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Dependence of Manual Grasping on the Behavioral Context: A Comparison between Arms and between Age Groups

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We evaluated the kinematics and dynamics of grasping in a typical laboratory situation (L) and in a more everyday-like situation (E), using right-handed subjects. Performance was compared when young subjects used their right versus left arm, and when young versus old subjects used their left arm. As in our previous work, multiple differences emerged between parameter values in the two contexts, L and E. These context differences were, however, more pronounced for the left rather than for the right arm of young subjects, and more pronounced for the left arm of young rather than older subjects. We propose an explanation based on the differential involvement of the dorsal and ventral cortical processing stream in L and in E: The differential involvement would be accentuated for the left arm of young, but not for the left arm of older subjects.

Keywords: Motor Control; Prehension; Context-Dependence; Sensorimotor Integration

Introduction

It has been suggested before that findings on motor performance, yielded in the laboratory, may not necessarily apply in everyday life (Chaytor & Schmitter-Edgecombe, 2003; Ingram & Wolpert, 2011). We have recently scrutinized this view by asking subjects to grasp and move a lever either in a typical laboratory context (L)—grasping was instructed, externally triggered, repetitive, and served no ultimate purpose—or in a more everyday-like context (E)—grasping was not explicitly instructed, self-initiated, embedded in complex behavior and had the ecologically valid purpose to earn money (Bock & Hagemann, 2010). Even though the mechanical constraints were identical in both contexts, movement kinematics and dynamics widely differed. These differences could not be reduced to a single underlying cause since factor analysis yielded multiple orthogonal factors (Bock & Züll, 2013). This led us to conclude that grasping is controlled by multiple functional modules which are differently sensitive to context.

Further research revealed that context-sensitivity can't be reduced to differences between L and E regarding movement speed, attention focusing or task complexity, since manipulations of those differences didn't consistently change context-sensitivity (Steinberg & Bock, 2013c). However, we observed a consistent effect of personality traits: context-sensitivity was accentuated in subjects who prefer slow, attentive and prudent processing (Steinberg & Bock, 2013b). We proposed that this processing style is characteristic for the ventral rather than the dorsal occipito-frontal stream in the human cortex (Goodale & Milner, 1992; Milner & Goodale, 1993). while the dorsal stream engages in quick automated reactions, the ventral stream specializes in slow and attention-demanding behavior (Buxbaum, Johnson-Frey, & Bartlett-Williams, 2005; Daprati & Sirigu, 2006; Rossetti & Pisella, 2002). Our interpretation thus links context-sensitivity to different cortical processing streams.

The present study investigates whether context-sensitivity, observed previously for the dominant arm, holds equally for the non-dominant arm. It is well established that movement performance is not the same for both arms: the non-dominant arm controls intersegmental torques less well (Sainburg & Kalakanis, 2000), which shows poorer performance on tasks requiring high precision (Gonzalez, Ganel, & Goodale, 2006; Wing, Turton, & Fraser, 1986; Woodworth, 1899), but better performance than the dominant arm on tasks requiring high speed (Annett, Annett, Hudson, & Turner, 1979; Carson, Chua, Goodman, Byblow, & Elliott, 1995; Elliott et al., 1993). It has been concluded that the non-dominant arm is optimized for controlling limb posture, and the dominant arm for regulating limb trajectory (Sainburg, 2004). Such a specialization might reflect the preferred arm use in bimanual activities: objects are typically held and stabilized by the non-dominant, and manipulated by the dominant hand (Grosskopf & Kuhtz-Buschbeck, 2006; Trevarthen, 2010). Arm specialization has also been linked to differences in the underlying control principles, feedback control for the non-dominant versus preplanning for the dominant arm (Sainburg & Kalakanis, 2000). Given these profound differences between arms, we reasoned that context-sensitivity might also be different. Specifically, we formulated two alternative hypotheses: according to the first, the non-dominant arm depends more heavily on sensory feedback and therefore should be *less* susceptible to extraneous influences such as behavioral context.

According to the second, the non-dominant arm is not well-practiced in manipulation tasks such as grasping and therefore should be *more* susceptible to extraneous influences such as behavioral context.

