A Neuropsychological Perspective on Measuring Sign Language Learning and Comprehension

R. Spiegel[1,2,3], S. Naqvi[4], J. Ohene-Djan[4], D.R. Moore[5] and E. Hsiao[5]
[1] Ludwig-Maximilians-Universität München, Institut für Medizinische Psychologie/Generation Research Ltd. Germany
[2] Technische Universität München, Medizinische Fakultät, Munich, Germany
[3] University of Cambridge, Wolfson College, Cambridge, United Kingdom
[4] University of London, Goldsmiths College, Department of Computing, United Kingdom
[5] Ohio University, College of Education, Athens, Ohio, USA

***Abstract*—In this paper we present a tentative neuropsychological explanation on sign-language comprehension. A spatial probability interface is applied to study levels of comprehension with regard to British Sign Language (BSL) sequences. The results of this study not only support the validity of the spatial probability interface as a means of expressing learning and comprehension, but also refer to gender differences. These differences are discussed in the light of present neuropsychological theory.**

***Index Terms*—Gender Differences, Sign Language Technology, Spatial Response, BSL, Sensory-motor Learning.**

I. INTRODUCTION

With the increasing use of neuroimaging techniques, the neuropsychology of both sign language and deafness has received a lot of attention in recent years [1]-[8]. There have been numerous studies trying to show how sign language is related to spoken language in terms of neural patterns and processes [3]-[4], [7]-[8]. The brain areas predominantly related to spoken language (Broca and Wernicke) are also active in deaf users of BSL. Lateralization patterns were similar too, with the left hemisphere being more active than the right hemisphere. In addition, deaf signers showed greater activity in the posterior occipito-temporal regions, perhaps reflecting the movement component in BSL [3]. Other studies (including those on American Sign Language and Japanese Sign Language) confirm the importance of the language dominant left hemisphere for signers [9]-[11]. It was also found that spoken and signed word production activates the same or similar regions, whilst language-related auditory and visual processing activates different regions of sensorimotor cortex. Moreover, the parietal cortex was activated more by signing than by spoken language [12]. Assuming that spoken and sign language have many neural processes in common, one may ask whether there are similar gender differences as there are for spoken language. It is widely known that, on average, females show slightly better language competence than males, while males show slightly better visuo-spatial competence than females [13]. The question is: do these differences also exist in terms of sign language, as sign language combines both aspects? Data from a longitudinal study focused on hearing children acting as interpreters for their deaf parents [14]. The study revealed that hearing daughters were more likely to act as interpreters and to be bilingual (fluent in American Sign Language and spoken English). This gender bias is also reflected among the general public, with females being far more likely to work as interpreters for the deaf. This does not imply, however, that female signers have more proficient sign language skills than male signers as sign language skills between signing males and females were not directly compared. The study interprets its findings in the light of social and cultural interests. In summary, it seems without doubt that gender differences do exist with regard to spoken language. Moreover, neuropsychological studies have provided evidence for sex-linked differences in cortical areas related to language processing [15]. It remains an open question, though, whether these differences play a role in terms of signing.

This paper aims to provide an explanation for some recent findings on measuring sign language comprehension through spatial response. Comprehension was measured with a spatial probability interface that was introduced by David Moore [16] and validated by Saduf Naqvi and colleagues [17]. The interface and its validation will be summarized in the next section because its explanation is vital for the following neuroscientific discussion.

