Wearable Therapist: Sensing Garments for Supporting Children Improve Posture

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ABSTRACT

This paper introduces a sensing garment to support posture coaching in children. The system measures back bending postures using acceleration sensors embedded in the garment. We present a sensing garment architecture and the evaluation of garments of different sizes in a study with 21 children. A vision-based reference system was used to evaluate sensor positions and measurement accuracy for 54 back bending postures and related head positions. Then, we asked eight physiotherapists to rate the children's back postures in this study. Ratings of experts correlated significantly with the back bending measurements obtained from the garment. The garment enables an objective assessment of back postures and could form the basis of a system that provides coaching feedback to improve postural control in children.

Author Keywords

Smart garments, SMASH, back posture, rehabilitation.

ACM Classification Keywords

J.3 Computer Applications: Life and medical sciences.

General Terms

Design, Experimentation, Measurement

INTRODUCTION

Ubiquitous systems have enormous potential to provide novel assistive solutions and resolve current healthcare challenges. Recent research efforts have been directed to develop garments with integrated sensors and processing functions to support daily activities and assist in particular care solutions. This paper addresses a special care application in movement and posture rehabilitation of children.

Good postural control promotes movement efficiency, endurance, and contributes to an overall wellbeing. To date, there is no satisfactory measurement technique that enables the evaluation of therapeutic approaches by monitoring postural habits during clinical stays and in daily-life. One typical postural condition among children is the development of a pronounced round back (kyphosis), which is usually correctable by early diagnosis and treatment. Due to poor back postures, bones are not properly aligned and muscles, joints and ligaments take more strain than they could cope with, which causes fatigue, muscular strain, and pain in later stages of life [6].

This contribution presents a novel approach to measure back bending using a non-tight fitting sensing garment architecture. Prototypes of different sizes were implemented using off-the-shelf pieces of clothing. The garment presented in this paper represents a first step to enabling coaching outside of laboratory environment. The use of casual garments promise to increase convenience while maintaining patient privacy.

In this work, we evaluate the feasibility of casual garments in a controlled experiment using a defined set of back postures. This investigation is a fundamental prerequisite to determine garment design and performance for coaching children during therapeutic interventions and everyday life.

Several garment-based implementations have been proposed for posture measurement [8, 3] and detection [4, 1]. Most current solutions require a tight fit and defined body-sensor alignment for robust recordings. While such a setup is feasible and accepted for expert-supervised evaluations, a tight fit is not feasible for everyday use. In particular for children, wearing comfort and minimal hindrance are most critical acceptance criteria. Casually fitting garments [2] overcome these restrictions, but can introduce sensor orientation errors as a consequence of garment alignment changes relatively to the wearer's body. None of the mentioned works addresses the particular contributions made in this paper:

- We introduce a loose fitting sensing garment architecture for sensing, processing, and analysis of back and head positions in children. Garments of different sizes were implemented with acceleration sensors to measure back bending in forward direction (sagittal plane).
- We deployed the system in a study with 21 healthy children and demonstrate the feasibility of the garment system to measure back bending postures ranging between 0° and 50°. We evaluated the measurement accuracy by comparing the garment to a vision-based reference system.

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- We demonstrate that the garment can assist therapists in assessments of a child's posture. Here, we compared posture rating results from eight rehabilitation professionals, experienced in the training with children, to the monitoring data obtained from the garment.

SENSING GARMENT SOLUTION

In consultation with therapists from the Children's Rehabilitation Center in Zurich, we developed a series of sensing garments in different sizes to study upper body and spine postures in children. As base layer, we used off-the-shelf long-sleeve shirts in sizes 140 cm and 152 cm. The design was selected to obtain an appealing casual cloth for everyday life of children between 7 and 14 years. Both shirts were used as a substrate to attach acceleration sensor units, processing hardware, and a battery. To analyze head positions, we attached one additional acceleration sensor unit to a cap, worn by children in addition to the shirt. Figure 1 shows the outside of one developed shirt, were we placed five acceleration sensor units. The hardware units were derived from the SMASH prototyping platform [2]. We simultaneously