We have shown before that context-sensitivity of grasping changes in old age; some parameters become more and other less context-sensitive, with no substantiable net change across all parameters (Bock & Steinberg, 2012). Again, these data have been yielded in the dominant arm. Since handedness is less pronounced in old age (Kalisch et al., 2006), we expected that any increase or decrease of context-sensitivity observed in the left arm of young subjects should be smaller in the left arm of seniors. To find out, the present study includes data from the non-dominant arm of elderly participants.

Methods

Participants

Forty-eight young (24.3 ± 3.9 years) and thirty older subjects (71.8 ± 7.4 years) participated. All were right-handed, free of musculoskeletal impairments, diseases of the nervous system and visual deficits except for corrected vision by self-report, and lived independently in the community. None of them had participated in research on grasping or cognition within the last 12 months. An ethical approval for this study was given by the institutional review board of the German Sport University Cologne, and all subjects signed an informed consent statement before participating. Half of the young subjects were tested using their dominant (right) arm. The other half of the young and all older subjects were tested using their non-dominant (left) arm.

Task and Procedure

Experimental hardware and procedures were as in our previous studies (Bock & Beurskens, 2010). Subjects sat at a table facing a 17 computer screen 67 cm ahead. A cylindrical lever of 4 cm length and 1.5 cm diameter was positioned 35 cm away from the front edge and 16 cm above the surface of the table 10 cm to the right of the screen or, for left arm testing, 10 cm to the left. The lever was covered by a hood from three sides, to ensure that subjects could only grasp it with the precision grip (thumb and index finger). The lever could slide 3.5 cm towards the subjects' body midline along a rail (see **Figure 1**), where it met a mechanical stop. A displacement sensor (Burster® 8740) registered the lever's position and a 6 df force transducer (ATI® Nano 17) registered the forces applied to the lever, both with a sampling rate of 250 Hz. A joystick was mounted 41 cm in front of the screen with its tip 12 cm above the table's surface, such that its distance from the lever was 32 cm horizontally and 4 cm vertically. Six reflecting markers of 6 mm diameter were placed on thumb and index finger of the subjects' grasping hand with double-sided adhesive tape, and two Vicon® MX-F20 3D high resolutions infrared cameras (sampling rate: 250 Hz, 1680 × 1280 pixels) registered their positions.

In a laboratory task (L), the joystick was locked in its central position and subjects touched its tip with thumb and index finger. At randomly varying intervals of 2 - 6 s, a green dot was displayed on the screen accompanied by a beep, prompting subjects to release the joystick and grasp the lever, to slide it towards them and back again, and then to return the hand to the joystick. In an everyday-like task (E), the joystick was unlocked and subjects were asked to play a computer game of chasing spiders on the screen with a joystick-driven cursor. A reward of .02 € was displayed near the right edge of the screen for each spider hit. Each game level terminated after 10 s, and subjects then had to collect their reward by moving the joystick to the center, grasping the lever, moving it towards them and back, and then returning their hand to the joystick. To keep the game motivating, speed and complexity of spider movement increased after every fifth level. No instructions were given on how to grasp the lever in task E, and subjects were not told that the purpose of their participation was to collect data on grasping. In accordance with our earlier study (Bock & Steinberg, 2012), spider speed was 30% lower in older subjects than in young ones.

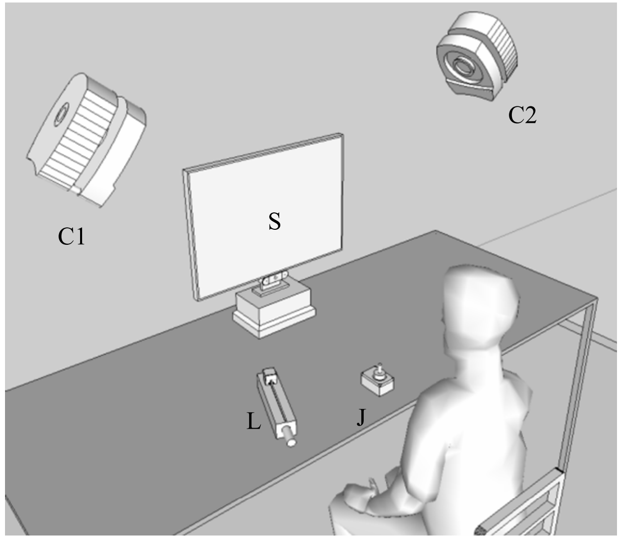

Figure 1.
Schematic representation of the experimental set-up with joystick (J), lever (L), screen (S) and cameras (C1 & C2).

