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LETTER TO THE EDITOR

Reply to 'Comment on ''Non-invasive monitoring of chewing and swallowing for objective quantification of ingestive behavior'''

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Abstract
Non-invasive monitoring of ingestive behavior is a novel area of research that has significant potential in obesity-related applications. This response to the comments by Dr Amft (2009 *Physiol. Meas.* **30** 517–20) highlights the importance of the methodology and reliability metrics established in our original publication (Sazonov *et al* 2008 *Physiol. Meas.* **29** 525–41) for the future development of automatic pattern recognition methods and clarifies some of the questions raised in Dr Amft's letter.

Keywords: monitoring of ingestive behavior, obesity, swallowing, chewing, mastication, deglutition, energy balance, wearable sensors, energy intake

Non-invasive monitoring of ingestion is an exciting and intriguing area of research. The worldwide growth of the obese population still puzzles researchers who cannot provide a definite answer to the etiology of this 'obesity epidemic'. Our work in the area is focused on developing compliant, non-invasive and easy-to-use devices for the monitoring of ingestive behaviors that may shed light on eating behaviors associated with obesity and be used in behavioral therapies. We want to know when each episode of ingestion takes place, how much was consumed and, preferably, determine the type and caloric density of the food being consumed. From the first journal publication of Amft and Troster in February 2008 (Amft and Troster 2008) we were glad to learn that somebody else shares our approach to non-invasive

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monitoring of ingestion. We are excited to see the growth of the research area and hope that it will lead to better methods of non-invasive monitoring and help in fighting the obesity epidemic.

We thank Dr Amft for his comments and would like to use this opportunity to respond to some of the key criticisms expressed in his letter. The goal of any introduction and literature review is to highlight the state of the art, rather than to point out every existing publication in the field and this means that it generally will not be possible to reference every work in the area. For example, our early conference publications on swallowing sound recognition (Makeyev *et al* 2007a, 2007b) were not referenced by Dr Amft in Amft and Troster (2008), which proposes such a methodology. Time is also a factor which cannot be discounted. The journal publication (Amft and Troster 2008) was published almost at the same time as our paper (February versus April of 2008), and thus it was not possible to include that publication in the review of prior work at the time the manuscript was written. The same can be said about the publications that came out several months later (Junker *et al* 2008) or have only recently been published (Amft and Troster 2009). We appreciate the opportunity to alert readers to earlier less-accessible conference publications of Amft *et al* (Amft *et al* 2005a, 2005b, 2007a, 2007b, Amft and Troster 2006).

Our publication makes the first, very crucial step in the design of automatic methods for the monitoring of ingestion, that is, establishing the reliability of the primary data. Automatic scoring is an active area of research which has yet to mature. Amft *et al* (2005) reported an accuracy of 99% in eating recognition and 80%–100% in food identification. However, when a certain food type (rice) was not properly detected or identified by the proposed algorithm it was omitted from the reporting to show artificially high accuracy of recognition and identification. As another example, Amft and Troster (2008) reported per-sample recognition rates of 86% for chewing and 70% for swallowing. These rates translate into lower rates of detecting actual masticatory sequences and instances of deglutition and make the methods proposed in Amft and Troster (2008) of limited practical application. It seems reasonable to suggest that without establishing the reliability of the manual score it is impossible to quantify what factor was responsible for such low recognition accuracy reported in Amft and Troster (2008): the proposed recognition algorithm or the quality of the manual score. Thus, we believe it is necessary to base our accuracy claims for any automatic algorithm by first establishing the reliability of manual scores. We are actively pursuing automatic recognition of chewing and swallowing in order to address this challenging area of research.

With no viable methods for automatic scoring available at this time, we employed manual raters to mark each event of ingestion and create a ‘gold standard’. Utilization of a multi-modal system including a video stream allowed the raters to better estimate crucial parameters such as event boundaries. High reliability of the manual scores was also achieved by a well-constructed formal protocol that defined how every known situation should be scored. While size constraints limit the publishing of our scoring protocol, it does contain guidelines on correct utilization of the scoring software, description of data streams to be used as aid during the scoring process and definitions of bite, chewing and swallowing events. Every rater used this protocol both in training on a sequence of test subjects (not reported) and in actual scores (reported) in our publication. All of this resulted in a score of bites, chews and swallows with known statistical reliability measures established by analyzing a subset of over 10 h (579 bites, 9719 chews and 1866 swallows) of data scored by three different raters. It should also be noted that the sample size for the intra-class coefficients analysis is defined by the number of epochs (1256–3770 for epoch duration ranging from 30 s–10 s) rather than bites, chews and swallows which represent the measure that is being rated. The described steps ensured a high accuracy of the manual score which in the future will result in a higher

accuracy of the training and validation data sets used for the design of automated computer algorithms and will establish the upper bound on reliability of the automatic scoring results.

Selection of the sensor modalities for the capturing of ingestion is as much an art as a science and should rely on objective analysis and proven performance. The performance of sensors working in conjunction with an automatic computer algorithm for identification of an event or quality of interest has to be validated on real data with the results compared to the reference score. For example, registering the tilt of the head by the chewing sensor may give additional clues when the intake of liquids takes place; however this hypothesis would need to be confirmed by a statistically valid approach. This is the topic of our ongoing research.

Overall, we completely agree with Dr Amft on the existence of huge unexplored possibilities of further research in the field on non-invasive monitoring of ingestion. There are numerous sensor modalities to be explored, both in detecting ingestion and estimating the properties of the food; there is a need for developing methods that can use sensor information and provide users of such techniques with informative feedback and insight into eating behaviors. We hope that such methodologies will lead to a better understanding of the etiology of obesity and new emerging therapies for the modification of eating behaviors.

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