II. THE SPATIAL PROBABILITY MEASURE

In laboratory experiments, sign language comprehension can be assessed by displaying video sequences of signers and by asking participants to interpret the sequences. Subsequently, participants can be asked to rate how much confidence they have in their responses. Traditionally, the confidence rating took place in a static, questionnaire-type format, with data being captured at a single point in time [18]. This way, participants were able to express their overall comprehension of a signed sequence. On the other hand, it is also necessary to understand which parts of the sequence participants grasp and which parts they do not comprehend. Because BSL is a visual language that uses combinations of hand and body movements along with facial expressions, comprehension must also involve the identification of errors expressed as incorrect facial expressions, incorrect dominant handshifts and other such body movements. Consequently, Moore [16] created a new interface that allowed for comprehension tests along various dimensions. It involves a triangle with differing answers at each point. Once a sequence is presented and a question is proposed, the participant's task is to move the mouse to a point within the triangle, where each corner stands for a different dimension, e.g. hand shift, body movement, facial expression. The point eventually indicates one's level of confidence in one or more of the possible answers. If one is confident about the facial expression and less confident about the hand shift, one's mouse click would be closer to the edge on the facial dimension and further away from it on the hand shift dimension. The mouse distance from the three corners is recorded. The distances from each corner are applied to calculate the level of the participants' certainty in their responses. Moore's original approach utilizes a static interface [16], where participants are presented with a question or a statement, and asked to indicate one of three answers on an equilateral, 3-dimensional triangle. The work carried out by Naqvi and colleagues builds upon this research by constructing a dynamic interface. This interface collects consecutive data over time whilst participants are viewing BSL video sequences. The triangle-method is depicted in Fig. 1.

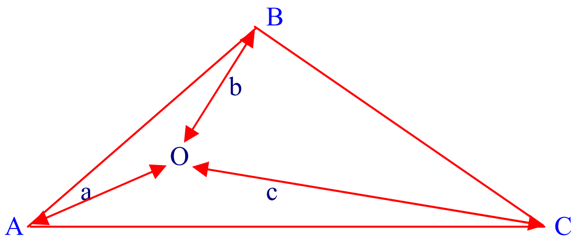

Figure 1. The interface of the Spatial Probability Measure [16], [17]

Following Moore [16], Naqvi and colleagues [17], segments a, b and c represent distances AO, BO, OC, from imaginative clicked point O to each of the vertices A, B and C. Because the sum of segments a, b and c can vary with each click, a percentage calculation is performed to compute a level of uncertainty towards a particular vertex. Equations 1 to 3 represent the spatial measurement calculations for each vertex, where A_u, B_u and C_u are measurements of uncertainty corresponding to each of three vertices (%).

$$A_u = \frac{a}{a+b+c} * 100 \qquad (1)$$

$$B_u = \frac{b}{a+b+c} * 100 \qquad (2)$$

$$C_u = \frac{c}{a+b+c} * 100 \qquad (3)$$

In the following validation experiment [17], deaf participants were presented various sequences and were asked to rate their confidence with regard to various aspects of the sequences. All participants were deaf and proficient signers with regard to the London regional dialect of BSL. Participants were randomly assigned to an Experimental group and a Control group. The Experimental group saw streaming video sequences of sign language with deliberately incorporated errors, whereas the Control group saw sequences without errors. Three sets of sequences about the following topics were recorded: a match between Arsenal London and Chelsea London football clubs; a robbery of an old woman who fought back, and a turbulent flight experience. Each set consisted of four video recordings. The first recording was correctly signed and subsequent recordings were done with the following deliberately incorporated errors: incorrect handshape, incorrect facial expression and dominant hand shift. A possible bias with respect to sequence presentation was avoided by choosing a Latin-square type of counterbalance condition. The results of this validation experiment are described in [17]. To enhance clarity, they will be summarized below. Because the authors in [17] are the same as the authors in this paper, the term "we" is used when summarizing the cross-validation experiment:

