom giving it a morphology that is very similar to that of a human. This provides the opportunity for the robot to engage in simple to complex motor activities with the children, for example, imitation games. The similarity in morphology also provides the opportunity for the robot to operate devices that can be used by people. These can be toys or musical instruments.

Several robots have the ability to move through an environment at various speeds. This locomotive ability provides the opportunity for interactions with the child such as chasing games or walking in step. [17] In some cases it is necessary to use a wheeled robot to maneuver with the children because of the greater robustness of the wheeled modality as compared to current legged walking robots.

INTERPERSONAL SYNCHRONNY

Moving in synchrony with another, entails entrainment to the other person. [12,21] This may be a form of mimicry which is an important social skill. [12] This entrainment is the bases for increasing interpersonal synchrony. This interpersonal synchrony is a dynamic process that emerges from the interplay between the members of the group. As they move together they mutually influence each other creating an emergent synchronous system that is self organizing. This system is an emergent social unit. [16,17]

Acting in a coordinated fashion with others promotes feelings of connectedness. [12] The activity of drumming with the robot and another child may promote social bonds. Wiltermuth and Heath found that synchronous activities can lead people to cooperate with others and further that this activity could lead to future cooperation. [26] This synchronous activity equips the actor with abilities that enable them to cooperate in the future.[9,26] Kirschner & Tomasello found that typically developing (TD) children can synchronize their drumming to a machine, but young TD children benefited from a social context where they were drumming with another child, enabling them to perform better in difficult tasks such as adjusting to a different tempo.

This is evidence for including a child-child-robot context[13]. The joint action task of drumming motivates the children to act in a cooperative way[13].

Musical synchrony interacts with the social synchrony during group music making .[5,17] Demos et al., 2011 found the synchronous activity acted as a social attractor that lead people to feel like they were synchronizing with other people. Interestingly the degree to which people felt they were in sync with others wasn't correlated with how much they were in sync to the other people, but rather to how much they were in sync with the music. The music acted as a social intermediary forming a bridge between the participants. [5] In this way the rhythm imparted into the group by the robot could act as a bridge between the two children. Other pro-social effects were observed by Hove and Rosen 2009, who found that interpersonal synchrony lead to feelings of affiliation. [11]

4. RHYTHM THERAPY

Therefore one of our training contexts capitalizes on interpersonal synchrony and is modeled on the principles of rhythm therapy. This application takes advantage of many of the features provided by the humanoid robots and provides many benefits sought through robot assisted training including cooperation and joint attention. [13,14] We have developed drumming activities where children could play drums along with the robot. This could be done in a dyadic context where a single child plays with the robot and in a triadic context where two children will play with a single robot. [14] Drumming is fairly complex yet achievable activity for the robot. With the appropriate programming, it is possible to achieve reliable drum hits that have a good sound using appropriate humanoid robots. Currently, we are developing clear drumming motions of the robot so that they are easily perceived and understood by the children[18].

5. ROBOT CONTOL

To support these activities the main capability necessary for the robot is the ability to successfully and repeatedly play a drum. The robot needs to be able to produce clear loud sounds in simple and complex patterns at a measured tempo. This seemingly simple set of requirements produces some interesting technical issues that need to be solved.

In order to produce a clear and loud report from the drum surface it is necessary to impact it with a quick forceful stroke. If we impact the drum with the robot's end effector (hands or fingers in the case of Nao) it will cause great stress and wear leading to failure of the mechanical structure. To overcome this we have the robot playing the drum with mallets or drumsticks. In this way the impact stress is taken by the mallet and is reduced by the time it reaches the robot's joints. Since the children are of varying motor ability we ask them to play the drum with their hands. The sounds generated by these two activities are similar and we have not seen any disconnect between the children and the robot based on the different drumming tools used i.e., sticks versus hands.

Figure 1. The Aldebaran Nao robot shown in position at the drum holding the drum mallets.

While drumming it is possible to over control the movements of the robot in an effort to be precise. The system has its own natural dynamics and cannot be completely constrained to a particular motion path rather it needs to move within its natural periodicity to produce the desired results[15]. If the system is over constrained to achieve an ideal movement it will entail additional mechanical stress and additional power to maintain the exact motion path needed to produce the desired result. Our solution to this problem is to use the forces in the joint system of the robot, mallet, and drum to our advantage. We are able to use simple control parameters to produce complex dynamics that emerge naturally from the system. These complex emergent dynamics are needed to produce the rich sound desired [6,15].