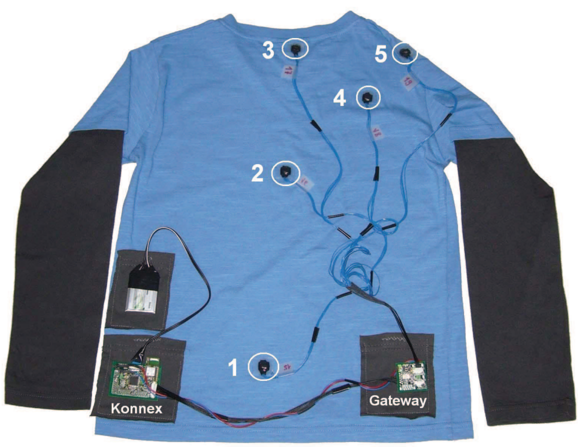

Figure 1. Dorsal view on a sensing garment for recording of back bending (shirt size 140 cm). Five acceleration sensors were attached to the shirts using silicone gel (positions encircled). The hardware units (Konnex, Gateway) and a battery were placed in pockets.

recorded data from different sensor locations to evaluate sensor positioning. Three sensors (1-3) were placed along the spine (verbratae L5, T10, C7) to capture back bending. An additional sensor (4) was placed at the scapula, as this region on the textile was found to be minimally affected by textile-skin movements [5]. Another sensor (5) was placed on the shoulder to analyze lateral bending of the spine.

All six sensor units (shirt and cap) were connected to a Gateway of the SMASH architecture [2]. Sensors were polled with a frequency of 16 Hz. The Gateway was used to combine data streams from all sensors and forward them to a SMASH Konnex, which in turn worked as system master for the shirt. While the Konnex was designed to perform classification tasks using data from the attached sensors, we chose to perform the analysis steps offline in this work. The data was transferred to a recording laptop using Bluetooth. For quick attachment during the study with children, all hardware units were placed in pockets at the shirt's outside.

VALIDATION OF THE GARMENT

Sensors attached to garments that are not tight fitting can incur orientation errors during movements, and subsequently provide inaccurate measurement results. We studied this effect and the garment's accuracy for monitoring children back postures. In particular, we compare here the performance of the sensing garment to a vision-based posture tracking. We focus in our study on spine bending in forward direction (sagittal plane) to capture the rounded back posture. In addition, we included the head orientation in our analysis, as we expected that the head influences the overall appearance of a child's postures.

The raw back angles determined with this approach are not practical for subsequent analysis by therapists. Instead, raw angles are mapped to a categorical angle scale to facilitate posture performance evaluation. For this step, the therapists involved in the design of this study specified a resolution of $5°$. To estimate feasibility of our system, we compare this specification to sensor orientation errors in our study.

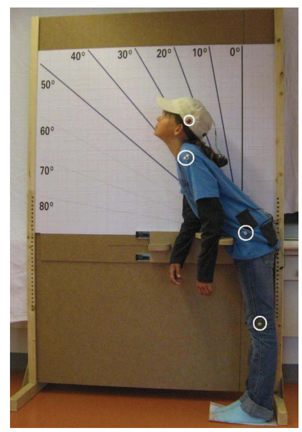

Figure 2. Child wearing the sensing garment of 152 cm and a sensor-attached cap during the study. The child performs a back bending posture of $40°$ in raised head position. Circles indicate the position of markers of the vision tracking system used for validation of the sensing garment.

Experimental procedure

In total 21 healthy children (11 boys, 10 girls) aged between 7 and 14 years (mean 10 years) and body heights of 126 cm to 156 cm (mean 143 cm) participated the study. Children taller than 146 cm wore the shirt of 152 cm, smaller children wore the shirt of 140 cm. The cap was adjustable and worn by all children.

We analyzed six back bending positions in a range of $0° - 50°$ in steps of $10°$. In each position, children adopted three head orientations, lowered-, normal-, and raised. Overall, six back bending, each with three head positions, resulted in 18 different posture classes. Each child repeated the experiment three times, resulting in total 54 postures. Between the experiment repetitions we asked the children to participate in a ball throwing competition. The purpose of this game was to restore the natural alignment of the shirt, to relax and motivate children for the subsequent measurements.

Figure 2 shows a child during the study, performing a back bending posture of $40°$ and raised head. We constructed an adjustable wooden frame to stabilize the children during the experiment. The frame also indicated the bending positions in angles. The bending positions with the frame was guided and supervised by a movement scientist. A second assistant annotated all performed postures on the recording laptop and controlled the recording hardware. A third student assistant controlled the function and position of a recording video camera and made a photo of each performed posture for later inspection and illustration.