Twenty deaf participants agreed to take part in our study. They all were able to use the London regional dialect of BSL proficiently. Unfortunately, 10 participants dropped out because they had other commitments as well. After randomly assigning participants to an Experimental and a Control group, the Experimental group saw streaming video sequences of sign language with deliberate errors, whilst the Control group saw streaming video sequences without errors. Because the signing of the Experimental group contained deliberate errors, it was expected that their spatial responses were somewhat further away from the target than the ones of the Control group (which contained no errors). Given that we had a specific hypothesis including the direction of the expected effect, we performed a one-tailed F-test. One-tailed F-tests correspond to one-tailed T-tests for independent samples according to the General Linear Model of Inferential Statistics. This implies that error probability levels can therefore be transferred from one to another. Our initial hypothesis was confirmed, as the average length for the Experimental group (Mean=117.87, Standard error=4,15) was significantly greater than the average length for the Control group (Mean=95.78, Standard error=11,33): $F(1,10)=3.35$, $p<.05$. To further validate the spatial response technique, we performed another, external confidence rating of each participant's open response (the one that was given during the interview following the experiment). In this rating we assessed how confident each participant felt in using the video technology and the graphical user interface to express their comprehension of the signed phrases. We first performed a content analysis by rating the participants' open responses. We then assigned values from 0 to 5 (zero expressing low confidence to 5 expressing high confidence). Subsequently, we calculated the correlation between the confidence rating and the previously mentioned length of responses. For this purpose, we chose the non-parametric Spearman correlation coefficient. We have decided in favor of this practice, as confidence ratings and content analyses are rarely on scaling levels that would justify parametric tests. According to the nature of the task, we could be sure that our rating was on ordinal scale level. As a result, the Spearman coefficient represented an adequate technique. To double-check, we did some additional analysis by calculating the parametric Pearson correlation coefficient. The analysis showed a significant negative correlation, R(Spearman)=-0.712, p=.01, where high confidence goes along with a short length (as expected). Because the parametric Pearson coefficient (R(Pearson)=-0.804, p<.01) confirmed this result, there was evidence that the spatial responses supported the ratings of the responses given.

Gaining a determination coefficient of greater than 50 percent (Rsquared>.5), the spatial measurement interface seems to show good validity. Now one may argue that this result was confounded with topic knowledge that participants could have had prior to the experiment. In this case, the signing itself would have been less relevant. In order to exclude a potential confound of this type, the partial correlation coefficient was calculated (controlling for topic knowledge). Nevertheless, the relevance of the result remained stable with R(partial)=-0.881, p<.01, Rsquared>.75, explaining over 75 percent of the variance. Consequently, there is at least some evidence to consider the spatial response measurement a valid technique in terms of helping people express their comprehension of signed sequences. It can be assumed that this technique may be extended to various learning studies, as it would be capable of monitoring progress and difficulties easily.

III. Gender differences

What follows are some very recent data. We analysed the effect of gender on the overall results. Turning to the group that contained deliberate errors first (Experimental group), females' spatial responses (Mean=110.84, Standard error=9.81) did not differ significantly from male spatial responses (Mean=121.39, Standard error=3.82), F(1,4)=1.615, p=.1365. Considering the Control group next (i.e. the group without deliberate errors), females (Mean=74.95, Standard error=13.47) performed significantly closer to target than males (Mean=116.61, Standard error=5.18), F(1,4)=8.33, p=.02. In other words, there was a partial effect of gender, with females seemingly being able to understand the signed language better than males. As has been discussed previously, the result of females performing better on language-related tasks is not new. On the other hand, males are considered to be more likely to succeed on spatial tasks. Possible reasons for these differences are genetic differences as well as different mechanisms in the various areas of the human brain. Interestingly, the task in our experiment is a mixture of both (signing as not only a language-, but also a spatially related task and the spatial response technique as another spatially related task). In spite of the seemingly large spatial component, female participants performed slightly better. As for sign language, this result is no surprise, because it had been shown that sign language predominantly makes use of the same cortical areas as spoken language [9]-[11], though exceptions were in place [12]. Consequently, the spatial response measurement per se does not seem to inhibit the apparently greater language competence in females. This would be in line with the purpose of our experiment, because we aimed to show that sign language is assessed in a valid way. However, one has to be careful and avoid making strong claims about validity or gender effects, as the results are based on a small sample size and further tests are strongly needed in order to support these tentative results. Moreover, the effect on gender differences was no a-priori hypothesis. Therefore, this result must not be interpreted as an experimental finding. Nevertheless, it could act as a means to generate new hypotheses (e.g. about gender differences), that could be tested in a separate experimental design subsequently. Only then would it be permitted to base any discrepancy in terms of performance on gender differences. So why might these gender differences eventually matter with regard to learning and comprehension of sign language? If it turned out that one gender had more difficulties in this regard or if it turned out that both genders had different types of problems, the training could be tailored to specifically meet these needs. Specifically tailored training is only possible, however, when more information about sign language learning / comprehension is generated. The spatial probability measure is a device that may help to generate this type of information, because it continuously permits to monitor learning / comprehension as the signed sequences are presented.