To exclude carryover effects, each subject was engaged in only one of the tasks. Thus, 12 young subjects were tested in L and 12 in E using their left arm, 12 young subjects were tested in L and 12 in E using their right arm, and 15 older subjects were tested in L and 15 in E using their left arm. Each subject had 3 - 5 practice trials with the pertinent task and hand, to ensure that procedures were understood, and data were then collected for 20 grasping responses per subject. Note that both tasks used the same objects (joystick and lever) in the same location, and required the same hand and lever movements; they only differed with respect to their context: grasping was instructed, repetitive and served no ultimate purpose in L, but was uninstructed, part of complex behavior and had financial gain as purpose in E.

Data Analysis

Registered data were reduced by an interactive computer algorithm to 20 parameters representing the means of kinematic and dynamic landmarks across trials, and 20 parameters representing the pertinent coefficients of variation. The additional parameter "Peaks" can't be parsed into a mean and a CV. A definition of all parameters is provided in **Table 1**. Each parameter was submitted to a two-way analysis of variance (ANOVA). Left and right arm performance of young subjects was compared with the between-factors Arm (left, right) and

Table 1.
Parameter definitions and the pertinent ANOVA outcomes*.

	Acronym	Definition		ANOVA left/right			ANOVA young/old		
				Task	**Arm**	**Task * Arm**	**Task**	**Age**	**Task * Age**
Transport component	TT (s)	Time from movement onset to lever contact (transport time)	Mean	70.7***	2.8	2.1	91.7***	10.6***	0.8
			CV	1.2	2.5	4.6*	4.7*	4.5*	0.0
	V_{max} (cm/s)	Peak tangential hand velocity	Mean	28.1***	8.9**	1.0	15.2***	3.1	11.8**
			CV	0.0	0.8	3.7	4.1*	3.8	3.5
	Skew-T	Ratio of deceleration time (V_{max} to lever contact) and TT	Mean	29.9***	0.0	3.3	7.8**	1.6	1.0
			CV	8.3**	0.0	0.1	16.4***	3.0	1.6
	Detour-V (cm)	Peak vertical distance of hand from a straight path	Mean	27.1***	7.8**	1.4	22.4***	1.8	0.4
			CV	7.1*	0.2	0.0	0.9	3.0*	1.6
	Detour-H (cm)	Peak horizontal distance of hand from a straight path	Mean	13.8***	11.1**	6.3*	22.0***	5.4*	10.6**
			CV	7.1*	1.1	3.4	0.0	0.6	0.3
Grasp component	GT (s)	Time during which finger aperture changes (grasp time)	Mean	79.5***	3.2	2.9	90.0***	7.6**	0.1
			CV	4.5*	2.5	4.5*	13.6***	5.9*	1.8
	PGA (cm)	Peak 3D distance from thumb to index finger (peak grip aperture)	Mean	6.1*	3.0	2.0	14.1***	1.1	0.4
			CV	1.8	0.2	1.5	0.0	3.5	0.0
	Peaks	Proportion of multi-peaked aperture profiles		17.2***	9.4**	2.0	12.3***	4.9*	4.8*
	t(PGA) (s)	Interval movement onset to PGA	Mean	102.3***	2.1	2.1	98.1***	4.9*	0.1
			CV	2.9	6.2*	0.5	11.3**	4.9*	3.9
	t(FGA) (s)	Interval PGA to lever contact (final grip aperture)	Mean	3.4	3.8	2.8	8.3**	6.3*	0.0
			CV	0.2	1.6	4.1*	0.6	5.9*	1.0
	Skew-G	Ratio of *t*(FGA) and GT	Mean	89.3***	1.3	0.0	40.9***	0.0	2.1
			CV	1.0	1.1	1.7	5.5*	4.0	0.0
	incli-start (˚)	Hand inclination with respect to horizontal at movement onset	Mean	0.0	0.5	1.7	2.9	2.2	0.3
			CV	1.7	1.4	0.0	0.1	1.5	0.7
	incli-100 (˚)	Hand inclination after 100 ms	Mean	0.9	0.0	2.4	7.7**	0.1	0.5
			CV	0.4	0.0	0.2	0.4	1.9	0.3
	incli-PGA (˚)	Hand inclination at time of PGA	Mean	4.3*	1.5	4.7*	16.3***	6.9*	0.8
			CV	5.3*	1.2	2.9	10.9**	0.3	1.3
	incli-end (˚)	Hand inclination at lever contact	Mean	7.8**	10.7**	3.9	16.4***	9.5**	1.8
			CV	7.2*	2.9	6.7*	13.0***	0.1	1.1
Coupling	Sync-start	Interval onset of finger opening and of hand transport	Mean	27.7***	1.7	1.6	27.2***	1.1	0.3
			CV	0.0	7.0*	11.2**	3.8	0.1	0.5
	Sync-peak	Interval *t*(PGA) and *t*(V_{max})	Mean	79.8***	1.7	3.9	61.5***	3.9	0.1
			CV	0.4	8.9**	0.5	2.7	1.9	5.7*
Lever manipulation	RT-lever (s)	Interval lever contact and onset of lever motion (reaction time)	Mean	11.1**	110.8***	0.7	8.9**	7.9**	2.2
			CV	1.3	3.1	1.8	0.2	0.8	0.4
	F-100 (N)	Force compressing the lever 100 ms after lever contact	Mean	25.6***	3.2	0.0	3.5	1.3	8.7**
			CV	7.2**	0.0	8.4**	0.4	4.3*	17.4***
	TQ-100 (N/mm)	3D lever torque 100 ms after lever contact	Mean	25.2***	3.4	0.0	35.6***	1.0	5.7*
			CV	9.6**	2.6	16.7***	7.2**	19.9***	15.0***
	LT (s)	Interval onset and end of lever motion (lever time)	Mean	12.7***	2.2	1.5	12.2***	0.6	3.3
			CV	0.1	5.8*	2.2	0.1	2.8	2.1

