Smart and Connected Actuated Mobile and Sensing Suit to Encourage Motion in Developmentally Delayed Infants[1]

Emily Rogers
Harvard School of Engineering and Applied Sciences,
Cambridge, MA 02138

Panagiotis Polygerinos
Harvard School of Engineering and Applied Sciences,
Cambridge, MA 02138;
Wyss Institute for Biologically Inspired Engineering,
Boston, MA 02115

Conor Walsh
Harvard School of Engineering and Applied Sciences,
Cambridge, MA 02138;
Wyss Institute for Biologically Inspired Engineering,
Boston, MA 02115

Eugene Goldfield
Wyss Institute for Biologically Inspired Engineering,
Boston, MA 02115;
Boston Children's Hospital,
Boston, MA 02115

1 Background

In 2004, 12.5% of infants born in the U.S. were born prematurely (less than 37 weeks gestation period), putting them at an increased risk of motor, cognitive, and behavioral deficits [1]. The risk of cerebral palsy, a condition characterized by delayed development, spasticity, poor balance, and difficulty or inability to walk, increases from 1.9% to 17.7% with a gestation period of less than 33 weeks [1]. Early intervention physical therapy has been shown to facilitate an infant's ability to reach motor development milestones [2]. However, because cerebral palsy is difficult to diagnose before the age of two, many infants do not begin receiving treatment until after gait and movement abnormalities have caused secondary health problems [2].

One developmental milestone that is very important for gait development is spontaneous infant supine kicking, exhibited from 2 to 9 months of age in typically developing infants [3]. Initially, kicking is a spontaneous exploratory behavior with highly unstructured joint motion [3]. The relationships between different parts of the leg become increasingly more established as joint coordination, movement planning, and reciprocal motion are learned [3]. Reaching the kicking stage later than typically developing infants exacerbates the locomotion problems that developmental delayed infants face.

Experiments on infant memory and behavior by Rovee-Collier have shown that infants as young as 2 months old are capable of forming process memories and learning and will modify their behavior in order to receive a reward [4]. Connecting the subjects' ankle to a hanging mobile, so leg kicking caused movement of the mobile, showed an increase in kicking frequency and amplitude [4]. By incorporating knowledge of infant learning into the design of a therapy device, spontaneous kicking can be encouraged in developmentally delayed infants by providing an external stimulus in response to kicking.

The soft wearable sensing suit presented in this paper (Fig. 1) is an early intervention treatment that will encourage kicking, improving joint coordination and gait development, and can be used as a precautionary treatment for at risk infants even before an official diagnosis is possible.

2 Methods

Discussions with clinicians as well as a literature review identified the need for an assistive device to encourage kicking in developmentally delayed infants. The device must measure joint angle of the hip and knee within ± 10 deg, provide a positive stimulus to encourage kicking, record the sensor data and information for later analysis, and it must be low cost. The final design (Fig. 2) is a soft spandex suit with sensors on the hips and knees, a control box, an external stimulus, and a graphical user interface (GUI).

The sensor suit is a soft, flexible, spandex one-piece suit that can be comfortably worn by the infant with zippers on the legs and arms. Thin pockets on the knees and hips hold the sensors in place and prevent contact with the infant's skin. Thin channels of fabric in the suit direct sensor wires away from the infant's body. The joint angle sensors are variable resistors (Flex Sensor 2.2". SEN-10264, Sparkfun Electronics, Niwot, CO) that output a voltage proportional to their bending. This voltage can be converted using a scaling factor to approximate the corresponding joint angle. The control box isolates the electronic components to add an extra factor of safety to the device. A microcontroller (Arduino Mega 2560 R3, A000067, Scarmagno, Italy) was programmed using SIMULINK, MATLAB to read the signal from the joint angle sensors, send the sensor data to the computer, and output the appropriate response to control the mobile. The mobile is attached to a DC motor that spins when infant kicking is detected. In Fig. 4 the dashed line represents the right hip and the solid line represents the left hip. In both Figs. 3 and 4, the labeled lines indicate when the mobile was turned on, corresponding to periods of infant

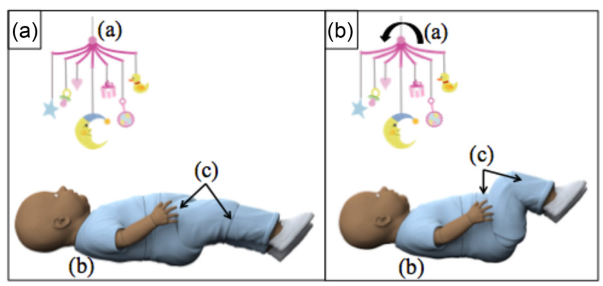

Fig. 1 (a) Mobile, (b) sensing suit, and (c) joint angle sensors. (*a*) Infant still, mobile off and (*b*) infant kicking, mobile spins.

