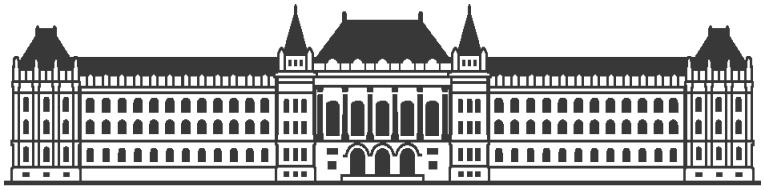

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Stimulus dependence and developmental differences in Probabilistic Categorization and Sequence Learning

PhD Thesis

Thesis booklet

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Budapest, 2012

Synopsys of the presented studies and theses

Four studies are included in the dissertation. Three out of the four use the Weather Prediction (WP) task, while the fourth study employs the Serial Reaction-Time (SRT) task. Study 1 is a neuropsychological study that applies the WP task to children with Specific Language Impairment. The rationale of the study is to test whether SLI is also associated with procedural learning deficits, as suggested by the Procedural Deficit Hypothesis (Ullman & Pierpont, 2005). Performance of children with SLI is compared to typically developing children and adults, this way we also acquired data on the development of probabilistic categorization measured by the WP task. Study 2 tests whether different inner structures of stimuli and stimulus-outcome relations affect learning performance, or whether learning is identical regardless of the set of stimuli. Transparent and Arbitrary stimulus-outcome associations are used. Also cue-combinations are provided either as standalone images presented simultaneously, or as different features of the same image. Here we also present data from children and adults. Study 3 also tests the effect of different stimulus sets from different domains, but the employed implicit learning paradigm is the Serial Reaction-Time task. The central focus of the study is (1) whether response sequences are acquired in the absence of one-to-one stimulus-response correlation, (2) whether unattended stimulus sequences are acquired, and (3) whether learning of response sequences are affected by unattended systematicity in stimulus appearance. Study 4 tests explicit awareness on the WP task using subjective self-insight measures, and comparing those to measures provided by a control group with no predictive structure in the task.

Thesis 1: Probabilistic categorization measured by the Weather Prediction task is impaired in Specific Language Impairment

Study 1 tests the Procedural Deficit Hypothesis of Specific Language Impairment (Ullman & Pierpont, 2005). If children with SLI have a procedural learning deficit, then it should be manifest in their performance on a non-linguistic procedural learning task like the WP task. According to the PDH, children with SLI are expected to perform similarly to adults with Parkinson's syndrome: they are expected to show chance-level performance (Knowlton, Mangels, & Squire, 1996). 16 children with SLI (mean age: 11;3, Sd: 1;3), 16 age-matched typically developing children and 16 adults (mean age: 20;5, Sd: 1;7) completed a version of the WP task that was modified to be suitable for testing children. Results showed that children with SLI performed significantly worse than typically developing children. Also, children with SLI only performed above chance level in Block 3. Strategy use was also compared. Results showed that only one third of the clinical group was able to develop any strategies, and the developed strategy was one of the singe strategies. At the same time, the majority of TD children used one of the single strategies, and one third managed to develop the multi-cue strategy. There were only two TD children not showing any signs of strategy use throughout the task. These results show that there is a procedural deficit in Specific Language Impairment. This is in line with the theories suggesting that language is related to procedural learning, and the underlying procedural deficit might explain a number of symptoms observed in SLI – in concert with the Procedural Deficit Hypothesis (Ullman & Pierpont, 2005).

Thesis 2: Performance on the WP task improves with age

In both Study 1 and Study 2, we tested children on the Weather Prediction task. Our hypothesis was that probabilistic categorization is age-dependent, and performance on the WP

task improves with age. Results showed that while in Study 1, a typically developing control group of 11;3 years mean age showed a numerically lower performance than young adults, the performance of the two groups did not differ from each other statistically. In Study 2 however, four groups of 8;6-8;9 year old children (SDs: 0;3-0;6) showed significantly lower performance than young adults of 20;9-21;6 years of age (SDs: 1;3-1;11). Also, children showed more single strategy usage, while the majority of adults relied on multi-cue strategy. These studies suggest a slow development with age, which is in concert with the improvement hypothesis of developmental changes in IL (e.g. Fletcher, Maybery, & Bennett, 2000).