Note: *Numbers are F-values with 1.44 degrees of freedom. *,** and ***Represent $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. For each parameter, ANOVA for the means is presented above ANOVA for the CVs.

Task (L, E). Left arm performance of young and older subjects was compared with the between-factors Age (young, older) and Task. Since the main effects of Task have already been analysed in several earlier publications, the present work focuses on the other effects.

Each parameter with a significant effect of Arm * Task was transformed by

$$\begin{aligned} \Delta &= \left|l_{rh} - E_{RH}\right| - \left|L_{LH} - E_{LH}\right| \\ \text{or } \Delta &= \left|L_{rh} - e_{rh}\right| - \left|L_{LH} - E_{LH}\right| \\ \text{or } \Delta &= \left|L_{rh} - E_{RH}\right| - \left|l_{lh} + E_{LH}\right| \\ \text{or } \Delta &= \left|L_{rh} - E_{RH}\right| - \left|L_{LH} + e_{lh}\right| \end{aligned} \quad (1)$$

where l_{rh}, e_{rh}, l_{lh} and e_{lh} are parameter values of individual subjects participating with their right hand in task L or E, or with their left hand in task L or E, respectively, while L_{RH}, E_{RH}, L_{LH} and E_{LH} are the corresponding group means. Thus, large scores represent a stronger task-dependence of the right compared to the left hand.

Significant effects of Age * Task were transformed accordingly. We then submitted the scores to factor analyses with varimax rotation, using the inclusion criterion F = 1.

Results

The right part of **Table 1** summarizes the ANOVA outcome for young subjects using the left or right arm in L or E.

As in our previous work (Bock & Steinberg, 2012; Bock & Züll, 2013; Steinberg & Bock, 2013a; Steinberg & Bock, 2013b), the effect of Task was significant for a number of parameters. The effect of Arm was significant for several parameters as well, and that of Task * Arm was significant for nine parameters. The latter were transformed into scores, and were then reduced by factor analysis to three orthogonal factors, explaining 64.5% of total variance (see **Table 2**).