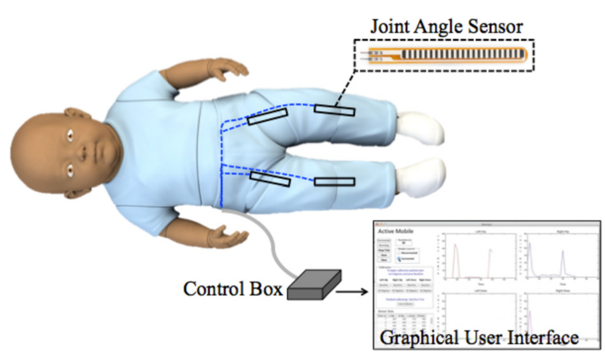

Fig. 2 Schematic of final device including sensing suit, joint angle sensors, control box, and GUI

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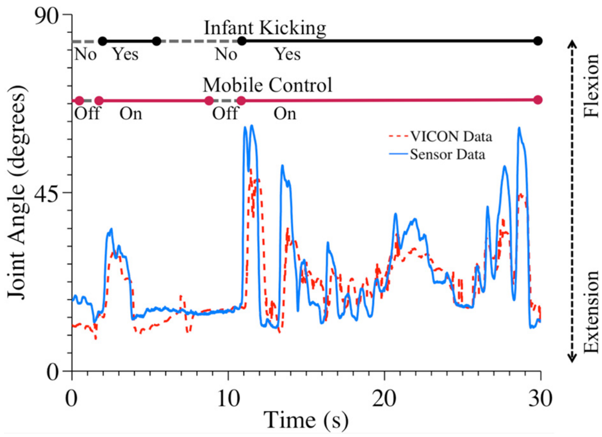

Fig. 3 Comparison of Vicon and joint angle sensors joint angle measurement of right hip. Horizontal lines indicate periods of infant kicking and mobile spinning.

kicking. A GUI was designed using MATLAB, for easy control of the device from a personal computer. The GUI allows the user to connect to the device, calibrate the sensors to read joint angles specific to the individual infant, view real-time plots of the infants motion, turn the mobile connection on or off, depending on their requirements, and save and analyze data.

3 Results

Preliminary testing was performed on a typically developing 3-month-old infant, the age of the intended target population. The subject was a volunteer (the mother of the infant gave informed consent) and testing was approved by the Harvard Medical Institutional Review Board (IRB). In order to analyze the performance of the device, motion capture technology (Vicon, T160, Denver, CO) was used to collect information about the infant's kicking and compare it to the data recorded by the sensing suit. The trial data were analyzed using visual reconstruction software (VISUAL 3 D, V3D-v5) to create a three-dimensional human model from the marker positions and calculate kinematics and joint angle.

A portion of the collected data is shown in Fig. 3 and demonstrates the ability of the sensing suit to capture accurately the direction of flexion/extension, the relative amplitude of kicking, and the periods of motion versus no motion. These results show that joint angle sensors alone are sufficient for effectively and accurately controlling the mobile and recording kicking data, without the need for costly monitoring equipment. The data were analyzed to determine the accuracy of the mobile control system. The control box was programmed to turn the mobile on if the change in joint angle at the hips was greater than 5 deg/s, and to turn the mobile off if the velocity was less than this. The sensitivity of the mobile response can easily be adjusted as the infant learns the relationship between their kicking and the reward. Figure 4 shows the right hip in blue and the left hip in red. In both Figs. 3 and 4, the red lines indicate when the mobile was turned on, corresponding to periods of infant kicking. The two second lag in response between the infant stopping motion and the mobile pausing is due to the relatively slow execution speed of the SIMULINK code, which could be optimized in future iterations.

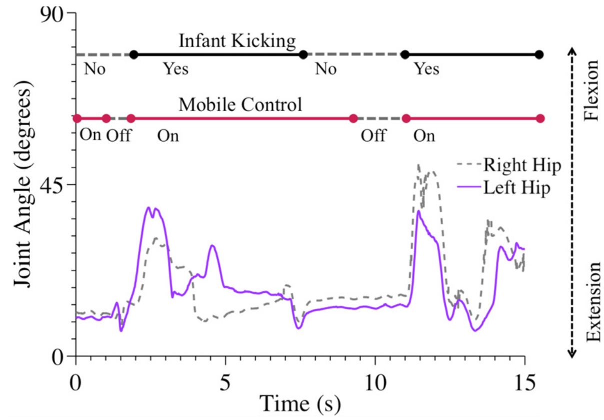

Fig. 4 Joint angle of right and left hip and corresponding mobile spinning

4 Interpretation

In this paper, a wearable sensing suit was shown to accurately measure joint angle during infant kicking and trigger an external stimulus to encourage kicking. This device has the potential to make early intervention treatment more accessible for developmentally delayed infants, improve joint coordination and gait development, and increase physical ability and overall quality of life. Future work will include interfacing the sensing suit with a previously designed actuator suit [5] that provides physical assistance to the infant in addition to encouragement from the stimulus. Further human subject testing is necessary to determine the behavioral effect of the system on development.

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