Center for Lifespan Psychology

Director: *Ulman Lindenberger*

Research Project 6: Sensorimotor–Cognitive Couplings

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Key Reference

Schaefer, S., Schellenbach, M., **Lindenberger, U.,** & Woollacott, M. (2015). Walking in high-risk settings: Do older adults still prioritize gait when distracted by a cognitive task? *Experimental Brain Research, 233,* 79–88. doi:10.1007/s00221-014-4093-8

Goal-directed behavior requires the seamless integration of perception, movement, and thought. Examples include the simultaneous performance of cognitive and motor tasks, the coordination of elementary body movements, and action planning. The project investigates how infants construct these integration skills and how they further evolve across the lifespan.

The Movement Lab, in which most of our research takes place, is equipped with a motion capture system allowing us to measure the positions of reflective markers attached to a participant's body with high temporal and spatial accuracy (see Figure 18). Motion capture can be combined with synchronized measurements of ground reaction forces control or muscle activity. The Lab is also equipped with a multichannel video system for behavioral studies with infants.

Coordination of Cognitive and Motor Performance in Dual-Task Situations

When a cognitive and a motor task need to be performed concurrently, older adults often show higher dual-task costs than younger adults and tend to prioritize the motor domain (Schaefer, 2014). However, we found that this prioritization may function less effectively in older relative to younger adults when multiple challenges are combined (Schaefer, Schellenbach, Lindenberger, & Woollacott, 2015). In our study, participants walked on a speed-adaptive treadmill as fast as possible through four different virtual environments: broad or narrow tracks; on ground level or an elevated level (see Figure 19). Young adults maintained their walking speed and kept the number of missteps low, even when walking on an elevated narrow track while performing a challenging working-memory task. In contrast, older adults actually increased their walking speed on elevated relative tracks and committed more missteps under cognitive load. In the real world, this strategy may be maladaptive and result in falls. We also investigated the influence of walking speed and cognitive load on gait regularity in children aged 7 or 9 years and young adults (Schaefer, Jagenow, Verrel, & Lindenberger, 2015). In all age groups, regularity of lower body coordination increased with walking speed. Children showed a U-shaped relationship between cognitive load and walking regularity, with the highest regularity in the easy cognitive task. In contrast, young adults' gait regularity was not influenced by cognitive load. These results indicate that the effects of cognitive load on motor performance are modulated by age, similar to what we observed in an earlier study comparing younger and older adults.

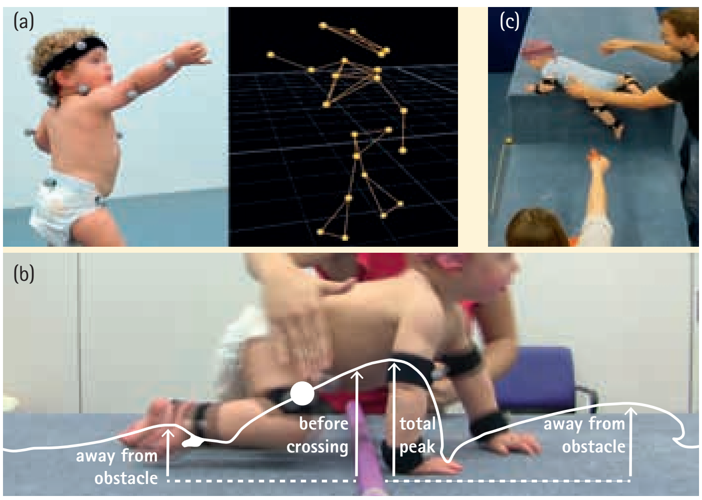

Figure 18. Experimental setups and measurements in the Movement Lab. (a) Infant equipped with reflective markers for motion capture and reconstructed 3D marker positions. (b) Infant crawling over obstacle. Anticipatory control is quantified in terms of knee clearance at the obstacle and away from the obstacle, measured by 3D motion capture. (c) Setup to investigate judgment of action possibilities and motor planning in infants. Here, the infant uses an alternative strategy (descending backward) on a step too high for him to walk or crawl down.

