Sensor-Enabled Detection of Stereotypical Motor Movements in Persons with Autism Spectrum Disorder

Matthew S. Goodwin
The Groden Center, Inc.
86 Mt. Hope Ave.
Providence, RI 02906 USA
mgoodwin@grodencenter.org

Stephen S. Intille
MIT Department of Architecture
Cambridge, MA 02139 USA
intille@mit.edu

Wayne F. Velicer
Psychology Department
University of Rhode Island
Kingston, RI 02881 USA
velicer@uri.edu

June Groden
The Groden Center, Inc.
86 Mt. Hope Ave.
Providence, RI 02906
jgroden@grodencenter.org

IDC '08, June 11-13, 2008 Chicago, IL, USA
ACM 978-1-59593-994-4

Abstract
Stereotypical motor movements are one of the most common and least understood behaviors occurring in individuals with Autism Spectrum Disorder (ASD). Problems with traditional methods for measuring movement stereotypy make it difficult to accurately determine when and why these behaviors occur. The current research overcomes previous measurement problems by utilizing wireless accelerometers and pattern recognition software to automatically and reliably detect stereotypical motor movements such as *body rocking* and *hand flapping* in children with ASD.

Keywords
stereotypy, Autism Spectrum Disorder, accelerometer, pattern recognition

ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

Introduction

Utilizing new measurement technologies that can be used in a variety of settings to comfortably and reliably assess and communicate stereotypical motor movements, an understudied, core diagnostic feature of Autism Spectrum Disorder (ASD), could provide an important step in advancing our knowledge of the phenomenology of this behavior. This brief report is divided into four primary sections. The first section describes diagnostic criteria for ASD, discusses the significance of stereotypical motor movements, and critically reviews assessment methods currently available for measuring stereotypy. The second section discusses the use of accelerometry to recognize physical activity. The third section presents data demonstrating the feasibility and accuracy of using accelerometry and pattern recognition to detect stereotypical motor movements in persons with ASD. The final section discusses the significance of this research and highlights future directions that can build on this effort.

Autism Spectrum Disorder & Stereotypy

Autism Spectrum Disorder

ASD is characterized by the following triad of impairments: deficits in socialization, communication, and circumscribed interests, including stereotypical behavior.

Stereotypy

Stereotyped behaviors are generally defined as repetitive interests and/or motor or vocal sequences that appear to the observer to be invariant in form and without any obvious eliciting stimulus or adaptive function. The current research focuses on the stereotyped and repetitive motor movement definition of stereotypy. Several motor stereotypies have been identified, the most prevalent among them being body-rocking, mouthing, and complex hand and finger movements [2].

Prevalence & Impact of Movement Stereotypy

There is a high prevalence of movement stereotypy reported in individuals with ASD. When severe, movement stereotypy can present several problems for individuals with ASD and their families. First, persons with ASD often engage in stereotyped movements for the majority of their waking hours. Preventing or stopping these movements is often problematic as individuals with ASD may become anxious, agitated, or aggressive if they are interrupted. Second, if left untreated, stereotyped movements can become the dominant behavior in an individual's repertoire and interfere with the acquisition of new skills and performance of established skills. Third, engagement in this behavior is socially inappropriate and stigmatizing and can complicate social integration in school settings and the community. Finally, stereotyped movements are thought to lead to self-injurious behavior under certain environmental conditions.

Measuring Movement Stereotypy

Paper-and-pencil rating scales, direct observation, and video-based methods represent traditional ways to assess movement stereotypy. From a measurement standpoint, all of these methods are problematic. Paper-and-pencil scales are subjective, can have questionable accuracy, and fail to capture inter-individual variations in the form, amount, and duration of stereotypy. Direct observation is often unreliable due to a host of factors (e.g., reduced accuracy in observing and documenting high-speed motor sequences; difficulty determining when a sequence has started and ended; limitations in the ability to observe concomitantly occurring stereotyped movements). Video-based methods that permit slow playback speeds and multiple viewing are often quite reliable, however, these methods are tedious and time consuming, making them impractical for most clinicians to use on a regular basis in applied settings.

In this work, sensor-enabled recognition of movement stereotypy is explored. The goal is to use sensor technology to provide a measure that may be more objective, detailed, and precise than rating scales and direct observation, and more time efficient than video-based methods.

Physical Activity Recognition & Accelerometery
Algorithms have been developed to detect overall motion levels using actigraphy. An actigraph is an accelerometer that aggregates motion over short windows of time, typically several seconds or several minutes long. "Cut points" for clinically meaningful activity intensity levels can be determined based on actigraph counts, and use of actigraphs for measurement of physical activity is an active area of research.