Vision-based reference system

To analyze the measurements obtained from the garment, we used a video analysis system. During the study, the position of several optical markers was simultaneously recorded with the garment sensors using a lateral camera view. Optical markers were placed at the cap above the ear, the shirt at the height of shoulder acromion, at the hip trochanter, and at the knee hollow. This configuration allowed measuring bending around the hip, and the head orientation separately. In a post-processing step we used the video analysis software *Dartfish ProSuite* ® to track markers and calculate orientation angles between them.

Garment validation results

Based on the combined vision- and garment-based posture recording, we compared back bending angles. We took the vision-based system as reference and derived the same angle information using the five garment-attached acceleration sensors.

Influence of the sensor position

The derived back bending angles of all garment-attached sensors correlated with angles obtained from the vision-based reference system on the p=0.01 significance level. An analysis of the individual sensor positions showed that sensors placed on the lower back (sensor 1 in Fig. 1) resulted in large errors when bending more than $30°$. For this bending the spine forms a curvature that requires sensors at the upper back instead of the lower back region. In contrast, sensors placed on the upper back (sensors 3, 5) are affected by orientation errors caused by head movements.
The lowest sensor orientation errors were observed for a placement on the rigid area of the scapula. Hence, we focused our further analysis on this sensor position.

Influence of the posture

Measurement accuracy of the garment depended significantly on the performed back- and head position. Figure 3 shows the median angular difference between back bending measured from static acceleration due to gravitation, compared to the vision-based reference system. The median was calculated by considering all 21 children. All postures, except the $50°$ bending with head raised, resulted in a median error below $5°$. This result confirms that the shirt achieves an orientation error below the requirement described before. Moreover, the results confirm that textile shifts caused by altering head position have a substantial influence on the sensor's measurement accuracy. Table 1 lists the percentage of samples that fall below our predefined sensor orientation error of $< 5°$, with respect to back bending. As back bending above $30°$ are rather unlikely for long periods in normal situations, we concluded that $> 84\%$ of recorded measurements are in the accepted accuracy range.

Back bending	**0°**	**10°**	**20°**	**30°**	**40°**	**50°**
Samples with SOE$< 5°$	97%	90%	84%	78%	74%	70%

Table 1. Percentage of samples with a sensor orientation error (SOE) $<$ $5°$ for all children, sensor on scapula.

EVALUATION OF CHILD POSTURES WITH THERAPISTS

With the convenient measurement performance we concluded that the garments provide valuable tools for therapists to monitor back postures. However, we did not expect to derive a posture quality metric from back bending or head position measurements alone. Previous attempts have shown that assessing postures by multiple measurables in adolescents is challenging [7]. Posture quality depends on the overall appearance of individual child, including balance and formation of limbs, hip, back, shoulder, and head. Consequently, this assessment would be difficult to make from a shirt alone, even with multiple sensors. Our aim is to develop an assistive system that could nevertheless provide feedback to child and therapist regarding posture performance during training and everyday life. For this purpose, we investigated the correspondence of posture measurements using our sensing garment and the assessment by expert therapists.

Evaluation procedure

We asked eight physiotherapists of the children's rehabilitation center to rate posture performances in our study. Considered physiotherapist had several years of experience. In a presentation we showed all 54 postures on pictures for 5 seconds in random order. Each posture was shown three times as it was performed by different children of our study. The physiotherapists rated the postures with respect to an optimal upright posture on a visual analogue scale (VAS). To avoid distortions due to alternating camera perspectives, we selected pictures from the same recording day. Moreover, we

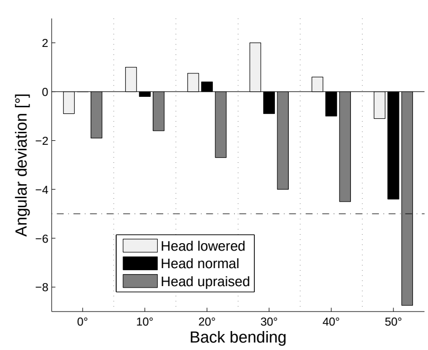

Figure 3. Median of angular deviation for all postures measured at the scapula position. The dashed line indicates the required bending resolution defined beforehand.

removed the angles that were printed on the wooden frame from all pictures before commencing with this evaluation.