Interaction of Cognitive and Motor Task Components

Cognition and motor control also interact when cognitive tasks require a complex motor response. We investigated the influence of response conflict on movements requiring a postural preparation in form of a weight shift, namely, lifting one foot from the floor in a standing position while ignoring visual distractors priming the same or the opposite response (see Figure 20a). Under balance

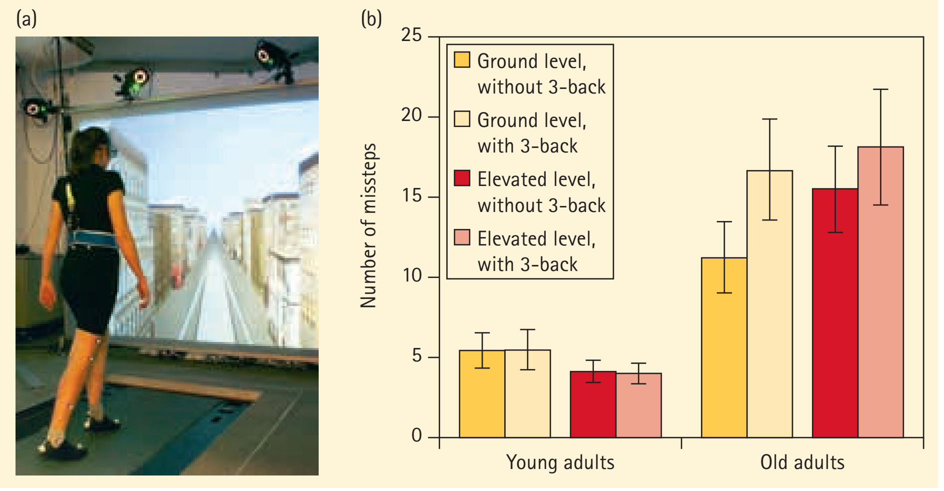

Figure 19. Coordination of cognitive and sensorimotor task demands during walking. (a) Experimental setup showing treadmill and virtual environment, walking on an elevated wide track. (b) Number of missteps on the narrow tracks on even ground and in the elevated setting with and without a concurrent working-memory task (3-back). Error bars represent the standard error of the mean (adapted from Schaefer, Schellenbach, Lindenberger, & Woollacott, 2015).

constraints, young adults showed automatic imitation tendencies for whole-body movements (Verrel, Lisofsky, & Kühn, 2014). In a subsequent age-comparative study (Verrel, Lisofsky, Kühn, & Lindenberger, 2016), older adults responded more slowly than younger adults, whereas stimulus-compatibility effects did not differ reliably by age (see Figure 20b). Compatibility effects as well as age differences in response latency were associated with postural preparation errors, pointing to erroneous response activation as their potential source. In ongoing studies, we seek to delineate the points in the action hierarchy, from goals to movement execution, at which these compatibility effects originate.

Movement Coordination, Anticipatory Control, and Action Planning

Motor behavior requires the coordination of multiple body parts to achieve desired action outcomes. We introduced a novel method that estimates interjoint coordination by quantifying the effect of artificially eliminating movement at individual joints. Applying this "freezing" method to the coordinative skill of cello bowing revealed pronounced differences between novices and expert cello players, especially for the wrist and elbow (Verrel, Woollacott, & Lindenberger, 2014). Our results emphasize the importance of coordination across multiple joints, in particular distal joints, for skilled motor performance.

Anticipatory control and advance planning are defining features of motor action. In collaboration with Karen Adolph (New York University, USA), we have begun to investigate anticipatory adjustments to locomotor movements in young infants crawling over small obstacles (see Figure 18b). Preliminary results indicate that infants use visual and haptic information for anticipatory adjustments of locomotion. In contrast to results from animal studies, however, anticipation was found to be unstable, showing high intra- and interindividual variability. Currently, we are investigating decision making, advance planning, and motor coordination in infants aged 10 to 16 months when confronted with height challenges that vary in difficulty (see Figure 18c). In particular, we explore how flexibly and adaptively infants use alternative strategies, such as descending via a sitting posture, sideways or backward, and to what extent these strategies generalize across environmental conditions, such as steps versus slopes, and across locomotor styles, such as crawling and walking.