Another problem facing mechanisms that need to produce repetitive motion in synchrony with external events is accumulating error. As the drumming robot produces each stroke it is acting in a natural system where some of the forces are not under its control. These forces can cause one stroke to take a different amount of time than another stroke. If the system is running in a linear fashion with each stroke starting after the previous one is finished then the tempo of the strokes will vary randomly based on these effects. These errors will accumulate over time causing the system to move further and further from the original timing. Our solution is to enable the system to move dynamically from one action to the next without regard for its current or previous position. The system is able to interpolate from any given initial position to the desired position at the required time to support the tempo. This prospective behavior works toward a desired future state rather than working off of a previously achieved state. [22]

6. DYNAMICS IN THE SYSTEM

In order to achieve the desired dynamics we use a biologically inspired model where we use the morphology of the robot in different ways depending on where we are in the task. In nature muscles can play different roles with little change in activation depending on the context. Muscles can act as motors, struts, and springs depending on their activation and the physical orientation of the entire system. We also use the forces in the system to drive the performance of the system as a whole [4]

Grasping: One way that biological systems detect objects within the environment is through haptic feedback. [3] Contact with an object is indicated through deformations of the entire system. We use this same technique to detect that the end effector is grasping the mallet by comparing the actual or measured joint angles of the fingers to the joint angles that being triggered by the control software. If the joint angles are less than the requested angles then there is something there that is restricting the movement of the fingers.

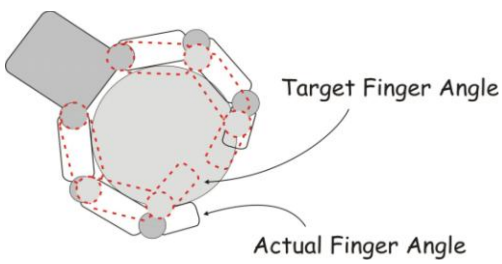

Figure 2. Here we see the end effector grasping the drumstick. The dotted line indicates the requested finger position. The solid line shows the actual resultant position. The difference indicates the presence of an object.

Arm Dynamics: The stiffness of the actuators is kept low throughout the cycle which enables them to be used as motors and dampers depending on where in the cycle at any given point. The elastic surface of the drum acts as a spring. The mallet is grasped loosely and can swing freely with momentum. The arm moves through an arc that is close enough for the mallet to swing to reach the drum head. The arm is beginning to return to the upswing while the mallet is impacting the surface of the drum. The mallet is being carried away from the drum head before it is able to bounce back into the drumhead eliminating any repercussive effects of multiple hits. The dynamics of the arm-end effector-mallet-drum run on a much faster scale than our program and we *do not have* to control it. We only have a projected joint angle trajectory as a sinusoid. Functionality emerges as a product of small parameter changes and context.[4,6,15,22]

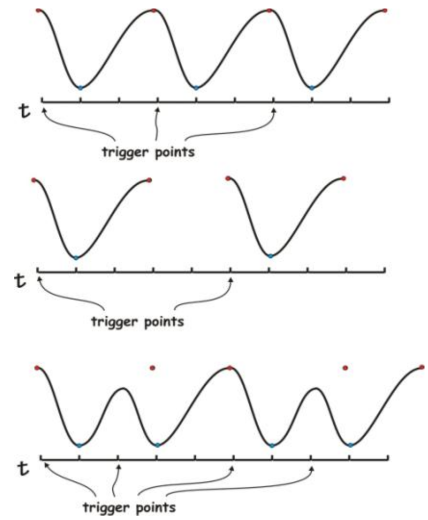

Figure 3. Arm Joint Angles over time. The top graph shows a continuous beat. The middle graph shows a tempo where the length of a cycle is longer than the time it takes to complete a down swing and an upswing. The bottom graph shows a rhythm where the time to complete the upswing is greater than the time before the next downswing. The arm only travels part of the way to the upper position before being triggered to go to the down stroke.

Arm Stroke Cycle: The arm is controlled by triggering the arm to move to a desired angle in a precise time t. At time t the arm is then triggered to move to the upper joint angle by time 2t. The speed at which the joint angles are altered follows a spline curve computed by a movement interpolator imbedded in the Nao's control software. Although the joint angles are being controlled the stiffness is low allowing the arm to naturally overshoot its target angle. The momentum of the mallet carries the head of the mallet into the drumhead. Due to the loose stiffness setting of the grasp of the end effector the mallet bounces freely off of the drum head without precise control. The time triggered for travel to up position is longer than down position time producing less force and stress on the system.