IV. Wider implications for the cognitive neuroscience of sign language

The spatial probability measure can assist when aiming to generate Cognitive Neuroscience models in order to explain the acquisition of sign language. For the acquisition of spoken language, a vivid discussion between various cognitive neuroscientists, linguists and philosophers has already taken place [19]-[31]. This discussion is often based on experimental data along with theoretical models to simulate spoken language learning [32]-[42]. For the various dialects of sign language, e.g. British Sign Language, American Sign Language, Polish Sign Language, Japanese Sign Language, Deutsche Gebärdensprache etc., it would be highly desirable to learn more about its acquisition by carrying out experiments and by creating more refined theoretical models.

The technology described in [16]-[17] might help to carry out the desired experiments on sign language acquisition, as it allows the continuous assessment of facial expressions and movements. However, one caveat remains in order. It needs to be kept in mind that the various sign languages incorporate a different amount of sensory-motor movement, so this effort might result in different theoretical models too. A detailed study of these processes may ultimately lead to better knowledge about sign language acquisition, which in turn might help to either create new theoretical models or to adapt already existing models on sensory-motor sequence learning to sign language acquisition [43]-[47]. The need to refer to sensory-motor learning is also based on the previously mentioned evidence from imaging studies. They had found that spoken and signed word production activated different regions of sensorimotor cortex, and that signing went along with higher activities in the parietal cortex than speaking [12].

Given that sign language learning technologies have become increasingly important, especially in the digital domain [48]-[54], the advantage of a technology that permits to monitor any progress or difficulties lies at hand. Moreover, sign language learning in children has become increasingly important [55], as there are critical periods in life when spoken language is learned more easily [23]. Similar processes may hold true for sign language (so far a Pubmed literature research has not identified any studies on this topic yet). Especially children (particularly those who are not able to read yet) may find it easier to use the spatial probability measure to express their comprehension rather than a traditional online questionnaire with check boxes, radio buttons, etc. It has yet to be shown, though, whether they are able to grasp the meaning of the spatial response technique adequately. For this purpose, further research would be necessary.

V. CONCLUSIONS

Gaining knowledge about sign language implies having a good technology to monitor progress and difficulties. The spatial probability measure seems to fulfill this criterion, but further validity checks will be needed. Taking gender differences into account is a good starting point, but will need larger sample sizes and further tests in order to reach a conclusion. Based on the data presented in this paper, the hypothesis could be formed that females show better British Sign Language proficiency. This hypothesis could be tested in future experiments. From theory [13], one would expect that females are better at language-related tasks, but one would also expect that males are better using the spatial probability measurement. Since the spatial probability measurement is easy to use and does not require complex spatial orientation, there is reason to believe that the technique does not gender-bias the answers. Moreover, Moore [16] found no gender-bias when validating his technique.

Given that the social implications of deafness can be enormous, it is highly desirable to facilitate the learning and comprehension of sign-language. Deaf people often need an interpreter for many aspects of daily life, e.g. when attending a doctor’s appointment, visiting a hairdresser, asking about advice in a department store etc. Unfortunately, not all close relatives, peers or loved ones are able to learn sign language easily. Research into sign language acquisition might help to overcome many present problems or difficulties to a large extent.

ACKNOWLEDGMENT

R.S. thanks the Institute of Medical Psychology (LMU, Munich, Germany) for enabling him to establish the Sensory-Motor Learning Lab (since 2004) and Wolfson College, University of Cambridge (UK) for electing him a Research Fellow. The authors thank Goldsmiths College, University of London, for providing the environment to carry out the experiments and Ohio University for the equipment to develop the technology. The authors especially thank all deaf participants for their willingness to take part in the study.

REFERENCES

[1] K. Emmorey, J.S. Allen, J. Bruss, N. Schenker and H. Damasio, “A morphometric analysis of auditory brain regions in congenitally deaf adults,” *Proc. Natl. Acad. Sci.*, vol. 100, pp. 10049-54, August 2003.