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Verrel, J., Woollacott, M. H., & **Lindenberger, U.** (2014). Articulated coordination of the right arm underlies control of bow parameters and quick bow reversals in skilled cello bowing. *Frontiers in Psychology, 5*:885. doi:10.3389/fpsyg.2014.00885

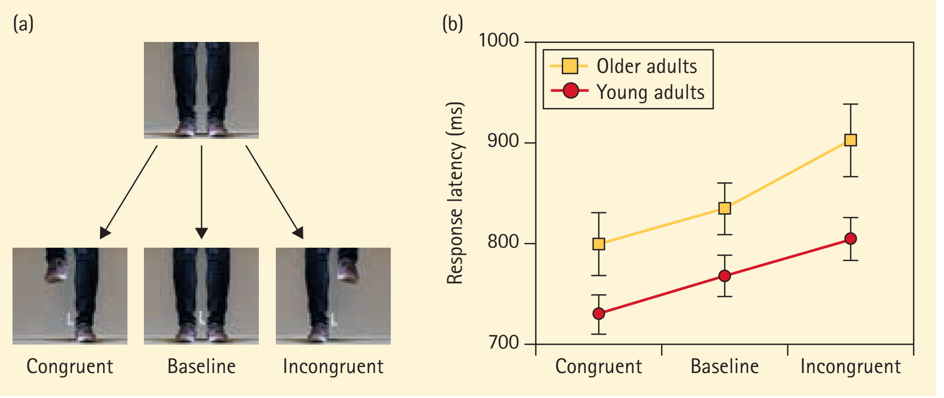

Figure 20. Response conflict in whole-body movements with balance constraints. (a) Exemplary stimuli (Verrel, Lisofsky, & Kühn, 2014; Verrel, Lisofsky, Kühn, & Lindenberger, 2016). Participants responded to the symbolic stimulus (L or R) by lifting their left or right foot off the floor. Visual distractors showed a congruent or incongruent movement. (b) Response times for young and older adults. Postural preparation errors showed an analogous pattern, and differences in response times between conditions and age groups were largely explained by erroneous postural preparation (adapted from Verrel, Lisofsky, Kühn, & Lindenberger, 2016).

Key References

Kleemeyer, M. M., Kühn, S., Prindle, J. J., Bodammer, N. C., Brechtel, L., ... **Schaefer, S.,** & **Lindenberger, U.** (2016). Changes in fitness are associated with changes in hippocampal microstructure and hippocampal volume among older adults. *NeuroImage, 131,* 155–161. doi:10.1016/j.neuroimage.2015.11.026

Kleemeyer, M. M., Polk, T. A., **Schaefer, S., Bodammer, N. C.,** Brechtel, L., & **Lindenberger, U.** (2017). Exercise-induced fitness changes correlate with changes in neural specificity in older adults. *Frontiers in Human Neuroscience, 11*:123. doi:10.3389/fnhum.2017.00123

Effects of Physical Exercise on Brain and Behavior

In close collaboration with the *Plasticity* project (pp. 153–156), we conducted an exercise intervention study to identify physiological mechanisms that may elucidate the positive association between regular physical activity on cognitive performance in old age. Fifty-two older adults exercised on bicycle ergometers for 6 months three times a week. Changes in fitness were associated with changes in hippocampal tissue density (measured by mean diffusivity), which in turn were associated with changes in hippocampal volume. These results suggest that fitness-related changes in hippocampal volume may be driven by an increase in cell membranes (Kleemeyer et al., 2016). In addition, we found a positive association between changes in fitness and changes in the specificity of neural responses to visual stimuli (see Figure 21; Kleemeyer et al., 2017), suggesting that regular physical exercise can help maintain neural specificity in older adults. In ongoing analyses of this data set, we examine whether changes in white matter and cerebral blood flow are associated with exercise-induced fitness changes.