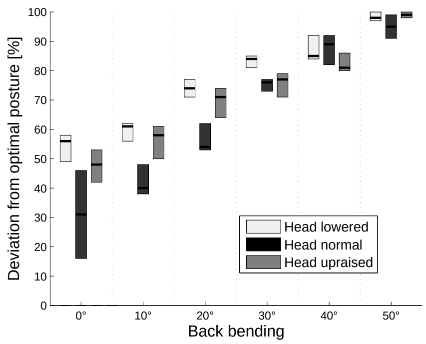

Figure 4. Expert ratings of posture performance with respect to an optimal upright posture. VAS results were converted to box plots. The boxes indicate standard deviations of ratings for each posture.

Evaluation results

Figure 4 shows the posture ratings for all analyzed back bending and head positions in box plots, where the box sizes indicate the standard deviations. The results show deviations and large variances in the ratings for the normal upright posture (child standing upright, normal head position). We interpret this result as a conservative rating behavior of the experts. Overall, the plot indicates that experts rated postures with small back bending regions with lower consistency than those in regions of high bending. Moreover, the diagram confirms a high influence of the head position on posture ratings in general. A lowered head increased the spine curvature and resulted in reduced posture ratings than normal or upraised head positions.

For all head positions our analysis showed a significant correlation (r=0.89) of back bending measured using the garment with ratings of the experts. From this result we concluded that back bending can be monitored using sensing garments. The measurement can be utilized to derive a postural metric that conforms to expert ratings.

CONCLUSIONS

We introduced in this work a sensing garment for monitoring back bending and evaluated it with 21 children. We compared garment sensor measurements against a vision-based reference system. Moreover, we analyzed expert therapists' ratings in comparison to the garment-based measurements.

An absolute sensor orientation error of less than 5°was observed for more than 84% of recorded samples with back bending smaller than 20°. We argue that, according to requirements defined with therapists, this result demonstrates sufficient bending posture fidelity of the garment. We found that sensors placed in middle and lower regions of the spine resulted in large measurement errors for angles above 30°. While sensors placed at the neck region were able to measure large back bending, sensor orientation errors were introduced by the head orientation. We concluded that a sensor placed at the scapula represents a compromise between these extremes.

An expert assessment of posture quality correlated significantly to the measured bending of the back. Hence, a single sensor placed in the region of the scapula proved to be a valuable tool for assessing bending postures. The proposed system can indeed complement visual assessment for small bending angles, as experts tended to judge these inconsistently. In contrast, for large bending angles the expert judgment is consistent while the garment introduces sensor orientation errors. Nevertheless, the interpretation of the bending by assistive systems requires further analysis and user studies. Our further work will investigate how the controlled lab experiment translates into everyday coaching for both, natural activities and specific rehabilitation exercises.

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REFERENCES

1. L. Dunne, P. Walsh, B. Smyth, and B. Caulfield. Design and evaluation of a wearable optical sensor for monitoring seated spinal posture. *Wearable Computers, 2006 10th IEEE International Symposium on*, pages 65–68, 2006.

2. H. Harms, O. Amft, D. Roggen, and G. Tröster. Smash: A distributed sensing and processing garment for the classification of upper body postures. In *BodyNets '08: Proceedings of the Third International Conference on Body Area Networks*, Tempe, AZ, USA, March 2008.

3. E. Lou, M. J. Moreau, D. L. Hill, V. J. Raso, and J. K. Mahood. Smart garment to help children improve posture. *Engineering in Medicine and Biology Society, 2006. EMBS '06. 28th Annual International Conference of the IEEE*, pages 5374–5377, Sept. 2006.

4. C. Mattmann, O. Amft, H. Harms, C. Tröster, and F. Clemens. Recognizing upper body postures using textile strain sensors. In *ISWC 2007: Proceedings of the 11th IEEE International Symposium on Wearable Computers*, pages 29–36. IEEE Press, Oct. 2007.

5. C. Mattmann, T. Kirstein, and G. Tröster. A method to measure elongations of clothing. In *Proc. 1st International Conference on Intelligent Ambience and Well-Being (Ambience05)*, Sept. 2005.

6. J. Salminen. The adolescent back. A field survey of 370 Finnish schoolchildren. *Acta paediatrica Scandinavica. Supplement*, 315:1, 1984.

7. A. Watson and C. Mac Donncha. A reliable technique for the assessment of posture: assessment criteria for aspects of posture. *J Sports Med Phys Fitness*, 40(3):260–70, 2000.

8. W. Y. Wong and M. S. Wong. Detecting spinal posture change in sitting positions with tri-axial accelerometers. *Gait & Posture*, 27(1):168–171, Jan. 2008.