[2] V.B. Penhune, R. Cismaru, R. Dorsaint-Pierre, L.A. Petitto and R.J. Zatorre, “The morphometry of auditory cortex in the congenitally deaf measured using MRI,” *Neuroimage*, vol. 20, pp. 1215-25, October 2003.

[3] M. MacSweeney, B. Woll, R. Campbell, P.K. McGuire, A.S. David, S.C. Williams, J. Suckling, G.A. Calvert and M.J. Brammer, “Neural systems underlying British Sign Language and audio-visual English processing in native users,” *Brain*, vol. 125, pp. 1583-93, July 2002.

[4] S. Peperkamp and J. Mehler, “Signed and spoken language: a unique underlying system?” *Lang. Speech*, vol. 42, 333-46, April 1999.

[5] J. Ronnberg, B. Soderfeldt and J. Risberg, “The cognitive neuroscience of signed language,” *Acta Psychol.*, vol. 105, 237-54, December 2000.

[6] D.P. Corina and S.L. McBurney, “The neural representation of language in users of American Sign Language,” *J Commun. Disord.*, vol. 34, 455-71, November 2001.

[7] D. Bavelier, D. Corina, P. Jezzard, V. Clark, A. Karni, A. Lalwani, J.P. Rauschecker, A. Braun, R. Turner and H.J. Neville, “Hemispheric specialization for English and ASL: left invariance-right variability,” *Neuroreport*, vol. 9, 1537-42, May 1998.

[8] K. Emmorey, *Language, cognition and the brain: Insights from sign language research*, Mahway, N.J.: Erlbaum, 2002.

[9] M.M. Haglund, G.A. Ojemann, E. Lettich, U. Bellugi and D. Corina, “Dissociation of cortical and single unit activity in spoken and signed languages,“ *Brain Lang.*, vol. 44, 19-27, January 1993.

[10] D.P. Corina, L. San Jose-Robertson, A. Guillemin, J. High and A.R. Braun, “Language lateralization in a bimanual language,” *J Cogn. Neurosci.*, vol. 15, 718-30, July 2003.

[11] K.L. Sakai, Y. Tatsuno, K. Suzuki, H. Kimura and Y. Ichida, “Sign and speech: amodal commonality in left hemisphere dominance for comprehension of sentences,” *Brain*, vol. 128, 1407-17, June 2005.

[12] N.E. Crone, L. Hao, J.Jr. Hart, D. Boatman, R.P. Lesser, R. Irizarry and B. Gordon, “Electrocorticographic gamma activity during word production in spoken and sign language,” *Neurology*, vol. 57, 1947-8, December 2001.

[13] S. Baron-Cohen, *The essential difference. The truth about the male and female brain.* New York: Basic Books, 2003.

[14] P. Preston, “Chameleon voices: interpreting for deaf parents,” *Soc. Sci. Med.*, vol. 42, 1681-90, June 1996.

[15] T.A. Knaus, A.M. Bollich, D.M. Corey, L.C. Lemen, A.L. Foundas, “Sex-linked differences in the anatomy of the perisylvian language cortex: a volumetric MRI study of gray matter volumes,” *Neuropsychology*, vol. 18, 738-47, October 2004.

[16] D.R. Moore, “Exploring gender effects on the spatial probability measure,” in *Proc. 5th IEEE Intern. Conf. on Advanced Learning Technologies (ICALT)*, Athens (Greece): IEEE Computer Soc., 2005, pp. 435-36.

[17] S. Naqvi, R. Spiegel, J. Ohene-Djan, D.R. Moore and E. Hsiao, “Measuring sign language comprehension through spatial response,“ in *Proc. Conf. and Workshop on Assistive Technologies for Vision and Hearing Impairment: Technology for Inclusion*, D.M. Hersh, Ed. Kufstein (Austria): euro-Assist-VHI-4, 2006.

[18] B. Shneiderman and C. Plaisant, *Designing the user interface: strategies for effective human-computer interaction.* Reading, MA: Addison-Wesley, 2004.

[19] J. Russell, *What is Language Development? Rationalist, Empiricist, and Pragmatist Approaches to the Acquisition of Syntax*, Oxford: Oxford University Press, 2004, pp. 1-11.