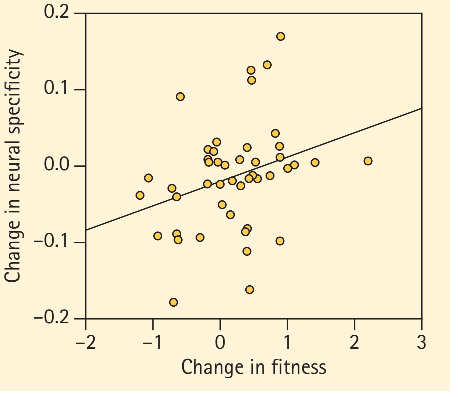

Figure 21. Relation between physical fitness and brain function. Scatter plot displaying a significant association between changes in fitness and changes in neural specificity, that is, the degree to which neural representations of different visual stimuli (e.g., faces and houses) can be discriminated by means of multivariate pattern analysis (adapted from Kleemeyer et al., 2017).

Research Project 7: Brain Imaging Methods in Lifespan Psychology

Research on human development seeks to delineate the variable and invariant properties of age-graded changes in the organization of brain–behavior–environment systems. Magnetic resonance imaging (MRI) and magnetic resonance spectroscopy (MRS) have become indispensable tools in this context, as they allow noninvasive assessment of brain function, anatomy, microstructure, and metabolism.

The two main goals of the *Brain Imaging Methods* project are: (i) to ascertain and improve the measurement quality of standard brain imaging protocols at the Center; (ii) to complement the standard imaging repertoire by advanced sequences with enhanced interpretability that hold promise in elucidating structural changes and physiological mechanisms related to maturation, learning, and senescence. In pursuing these goals, the project serves as a resource to other projects interested in imaging (e.g., Kleemeyer et al., 2016; Wenger et al., 2017).

Structural and quantitative MRI methods occupy a central place in the project. During the reporting period, the project has focused on (i) high-resolution T_1-weighted imaging to obtain estimates of volume or thickness of specific substructures of the brain; (ii) diffusion imaging and multiparametric mapping (MPM) to obtain brain maps that permit quantitative estimates of histological parameters; (iii) susceptibility-weighted imaging to obtain maps of mineralization, especially for the brain's deep gray matter structures; and (iv) myelin water fraction (MWF) imaging by mapping the fraction of shortest T_2 relaxation rates quantitatively. The latter method provides an estimate of the portion of water molecules located between myelin sheaths, presumably reflecting the degree of myelination within white matter. Work on MPM profits from collaboration with Nikolaus Weiskopf (MPI for Human Cognitive and Brain Sciences, Leipzig, Germany).

Functional MRI and MRS are used to provide maps and spectra of brain activity during task performance or at rest. The project takes special interest in: (i) high-resolution functional imaging of the hippocampus; (ii) task-related, time-resolved applications of proton MRS, with a focus on glutamate and GABA; and (iii) phosphorus MRI to capture individual differences in brain metabolism. Work in this area involves collaborations with Mara Mather (University of Southern California, Los Angeles, USA), Florian Schubert (Physikalisch-Technische Bundesanstalt, Berlin, Germany), and Jeff Stanley (Wayne State University, Detroit, USA).

In the following, we provide additional details on three of the methods that have been the focus of our attention during the reporting period.

Diffusion Imaging

Diffusion imaging captures the movement of water molecules, termed diffusion. Diffusion in tissue is hindered by cell membranes. Therefore, the orientation-dependent diffusion profiles provide information about tissue microstructure. For instance, when water molecules are observed in myelinated neuronal fibers, their diffusion is less hampered along than across fiber tracts. Diffusion within a voxel (a three-dimensional data point) is often captured by a tensor (ellipsoid) model. However, by permitting only one directional description per voxel, diffusion tensor imaging provides an impoverished, and at times inaccurate, picture of histological reality; for instance, the crossing of fibers may go unnoticed. To enhance the microstructural veridicality of diffusion imaging, the project is working on multishell diffusion imaging acquisition schemes to improve the precision of orientational information. Diffusion models under scrutiny are the sticks-and-ball model (used by FMRIB Software Library, FSL), constrained spherical deconvolution (implemented in MRtrix), and physiologically motivated multicompartment models (e.g., neurite orientation dispersion and density imaging, NODDI). We plan to use multishell diffusion imaging in combination with nontensor diffusion modeling to move toward a more

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