Thesis 3: Cue-based cue presentation enhances categorization performance in the WP task

Study 2 tested whether the structure of cue presentation accounts for the differences observed between the Weather Prediction task and the Ice-Cream task (Hopkins, Myers, Shohamy, Grossman, & Gluck, 2004; Shohamy, Myers, Onlaor, & Gluck, 2004; Shohamy, Onlaor, Myers, & Gluck, 2001). We compared versions of the WP task in which cues either appeared as standalone images (Cue-based conditions), or as features of one combined image (Holistic conditions). Based on previous studies we hypothesized that Cue-based presentation would lead to better performance than if cues are presented as features of the same image. Also, based on previous literature, cue presentation was hypothesized to lower the chance of multi-cue strategy usage. Results showed that performance on the Cue-based conditions were significantly higher than in the case of the Holistic conditions. Results on strategy use revealed that Holistic versus Cue-based stimulus presentation does not affect strategy use. These results suggest that in fact, the holistic presentation of cues lead to a significantly lower level in performance, but not in strategy use.

Thesis 4: Transparency between cues and outcomes enhances categorization in the early stages of the task

Our major question in connection with the IC task was whether the WP and IC tasks are in fact only differ in the holistic versus cue-based nature of cue-presentation. In Study 2 we also tested whether a transparent link between cues and outcomes affects performance. In the Transparent conditions cues were fragments of a line-drawing, whereas feedback revealed the complete line-drawing; showing why exactly the cues led to the specific outcome. We hypothesized that cue-outcome transparency would enhance early learning performance, as it serves as an anchor point. However, we also expected that this advantage turns into a disadvantage, as observed by earlier studies of Shohamy et al (2004; 2001). Results showed that in the early blocks transparency between cues and outcomes enhances categorization performance; while in the later phases performance was higher for the Arbitrary conditions, where the only link between cues and outcomes was the statistical association provided by feedbacks. Analysing strategy use revealed that participants of the Arbitrary conditions are more likely to develop a multi-cue strategy during the task, whereas participants of the Transparent conditions use the single strategies. These results suggest that cue-outcome transparency enhances participants to learn single-cue-outcome associations, however these associations seem to be stronger, and more difficult to modify. This way, participants become unable to combine cues.

Thesis 5: Response learning is present in the SRT task even in the absence of one-to-one stimulus-response mapping

Study 3 employed the SRT task, and focused on whether response and perceptual sequential structures are acquired in the absence of the other. In the Response condition of Study

3, participants faced a six block SRT task with no one-to-one mapping of stimuli and responses. Participants faced pictures of four categories. The pictures were those of mammals, furniture, fruits or tools. Participants had to respond with a button press in accordance with the category of the stimulus. Within each category, the specific pictures appeared randomly. Our hypothesis was that response sequence learning takes place even in the absence of a perceptual sequence. Results confirmed our hypothesis, as participants showed a significant sequence specific increase in reaction times.

Thesis 6: Response-independent perceptual learning does not appear on a short, 6 block SRT task

We showed that response sequence learning may take place in the absence of a correlating stimulus sequence. The question of the Stimulus location condition of Study 3 was whether an unattended stimulus-location sequence can be acquired. In the Stimulus location condition of Study 3, participants faced a 6-block SRT task in which they had to respond to categories of pictures. There were ten pictures within each category, and both appearances of within and between category elements were random. Stimuli could appear in the four corners of the screen. There was a 12-element-long sequence in the location of the stimuli, while participants had to respond to the identity of the stimuli. Our hypothesis was that an unattended perceptual sequence will not affect reaction times (Riedel & Burton, 2006). Results showed that the removal of the stimulus location sequence caused no RT increase. Results confirm earlier studies (Riedel & Burton, 2006) showing that pure perceptual learning does not take place in the SRT task if the perceptual sequence is not in the response domain.