Recent work has shown that supervised and un-supervised learning pattern classification algorithms can be used to detect a variety of physical activities [1]. The use of multiple accelerometer sensors permits an algorithm to use the information about relationships between characteristics of movement between different sensors and axes within sensors. Features of each raw signal are computed, such as the frequency of motion, the temporal extent and variability of the movement, the amplitude of motion changes, and compared between sensors located on different limbs. If a sensor is worn at a known orientation on the body, the change of orientation of a limb can be determined. By comparing the change in orientation of sensors on multiple limbs, relative patterns of motion between limbs can be identified.

Accelerometers & Pattern Recognition to Assess Stereotypical Motor Movements
We are aware of only one pilot study using accelerometers to detect movement stereotypy [3]. In that work on recognition of hand flapping, 69% of events were automatically detected with HMM, but the data was acquired from healthy individuals mimicking the movements – no individuals with autism performing the movement were actually observed. In the current study, algorithms for real-time body rocking and hand flapping stereotypy detection were developed using acceleration data obtained from six participants with ASD using Massachusetts Institute of Technology Environmental Sensors (MITes).

Figure 1 shows the MITes hardware and a MITe sensor in a protective plastic case. A MITes receiver can either be incorporated into a sleeve that attaches to a PDA or connected via USB port to a computer. Transmitting accelerometer data at 200Hz, MITes operate for 30 hours on a single battery. MITes are the smallest, lightest, and least expensive wireless three-axis accelerometer sensors available to the research community. They are the only wire-free option that permits raw three-axis accelerometer data to be conveniently collected from up to six points on the body without constraining body movement.

Figure 1: The MITes 3-axis wireless accelerometer sensors housed in plastic cases with external battery holder. In this example, cases are worn on the wrists using elastic armbands.

In the present study, we repeatedly observed (i.e., until at least a total of 50 instances of naturally-evoked, idiosyncratic hand flapping and/or body rocking occurred per participant) six adolescent males ranging in age from 7-18 yrs with DSM-IV diagnoses of ASD in a laboratory setting. All sessions were video recorded and data on limb motion of hand flapping and body rocking was collected using MITes placed on each participant's wrists and torso.

Accelerometer data was compared to offline, observer-rated, time-stamped video tapes documenting start and end times (with .90 inter-rater reliability) for each participant's stereotypical motor movements. Using a 0.4 second sliding window with 50% overlap between consecutive windows, filters were developed for the accelerometer datasets that converted the continuously sampled motor data into discrete movement attributes (e.g., frequency of motion, temporal extent and variability of the movement, amplitude of motion changes, correlation between sensors). Using J48 Decision Tree classifiers with ten, ten-fold cross-validation, the automated pattern recognition algorithms, on average, correctly identified hand flapping and body rocking across participants 82%-97% of the time (Table 1).

Participant	% Correctly Classified	Kappa
1	82	.65
2	95	.63
3	96	.64
4	92	.80
5	85	.68
6	97	.91

Table 1: Average across session percentage of correctly classified instances of movement stereotypy and corresponding kappa statistic for each participant.

Significance & Future Directions

This research demonstrates that accurate, reliable, and valid movement stereotypy recognition can be achieved in individuals with ASD using accelerometer data and pattern recognition algorithms in laboratory settings. We are currently extending this work into classrooms to evaluate recognition rates in the natural environment.

Obtaining detailed and accurate information on the occurrence, topography, frequency, duration, and setting events associated with movement stereotypy is critical to understanding this potentially disruptive behavior. However, challenges in measurement using traditional methods prevent reliable documentation of the behavior and thus makes it difficult to evaluate when and why movement stereotypy occurs. An innovative strategy for assessing stereotypical motor behaviors that includes wireless sensors and computerized pattern recognition software that automatically detect stereotypy could remedy this problem and have significant clinical implications. First, reliable recording of stereotypy would enable researchers to study what functional relations may exist between stereotypy and specific antecedents and consequences. These relations may arise differentially in various environmental settings, in the presence of demand tasks, or in the presence of physiological influences. Second, documentation of movement stereotypy before and after an experimental treatment would facilitate efficacy studies of behavioral and pharmacologic interventions intended to decrease the incidence or severity of stereotypy. Third, future work could incorporate wireless sensors and computerized pattern recognition algorithms into a portable, real-time, wireless device (i.e., mobile phone, PDA) that detect movement stereotypy automatically, enabling teachers, therapists, and caregivers to gather data that can assist with treatment decisions.

References

[1] Bao, L. & Intille, S. S. Activity recognition from user-annotated acceleration data. In *Proc. PERVASIVE 2004* (2004), 1-17.

[2] LaGrow, S. J. & Repp, A. C. Stereotypic responding: A review of intervention research. *American Journal of Mental Deficiency 88*, (1984), 595-609.

[3] Westeyn, T., et al. Recognizing mimicked autistic self-stimulatory behaviors using HMMs. *In Proc. IEEE Int. Symp. On Wearable Computers* (2005), 164-169.