To obtain a global measure of Task * Arm effects, we normalized each parameter p with Task * Arm significance by

$$P' = P/L_{RH} \quad (2)$$

and then calculated the rms value of p' across parameters.

The outcome is depicted in **Figure 2(a)**: the nine parameters with Task * Arm significance were task-independent for the right, but task-dependent for the left hand.

We then replicated the same procedure for factor rather than parameter values, yielding the outcomes in **Figures 2(b)-(d)**: the same pattern described above also emerged for each factor.

The right part of **Table 1** summarizes the ANOVA outcome for young and older subjects using the left arm. Again, a number of parameters showed significant effects of Task and/or Age, and eight parameters yielded significant effects of Task * Age. The latter were reduced by factor analysis to three orthogonal factors explaining 69.29% of total variance (see **Table 3**). The right part of **Figure 2** illustrates that parameters with significant Task * Age interactions were task-dependent in young but not in older subjects, and that this is reflected by all three factors, although to a varying degree.

Discussion

The purpose of our study was to evaluate the role of context when grasping with the non-dominant arm. The outcome confirms once more that the kinematics and dynamics of grasping are context-sensitive (effects of Task in **Table 1**), and documents differences for grasping with the left versus right arm (effects of Arm in **Table 1**). The arms differed with respect to speed and accuracy, as expected from literature (see Introduction), but they also differed with respect to path shape (detour-H and detour-V) and final hand posture (incli-end). The latter findings can't be explained by biomechanical constraints since the task was exactly mirror-symmetrical for the two arms, and rather support the existence of different control principles for the two arms (Grosskopf & Kuhtz-Buschbeck, 2006; Sainburg & Kalakanis, 2000; Trevarthen, 2010). Most importantly for the purposes of our study, context-sensitivity was not the same for both arms (effects of Task * Arm in **Table 1**). Specifically, nine parameters showing no context-sensitivity for the right arm did show such sensitivity for the left arm; this result emerged when all nine parameters were considered together, and also when each grasping factor was considered separately. From this we conclude that context played a *larger* role for the left arm, as stipulated by our second hypothesis, and not a *smaller* role, as stipulated by the first hypothesis (see Introduction). We therefore discard the view that the non-dominant arm is *less* influenced by context because of its stronger reliance on sensory feedback, and rather adopt the alternative view that it is *more* influenced by context because of its low experience with manipulation tasks such as grasping. Obviously, further work will be needed to substantiate this view. One possible approach could be to compare right- and left-handed subjects in our paradigm. Since righthanders strongly prefer to grasp with their right arm while lefthanders exhibit no arm preference (Gon-