By using these principals we were able to take advantage of the forces in the task to and use minimal control whole producing complex dynamics. The end result is clear drumming that can be easily controlled to produce multiple rhythms.

7. EXPERIMENTAL DESIGN

Subjects: 14 typically developing children between 4 to 8 years of age have been observed over a 12 session training protocol delivered over six weeks (2 sessions per week). Two children with an age difference of approximately two years interacted with Nao and a mobile robot Rovio (Wowwee, Inc.) during each 45-minute training session. Pretest and posttest assessments were conducted before and after training.

Testing protocol: Pretests and posttests involved tasks-specific actions (rhythmic gross motor and drumming actions) within the training context with the robot. We also conducted generalized tests using standardized assessments such as the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) [2] and the Sensory Integration and Praxis Test (SIPT) [1]. Specifically, the bilateral coordination subtest of the BOTMP measured changes in bilateral gross motor coordination and the bilateral motor coordination subtest of the SIPT measured changes in rhythmic coordination of arm and leg movements such as hand patting, leg stomping, and foot tapping. Lastly, we also have a generalized synchrony test wherein the two children who worked together with the robot were engaged in rhythmic activities with each other in a novel testing environment excluding the robot. The children moved together during dual-limb clapping, multilimb march and clap, symmetrical and alternate drumming, as well as "walk in step" actions.

Training Protocol: During each training session, the two children stood beside each other and in front of the Nao robot. The first six sessions involved rhythmic themes such as start and stop motions, slow and fast motions, move on a steady beat, small and large motions, move in turns, and move on a count. The last six sessions were a combination of these themes. Each training session involved the following conditions:

a) Introductory statements: Nao greeted the children and asked them about their day.

b) Warm up: Both children performed stretching exercises with Nao as a warm up activity.

c) Action: The next three conditions involved three, 30-second components: "copy robot", "move together", and "free action". Both children were asked to move with the Nao during whole body rhythmic actions such as clapping and marching.

d) Drumming: Both children and Nao performed symmetrical and alternate drumming based on the musical theme of the day. During later sessions, the robot and the children performed various complex quarter and eighth note patterns.

e) Walking: Both children followed Rovio along different spatial paths based on the themes of the day. The paths followed were simple shapes or letters. Later, the children were asked to guess the shape or the letter. Children were allowed to draw out the path on paper to help them guess the shape or letter produced by their path.

f) Leave taking: The Nao robot ended the session with a good bye statement.

Data Analyses: Standardized testing scores: Raw scores and standard scores from the standardized tests will be used to examine training-related improvements in gross motor coordination as well as rhythmic coordination for each child. Generalized synchrony test: During this test, we collected hand, foot, and joint kinematics from both limbs of both children using retroreflective markers placed on the children's body segments which were tracked using the Vicon Motion Analysis System (Vicon, Inc., Sampling rate: 120 Hz). We will be comparing the kinematic patterns of the two limbs of each child to measure intrapersonal synchrony or complex motor coordination. We will also compare the kinematic patterns of the two corresponding limbs of the two children to measure the interpersonal synchrony between the two children. Using continuous relative phase (CRP) analyses, we plan to assess the percent of data wherein children move in "complete synchrony" (values ranging from 0-60°), "opposite synchrony" (values ranging from 120-180°), and "off synchrony" (values ranging from 60-120°). Verbalization and joint attention patterns: We will also code the changes in frequency of spontaneous verbalizations and spontaneous joint attention patterns (shifts in eye gaze and/or head turns between the robot and the other child) across training sessions to measure the quantitative changes in socialization between the two children.

Expected Results: Children may show improvements in gross motor coordination, rhythmic coordination of hands and feet, and sociability (i.e., increased rates of child-directed verbalizations and rates of joint attention bids). In addition, these changes may occur within the training context as well as in the generalized testing context.

8. CONCLUSION

Overall, we believe that the robot-child-child training context is an engaging context to facilitate motor and social skills in school settings. Such a training context may be a valuable tool to facilitate socialization between typically developing children as well as children with social and motor impairments such as children with Autism Spectrum Disorders. We were able to achieve good robotic performance of the drumming actions using biologically inspired design principles. These techniques show promise for further development for optimized robotic performance. This ongoing work is the result of an interdisciplinary collaboration of psychology, physical therapy, education, electrical engineering, and computer science.

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