Thesis 7: Probabilistic perceptual information impairs response sequence learning

The Response and Stimulus location conditions of Study 3 confirmed that response sequences may be learnt without a one-to-one mapping between stimuli and responses, and that the unattended stimulus location sequence is not subject to learning – at least in such a six-block setting of the SRT task. Some earlier studies suggested that effector-, response- and perceptual types of learning may not necessarily be independent of each other, but might interact (Deroost, Zeeuws, & Soetens, 2006; Nattkemper & Prinz, 1997). In the Extra condition of Study 3 we tested whether the stimulus domain has any effect on learning the response sequence. Participants faced a response sequence identical to that of the Response condition. The appearance of the stimuli however varied in a probabilistic way: each category had a high frequency location (appearing at this location in 55% of all cases), and three low frequency locations (appearing at these locations in 15-15% of all cases). Results showed that learning both the response sequence and the location frequency was reduced in this simultaneous condition. This suggests that while pure perceptual learning did not appear in the unattended domain (Stimulus location condition), a probabilistic structure in the perceptual domain had a detrimental effect on response sequence learning and vice versa. This is in concert with earlier results suggesting that the different learning domains are in interaction (Deroost et al., 2006; Nattkemper & Prinz, 1997).

Thesis 8: Explicit knowledge plays an important role in learning the WP task

In Study 4, we investigated whether participants consider their own decisions explicit or implicit. Item-by-item subjective self-insight measures were collected: participants were

prompted after each decision to characterize the basis of their response: Guessing, Intuition, 'I think I knew the answer', Memory or Rule-knowledge. As introspection is not necessarily a reliable measure, especially in implicit learning (Frensch & Rünger, 2003), responses of participants in the Experimental condition (facing the original WP task) was compared to those of a Control condition. The Control condition lacked a predictive structure: cues and outcomes were paired randomly. Results showed that Experimental participants responded with significantly more explicit answers than the Control condition. Also, for both groups, implicit performance was at chance level, and the two groups only differed in explicit performance: chance level for Control participants, while a performance almost reaching 90% in the Experimental condition. Examining strategy use, participants using single strategies gave less explicit answers than multi-cue users, but they showed the same level of performance on both implicit and explicit decision. These results contradict both the implicit-first (Knowlton et al., 1996) and strategy hypotheses (Gluck, Shohamy, & Myers, 2002), and are in line with the explicit theory (Lagnado, Newell, Kahan, & Shanks, 2006).

These results, suggesting that learning on the WP task is explicit, require integration with previous results, as there is a discrepancy with Thesis 1. Thesis 1 states that implicit/procedural learning measured on the WP task is impaired in SLI, while Thesis 8 states that the WP task is explicit in adults. There are four possible resolutions to this controversy. On the one hand, it is a possible that learning on the WP task is implicit in children, and explicit in adults. Potential support for this hypothesis comes from previous studies showing that learning on the SRT task elicits subcortical activation in children and cortical activation in adults (Thomas et al., 2004). Other studies using the SRT task provided how many participants were able to develop explicit knowledge during the learning process, but did not compare the numbers directly across age-groups. Looking at these data across studies, we see that the rate of younger children and the rate of older children developing conscious access are very similar (50% in 10-year-olds, 37% in 7-

year-olds Thomas & Nelson, 2001). This argues against the claim that children rely more on implicit learning, while adults are more prone to use explicit strategies. Clearly, more research is needed to disentangle the contribution of implicit/explicit knowledge to performance on these tasks.

The other possibility is that learning on the WP task is explicit in children as well. In this case, the impaired WP performance in SLI requires an alternative explanation. First, there is evidence that declarative memory is also impaired in SLI (Gathercole & Baddeley, 1990), which might account for the impaired declarative WP performance. Previous results also revealed severe executive deficits in SLI (Henry, Messer, & Nash, 2012). As clinical studies confirmed the relationship between the SRT task and executive functions (Jackson, Jackson, Harrison, Henderson, & Kennard, 1995), the executive deficit might contribute to deficient learning on the WP task. A last possibility considers the nature of the deficit in SLI. Hsu and Bishop (2010) contrasts procedural and statistical learning deficits, and suggests that the two hypotheses are not identical. According to their view, statistical learning is the acquisition of general statistical information, regardless of the declarative versus procedural nature of the task. That is, statistical learning deficit may be apparent in both declarative and procedural tasks that require the extraction of statistical information. Here again, more research is needed to conclude the origins of the probabilistic categorization impairment observed in SLI.