[20] N. Chomsky, *New Horizons in the Study of Language and Mind*, Cambridge, UK: Cambridge University Press, 2000, Foreword p. XIV.

[21] N. Chomsky, *Rules and Representations*, Oxford: Basil Blackwell, 1980, pp. 189-192.

[22] E. Bates and J.L. Elman, "Learning rediscovered," *Science*, vol. 274, pp. 1849-1850, December 1996.

[23] J.L. Elman, E. Bates, M.H. Johnson, A. Karmiloff-Smith, D. Parisi and K. Plunkett, *Rethinking Innateness: A Connectionist Perspective on Development*. Cambridge, MA: MIT-Press, 1996.

[24] S. Pinker, "Out of the minds of babes," *Science*, vol. 283, pp. 40-41, January 1999.

[25] G.F. Marcus, "Can connectionism save constructivism.," *Cognition*, vol. 66, pp. 153-182, May 1998.

[26] C.S. Peirce, "The icon, the index and the symbol," in *Collected Papers of Charles Saunders Peirce*, vol. II, C. Hartshorn and P. Weiss, Eds. Cambridge, MA: Harvard University Press, 1932, pp. 156-173.

[27] R. Rorty, "Universality and truth," in *Rorty and his Critics*, R.B. Brandom, Ed. Oxford: Basil Blackwell, 2000, pp. 1-24.

[28] J. Piaget, *The Psychology of Intelligence*. London: Routledge and Kegan Paul, 1948.

[29] M. Tomasello, *First Verbs: A Case Study in Early Grammatical Development*. Cambridge UK: Cambridge University Press, 1992.

[30] M. Tomasello, *The New Psychology of Language: Cognitive and Functional Approaches to Language Structure*. Mahwah N.J.: Erlbaum, 1998.

[31] M. Tomasello, The *Cultural Origins of Human Cognition*. Cambridge, MA: Harvard University Press, 1999.

[32] K. Plunkett and J.L. Elman, *Exercises in Rethinking Innateness*. Cambridge, MA: MIT-Press, 1997.

[33] P. McLeod, K. Plunkett and E.T. Rolls, *Introduction to Connectionist Modelling of Cognitive Processes*. Oxford: Oxford University Press, 1998.

[34] M. Negishi, "Do children learn grammar with algebra or statistics?" *Science*, vol. 284, p. 433, April 1999.

[35] G.F. Marcus, S. Vijayan, S. Bandi Rao and P.M. Vishton, "Rule learning in seven-month-old infants," *Science*, vol. 283, pp. 77-80, January 1999.

[36] G.F. Marcus, *The Algebraic Mind: Integrating Connectionism and Cognitive Science*. Cambridge, MA: MIT-Press, 2001.

[37] D.E. Rumelhart, G.E. Hinton and R.J. Williams, "Learning representations by backpropagating errors," *Nature*, vol. 323, pp. 533-536, October 1986.

[38] D.E. Rumelhart and J.L. McClelland, *Parallel Distributed Processing*, vol. I, Cambridge, MA: MIT-Press, 1986.

[39] J.L. McClelland and D.E. Rumelhart, *Parallel Distributed Processing*, vol. II, Cambridge, MA: MIT-Press, 1986.

[40] J.A. Anderson and E. Rosenfeld, *Talking Nets*, Cambridge, MA: MIT-Press, 1998.

[41] R. Spiegel, "Cognitive modeling of symbolic-like relationships with the adaptive neural network associator (ANNA)," *Proc. IEEE Int. Joint Conf. Neural Networks (IJCNN)*, 2003, vol. 4, pp. 2746-2751.

[42] R. Spiegel, "A novel approach to extract rules from sequences of phonemes," *Proc. Cambridge First Postgr. Conf. on Language Research (CamLing)*, 2003, pp. 494-500.

[43] R. Spiegel, "Human and machine learning of spatio-temporal sequences: an experimental and computational investigation," PhD-thesis, University of Cambridge (UK), 2002.