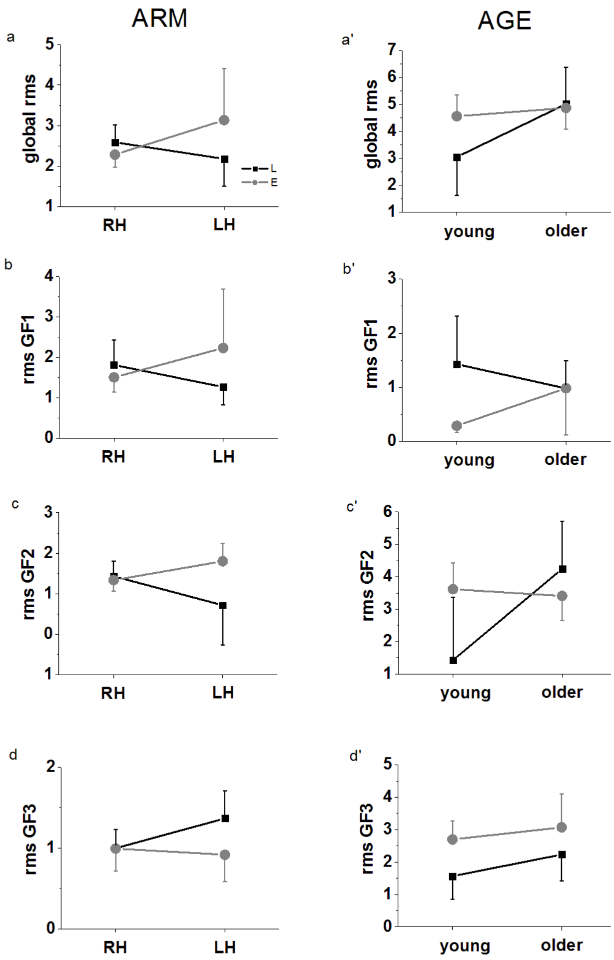

Figure 2.
Root mean square values across parameters with significant Task * Arm effects (a, a') and for each constituent factor (b-d, b'-d'). Graphs at the left illustrate the differences between right and left hand in young subjects, and those to the right the differences between the left hand of young and older subjects. Symbols represent averages across subjects, and error bars the pertinent interindividual standard deviations.

Table 2.
Outcome of factor analysis for parameters with significant Task * Arm effects*.

	Acronym	GF1	GF2	GF3
Transport component	detour-H			
	CV TT			
Grasping component	incli-PGA	0.69		
	CV incli-end			0.66
	CV GT	0.93		
	CV *t*(FGA)			
Coupling	CV Sync-start	0.69		
Lever manipulation	CV F-100		0.92	
	CV TQ-100		0.91	
Expl. variance		0.26	0.24	0.15

Table 3.
Outcome of factor analysis for parameters with significant Task * Age effects*.

	Acronym	GF1	GF2	GF3
Transport component	detour-H			0.77
	V_{max}			
Grasping component	Peaks			0.78
Coupling	CV Sync-peak			
Lever manipulation	F-100	0.86		
	TQ-100	0.90		
	CV F-100		0.89	
	CV TQ-100		0.84	
Expl. variance		0.25	0.24	0.20

Note: ***Tables 2** & **3**, Numbers are factor loadings, only values ≥ 0.6 are shown. The bottom row indicates the fraction of total variance explained by the respective factor. GF stands for grasping factor.

zalez, Whitwell, Morrissey, Ganel, & Goodale, 2007a), the nondominant arm of lefthanders is experienced with manipulation tasks and their Task * Arm effects should therefore be less pronounced than in righthanders, if our second hypothesis is indeed correct.

In our previous work, we have related context-sensitivity to the existence of two occipito-frontal processing streams in the human cortex: A dorsal stream is mainly concerned with fast automated reactions, and a ventral stream dealing with slow, attention-demanding behavior (Buxbaum et al., 2005; Goodale & Milner, 1992; Rossetti & Pisella, 2002). Since both streams are interconnected (Goodale & Westwood, 2004), processing of a given sensorimotor action may not be exclusively confined to one of the two streams, but may involve both of them in varying degrees. Given these facts, we posit that young subjects using their right arm in L will preferentially engage the dorsal stream, since L requires externally triggered, stereotyped behavior. In E, however, they will more strongly involve the ventral stream since E requires complex, volitional behavior. This view is illustrated in a simplified fashion by the top half of **Figure 3**. The bottom half of that figure illustrates how the neural activation might change when young subjects use their left arm. Since arm is specialized for postural rather than volitional responses (see Introduction), its control circuitry might be well suited for the automated responses in L, but might require particularly strong ventral activation for the volitional responses in E. Accordingly, **Figure 3** shows no difference between left and right arm in L, but a shift towards the ventral stream for the left arm in E. Note that as a consequence, context sensitivity (i.e., the difference between L and E) is more pronounced for the left than for the right arm, as observed experimentally.

Our data further show that grasping performance is affected by old age (effects of Age in **Table 1**). Elderly persons expectedly differ from younger ones regarding movement duration and variability, but also regarding path shape and hand posture. Most importantly for the purposes of our study, context-sensitivity of the left arm differed between age groups (effects of Task * Age in **Table 1**): eight parameters showing context differences in young subjects showed smaller, null or even inversed context differences in the elderly, with the net effect across all parameters being an absence of an appreciable context-sensitivity. In other words, the increase of context-specificity from the dominant to the non-dominant arm, as observed in young subjects, was attenuated if not absent in the elderly. This conforms to our expectation (see Introduction), according to which less pronounced handedness in old age is paralleled by less pronounced differences between the two arms regarding context-sensitivity. Referring back to **Figure 3**, one could argue that seniors grasping in E can't increase the ventral contribution when using their left rather than their right arm, and their performance with the left arm therefore resembles that of young subjects using their right arm.