References

Deroost, N., Zeeuws, I., & Soetens, E. (2006). Effector-dependent and response location learning of probabilistic sequences in serial reaction time tasks. *Experimental Brain Research, 171*(4), 469-480.

Fletcher, J., Maybery, M. T., & Bennett, S. (2000). Implicit learning differences: a question of developmental level? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 26*(1), 246-252.

Frensch, P. A., & Rünger, D. (2003). Implicit learning. *Current Directions in Psychological Science, 12*(1), 13-18.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection. *Journal of Memory and Language, 29*, 336-360.

Gluck, M. A., Shohamy, D., & Myers, C. (2002). How do people solve the "weather prediction" task?: Individual variability in strategies for probabilistic category learning. *Learning & Memory, 9*(6), 408-418.

Henry, L. A., Messer, D. J., & Nash, G. (2012). Executive functioning in children with specific language impairment. *Journal of Child Psychology and Psychiatry, 53*(1), 37-45.

Hopkins, R. O., Myers, C. E., Shohamy, D., Grossman, S., & Gluck, M. (2004). Impaired probabilistic category learning in hypoxic subjects with hippocampal damage. *Neuropsychologia, 42*(4), 524–535.

Hsu, H. J., & Bishop, D. V. M. (2010). Grammatical Difficulties in Children with Specific Language Impairment: Is Learning Deficient? *Human Development, 53*(5), 264-277.

Jackson, G. M., Jackson, S. R., Harrison, J., Henderson, L., & Kennard, C. (1995). Serial Reaction-Time Learning and Parkinsons-Disease - Evidence for a Procedural Learning Deficit. *Neuropsychologia, 33*(5), 577-593.

Knowlton, B. J., Mangels, J. A., & Squire, L. R. (1996). A neostriatal habit learning system in humans. *Science, 273*(5280), 1399-1402.

Lagnado, D. A., Newell, B. R., Kahan, S., & Shanks, D. R. (2006). Insight and strategy in multiple-cue learning. *Journal of Experimental Psychology: General, 135*(2), 162-183.

Nattkemper, D., & Prinz, W. (1997). Stimulus and response anticipation in a serial reaction task. *Psychological Research, 60*, 98–112.

Riedel, B., & Burton, A. M. (2006). Auditory sequence learning: differential sensitivity to task relevant and task irrelevant sequences. *Psychological Research, 70*(5), 337-344.

Shohamy, D., Myers, C. E., Onlaor, S., & Gluck, M. A. (2004). Role of the basal ganglia in category learning: How do patients with Parkinson's disease learn? *Behavioral Neuroscience, 118*(4), 676-686.

Shohamy, D., Onlaor, S., Myers, C., & Gluck, M. (2001, March). *Category learning in Parkinson's disease: The effect of stimulus presentation on performance.* Paper presented at the 8th Annual Meeting of the Cognitive Neuroscience Society, New York.

Thomas, K. M., Hunt, R. H., Vizueta, N., Sommer, T., Durston, S., Yang, Y. H., & Worden, M. S. (2004). Evidence of developmental differences in implicit sequence learning: An fMRI study of children and adults. *Journal of Cognitive Neuroscience, 16*(8), 1339-1351.

Thomas, K. M., & Nelson, C. A. (2001). Serial reaction time learning in preschool- and school-age children. *Journal of Experimental Child Psychology, 79*(4), 364-387.

Ullman, M. T., & Pierpont, E. I. (2005). Specific language impairment is not specific to language: the procedural deficit hypothesis. *Cortex, 41*, 399–433.