[44] R. Spiegel, M.E. Le Pelley, M. Suret and I.P.L. McLaren, "Combining fuzzy rules and a neural network in an adaptive system," *Proc. IEEE Int. Conf. Fuzzy Systems* (IEEE World Congr. on Comptl. Intelligence), 2002, pp. 270-275.

[45] R. Spiegel and I.P.L. McLaren, "Abstract and associatively-based representations in human sequence learning," *Phil. Trans. Roy. Soc. London*, vol. B358, pp. 1277-1283, July 2003.

[46] R. Spiegel and I.P.L. McLaren, "A hybrid cognitive-associative model to simulate human learning in the serial-reaction time paradigm," *Proc. AISB: Adaption in Artificial and Biological Systems*, T. Kovacs and J.A.R. Marshall, Eds. Bristol: Society for the Study of Artificial Intelligence and Simulation of Behaviour, vol. 1, pp. 74-90, April 2006.

[47] R. Spiegel and I.P.L. McLaren, "Associative sequence learning," *J. Expt. Psychology: Animal Behavior Processes*, vol. 32, pp. 150-163, April 2006.

[48] http://www.learnbsl.org

[49] L. Allsop and C. Mason, *A two-hour introduction to British Sign Language presented by Lorna Allsop and Clive Mason*, British Deaf Association Video Service, Classification BSL 9, 2002.

[50] J. Ohene-Djan, J. Bassett-Cross, A. Mould and R. Zimmer, "MAK-messenger and finger chat: communications technologies to assist in the teaching of signed languages to the deaf and hearing," *Proc. 4th IEEE Intern. Conf. Adv. Learn. Technologies*, Joensuu (Finland), 2004.

[51] J. Ohene-Djan, R. Zimmer, M. Gorle and S. Naqvi, "A personalisable electronic book for video-based sign language education," *Educational Technology and Society*, vol. 6, pp. 86-99, October 2003.

[52] J. Ohene-Djan and R. Shipsey, "E-subtitles: emotional subtitles as a technology to assist the deaf and hearing-impaired when learning from television and film," *6th IEEE Intern. Conf. Adv. Learning Technologies (ICALT)*, Kerkrade (Holland): IEEE Computer Society, pp. 464-66, July 2006.

[53] J. Ohene-Djan and S. Naqvi, "An adaptive www-based system to teach British Sign Language," *Proc. 5th IEEE Intern. Conf. Adv. Learning Technologies (ICALT)*, Kaohsiung (Taiwan): IEEE Computer Society, pp. 575-79, July 2005.

[54] K.O. Nurzyńska and A. Duszeńko, "Interactive system for Polish signed language learning," *International Journal of Emerging Technologies in Learning*, vol. 1(3), pp. 1-5, November 2006.

[55] S. Naqvi, J. Ohene-Djan and R. Spiegel, "Testing the effectiveness of digital representations of sign language with children," *Instructional Technology and Education of the Deaf Symposium*, Rochester, N.Y.: National Institute for the Deaf, pp. 1-7, June 2005.

AUTHORS

R. Spiegel is with the Institute of Medical Psychology, Ludwig-Maximilians University (LMU) and its affiliated Generation Research Program Ltd., Goethestr. 31/1, D-80336 Munich, Germany and with the Medical Schools of both Munich universities (LMU and TU, e-mail: rainer.spiegel@campus.lmu.de). From 2002 to 2006 he has been Fellow of Wolfson College, University of Cambridge, Cambridge CB3 9BB, United Kingdom.

S. Naqvi is with the Department of Computing, Goldsmiths College, University of London, New Cross, SE14 6NW, United Kingdom (e-mail: s.naqvi@gold.ac.uk).

J. Ohene-Djan is with the Department of Computing, Goldsmiths College, University of London, New Cross, SE14 6NW, United Kingdom (e-mail: j.djan@gold.ac.uk).

D.R. Moore is with the College of Education, Ohio University, McCracken Hall, Athens, OH 45701, USA (e-mail: moored3@ohio.edu).

E. Hsiao is with the College of Education, Ohio University, McCracken Hall, Athens, OH 45701, USA (e-mail: eh247904@ohio.edu).

Manuscript received 25 December 2006.