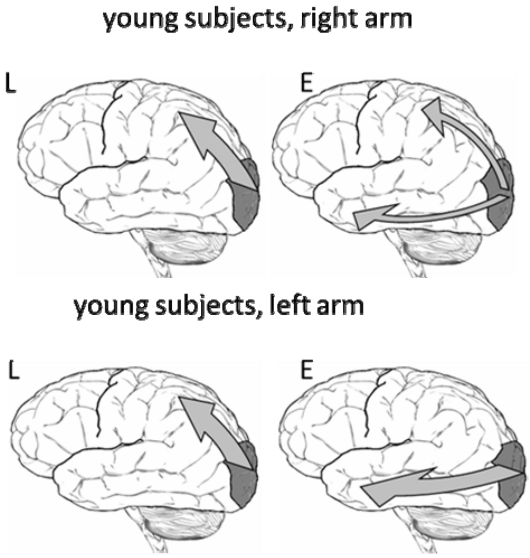

Figure 3.
Schematic representation of assumed sensorimotor processing through the dorsal and the ventral stream in task L and E, when young subjects use their right versus left arm.

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REFERENCES

Annett, J., Annett, M., Hudson, P. T., & Turner, A. (1979). The control of movement in the preferred and non-preferred hands. *The Quarterly journal of experimental psychology, 31,* 641-652. http://dx.doi.org/10.1080/14640747908400755

Bock, O., & Beurskens, R. (2010). Changes of locomotion in old age depend on task setting. *Gait & Posture, 32,* 645-649. http://dx.doi.org/10.1016/j.gaitpost.2010.09.009

Bock, O., & Hagemann, A. (2010). An experimental paradigm to compare motor performance under laboratory and under everyday-like conditions. *Journal of Neuroscience Methods, 193,* 24-28. http://dx.doi.org/10.1016/j.jneumeth.2010.08.005

Bock, O., & Steinberg, F. (2012). Age-related deficits of manual grasping in a laboratory versus in an everyday-like setting. *Ageing Research, 3.* http://dx.doi.org/10.4081/ar.2012.e7

Bock, O., & Züll, A. (2013). Characteristics of grasping movements in a laboratory and in an everyday-like context. *Human Movement Science, 32,* 249-256. http://dx.doi.org/10.1016/j.humov.2012.12.009

Buxbaum, L. J., Johnson-Frey, S. H., & Bartlett-Williams, M. (2005).

Deficient internal models for planning hand-object interactions in apraxia. *Neuropsychology Review, 43,* 917-929. http://dx.doi.org/10.1016/j.neuropsychologia.2004.09.006

Carson, R. G., Chua, R., Goodman, D. A., Byblow, W., & Elliott, D., (1995). The preparation of aiming movements. *Brain and Cognition, 28,* 133-154. http://dx.doi.org/10.1006/brcg.1995.1161

Chaytor, N., & Schmitter-Edgecombe, M. (2003). The ecological validity of neuropsychological tests: A review of the literature on everyday cognitive skills. *Neuropsychology Review, 13,* 181-197. http://dx.doi.org/10.1023/B:NERV.0000009483.91468.fb

Daprati, E., & Sirigu, A. (2006). How we interact with objects: Learning from brain lesions/How we interact with objects: Learning from brain lesions. *Trends in Cognitive Science, 10,* 265-270. http://dx.doi.org/10.1016/j.tics.2006.04.005

Elliott, D., Roy, E. A., Goodman, D. A., Chua, R., Carson, R., Maraj, B., et al. (1993). Asymmetries in the preparation and control of manual aiming movements. *Canadian Journal of Experimental Psychology, 47,* 570-589. http://dx.doi.org/10.1037/h0078856

Fagard, J., & Lockman, J. J. (2005). The effect of task constraints on infants' (bi)manual strategy for grasping and exploring objects. *Infant Behavior and Development, 28,* 305-315. http://dx.doi.org/10.1016/j.infbeh.2005.05.005

