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**Review of the dissertation of Katarzyna Patro about
"Mental associations between numbers and space before school education"**

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Dear Sir or Madam,

The dissertation of Katarzyna Patro tackles the problem of early origins and development of the mental number line, an association between numbers and space: small numbers are associated with the left direction in space, large number with the right direction. This association has shown to be a very important pre-condition for the children's later mathematical skills.

In the introductory part of the thesis, which is part of a co-tutelle dissertation done at the Eberhard Karls University in Tuebingen and the University of Warsaw (Uniwersytetu Warszawskiego), the author presents the most dominant approach meant to account for origins and direction of this association. This approach states that spatial-numerical associations (SNA) arise as a spillover of directional reading habits. This is widely supported by cross-cultural studies. The thesis criticizes this interpretation. The author shows that this explanation of the origin of spatial-numerical associations faces a serious problem: these associations develop already *before* children's formal literacy acquisition. Children do not learn to read, and then build the spatial-numerical associations based on these experiences, but they even show such associations before they can read.

The author argues that the traditional reading hypothesis should be reconsidered and extended. She achieves this aim by examining several preliterate sources of number-space



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hand-related reference frames – and not cultural knowledge on script organization as it has been discussed till now – are important for establishing the direction of number processing in this early developmental period. However, the study was only correlational, so the author refrained from making strong conclusion as to causality of this relation.

Study 3 bases on a publication in *Developmental Science*, which has an impact of 4.3 and is one of the best journals in developmental psychology. The study further explores whether any other directional experiences, not related to reading and writing, could cause early SNA formation. The study realizes a training design, which allows examining causality. Children have to move an object across the touchscreen either from left to right or from right to left. The study shows impressively that already 10-15 minutes of this non-reading and non-numerical directional experience were sufficient to induce respective associations between numerical magnitudes and sides in space: the children trained in left-to-right movement constructed left-to-right SNA, whereas the children trained with right-to-left movement constructed the reversed SNA. These results are highly important, as they provide the first evidence-based explanation on how numbers can be linked to space independently of reading skills. They show a causal link between short-term visuo-motor activities and subsequently measured number-space associations. The author argues that simple activities, such as manual games, dominant in a given society, shape number-space associations in children in a way similar to lifelong reading training. However, the study found no training effect on the direction of object counting with another measure for SNA. Katarzyna Patro discusses this dissociation in training effects thoroughly; in her view, this finding confirms the multidimensionality of SNA: cardinal and ordinal SNAs, as they were introduced in study 1, might refer to different aspects of number-space processing.

Whereas study 3 focused on the role of spatial training in construction of SNA, **study 4** (based on a peer-reviewed publication: Patro et al., 2015, *Journal of Cognitive Psychology*) explored the role of bodily constraints in this process. The author follows up on her findings reported in study 2 on the relation between direction of object counting and the hand used by a child. This time, she tests causality of this relation. Children were asked to count objects with a particular hand so it could be directly tested whether the hand side indeed enforces spatial biases in counting. This prediction has been confirmed. What is more, the influence of hand was especially evident when objects were presented close to a child's body. This clearly shows that counting direction of children should not be solely interpreted in terms of their potential cultural preferences. Also bodily or situational constraints like an ability/disability to reach a contralateral object with a hand should be considered. These findings and conclusion extend the original repertoire of SNA determinants by ac-

Katarzyna Patro did this research self-reliantly. Her work is creative and convincing with regard to theory, methods and results. She managed to present an overall theory frame where her studies deliver empirical evidence for several processes described in this frame. The distinction of different categories of SNA is theoretically and empirically convincing.

So in sum, this dissertation clearly meets the requirements for a doctoral thesis according to the regulations of the University of Warsaw ("art. 13 ustawy z dnia 14 marca 2003 o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki - Dz. U. nr 65, poz. 595"). I strongly plead for acceptance of the thesis. I even appoint for "distinction" because of its extraordinarily high quality.

Best regards,



Prof. Dr. Ulrike Cress