Gonzalez, C. L. R., Ganel, T., & Goodale, M. A. (2006). Hemispheric specialization for the visual control of action is independent of handedness. *Journal of Neurophysiology, 95,* 3496-3501. http://dx.doi.org/10.1152/jn.01187.2005

Gonzalez, C. L. R., Whitwell, R. L., Morrissey, B., Ganel, T., & Goodale, M. A. (2007). Left handedness does not extend to visually guided precision grasping. *Experimental Brain Research, 182,* 275-279. http://dx.doi.org/10.1007/s00221-007-1090-1

Gonzalez, C. L. R., & Goodale, M. A. (2009). Hand preference for precision grasping predicts language lateralization. *Neuropsycholgia, 47,* 3182-3189. http://dx.doi.org/10.1016/j.neuropsychologia.2009.07.019

Goodale, M., & Milner, A. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences, 15,* 20-25. http://dx.doi.org/10.1016/0166-2236(92)90344-8

Goodale, M. A., & Westwood, D. A. (2004). An evolving view of duplex vision: Separate but interacting cortical pathways for perception and action. *Current Opinion in Neurobiology, 14,* 203-211. http://dx.doi.org/10.1016/j.conb.2004.03.002

Grosskopf, A., & Kuhtz-Buschbeck, J. P. (2006). Grasping with the left and right hand: A kinematic study. *Experimental Brain Research, 168,* 230-240. http://dx.doi.org/10.1007/s00221-005-0083-1

Ingram, J. N., & Wolpert, D. M. (2011). Naturalistic approaches to sensorimotor control. *Progress in Brain Research, 191,* 3-29. http://dx.doi.org/10.1016/B978-0-444-53752-2.00016-3

Kalisch, T., Wilimzig, C., Kleibel, N., Tegenthoff, M., Dinse, H. R., & Miall, C. (2006). Age-related attenuation of dominant hand superiority. *PLoS ONE, 1,* e90. http://dx.doi.org/10.1371/journal.pone.0000090

Milner, A., & Goodale, M. (1993). Visual pathways to perception and action. *Progress in Brain Research, 95,* 317-337. http://dx.doi.org/10.1016/S0079-6123(08)60379-9

Rossetti, Y., & Pisella, L. (2002). Several "Vision for Action" systems: A guide to dissociating and integrating dorsal and ventral functions (tutorial). In W. Prinz, & B. Hommel (Eds.), *Attention and performance; common mechanisms in perception and action* (pp. 62-119). Oxford: Oxford University Press.

Sainburg, R. L., & Schaefer, S. Y. (2004). Interlimb differences in control of movement extent. *Journal of Neurophysiology, 92,* 1374-1383. http://dx.doi.org/10.1152/jn.00181.2004

Sainburg, R. L., & Kalakanis, D. (2000). Differences in control of limb dynamics during dominant and nondominant arm reaching. *Journal of Neurophysiology, 83,* 2661-2675.

Steinberg, F., & Bock, O. (2013). Context dependence of manual grasping movements in near weightlessness. *Aviation, Space, and Environmental Medicine, 84,* 467-472. http://dx.doi.org/10.3357/ASEM.3348.2013

Steinberg, F., & Bock, O. (2013). Influence of cognitive functions and behavioral context on grasping kinematics. *Experimental Brain Research, 225,* 387-397. http://dx.doi.org/10.1007/s00221-012-3379-y

Steinberg, F., & Bock, O. (2013). The context dependence of grasping movements: An evaluation of possible reasons. *Experimental Brain Research, 229,* 587-594. http://dx.doi.org/10.1007/s00221-013-3618-x

Trevarthen, C. (2010). Hemispheric specialization. In R. Terjung (Ed.), *Comprehensive Physiology* (pp. 1129-1190). Hoboken, NJ: John Wiley & Sons, Inc.

Wing, A. M., Turton, A., & Fraser, C. (1986). Grasp size and accuracy of approach in reaching. *Journal of Motor Behavior, 18,* 245-260. http://dx.doi.org/10.1080/00222895.1986.10735380

Woodworth, R. (1899). The accuracy of voluntary movement. *Psychological Review, 3,* 1-119.