

Appendix 1

Order of conditions

First, we wanted the participants to follow the trajectory of learning an action, then executing it practically, and then putting it to uses that are increasingly detached from praxis (demonstration, pantomime for teaching and pantomime for communication; see the principle of cognitive parsimony in Section 2.3 of the manuscript). As argued by Gärdenfors (2022), this order represents the ascending level of cognitive demand on performing an action, and is motivated by the principle of cognitive parsimony saying that if the cognitive capacities required for an activity A are included in those required for an activity B, then, A is cognitively more demanding than B (for details, see Section 2.2 of the manuscript).

Secondly, since the actions were novel to the participants, we decided that the conditions involving the use of the object (praxic action and demonstration) should precede the other two – pantomimic – conditions. In this regard, we followed an experimental procedure used in studies on pantomiming tool-use (Cubelli et al., 2000; Bartolo et al., 2003; Osiurak et al., 2023; see Section 2.2 of the manuscript). Since pantomime requires prior knowledge of how to execute an action (“acting-as-if” must be preceded by “acting”; see Section 2.3 of the manuscript), such an ordering of the conditions served to help the participants routinise movement patterns typical of each of the actions before they engaged in pantomiming them. Accordingly, counterbalancing could only be applied to two out of four experimental conditions: pantomime for teaching and pantomime for communication. Here, apart from the theoretical considerations (principle of cognitive parsimony, see Section 2.3 of the manuscript), the decision to keep pantomime for communication as the last condition was dictated by the experiment’s logistics. This condition involved the use of additional video materials (see below), and putting it at the end of the experimental sequence appeared least disruptive for the participants’ focus on the tasks. Additionally, verbal reports from a pilot study during which we implemented different orders of the conditions indicated that its participants felt least confused by the instructions and least fatigued, when the tasks followed the sequence: praxic action, demonstration, pantomime for teaching and pantomime for communication.

For all these reasons, we concluded that counterbalancing the conditions would produce a stronger confounding bias than keeping the conditions fixed in the order described above. To minimise the impact of potential order effects, our participants took 3-to-5-minute breaks between each experimental task (Bordens & Abbott, 2011). Breaks were used by the experimenters to check the calibration of the sensors. Afterwards, the participants were asked to move freely around the room and relax. We return to the problem of order effects in Section 5.4. of the manuscript.

The motivation to design the fourth condition in a different way than the other three has to do with the semiotic nature of pantomime for communication (see 2.3 of the manuscript for its

theoretical significance). One of the key characteristics of sign use, including pantomimic and gestural sign use, is the ability to distinguish a sign standing for one concept from a sign standing for another, often closely related, concept (see Deacon, 1997 and Zlatev, 2018, for semiotic distinctiveness; see Vigliocco et al., 2002 and Wilson et al., 2014, for semantic crowding). Within the tradition of experimental semiotics, which studies how participants improvise communication (Galantucci & Garrod, 2011), a standard paradigm for bringing out this characteristic is to present participants with a meaning space, which contains a finite set of confusable concepts (Garrod et al., 2007; Theisen et al., 2010). We followed this procedure by adapting a silent-gestures referential task, where the actor has to use improvised bodily communication to represent a concept to the recipient (Fay et al., 2013; Christensen et al., 2016; Schouwstra & de Swart, 2014). Although in our study there was no direct interaction between the actor and the recipient (see above), we assumed that our set-up for the last experimental condition would be conducive to foregrounding kinematic features specific to the communicative context.

References

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Modelling

Each response variable – apart from acceleration and duration – was obtained from raw data files containing x, y and z coordinates of a joint at a given timestamp of a recording. The python script used to obtain these variables is available under our osf repository (https://osf.io/s2bh8/?view_only=bad27b79f1a84a4da8fa947b797575f7). Rokoko Studio natively collects and outputs acceleration data, which we used in the analysis. To measure the influence of praxic action, demonstration, pantomime for teaching and for communication, we fit five linear regression models to datasets containing velocity, duration, acceleration, volume and pause duration. Before fitting the models to their respective datasets, we also standardized (z-scored) all variables apart from duration and rest.

Since we assumed that each activity can vary in terms of our variables (e.g., a trivela kick may be performed with greater velocity than a baseball pitch or *vice versa*), we started by building a model containing a random intercept for the activity:

$$model = lmer(response_{var} \sim Condition + (1|Activity))$$

However, we can assume that in addition to varying parameters between activities, these same parameters can vary between individuals. In order to capture this effect, we added one more varying intercept, standing for the participant, to the model:

$$model = lmer(response_{var} \sim Condition + (1|Activity) + (1|Participant))$$

In addition, we built a null model containing only the activity as an intercept in order to compare the two in terms of their performance:

$$nullmodel = lmer(response_{var} \sim 1 + (1|Activity))$$

We used ANOVA test to compare the models' performance. In each case, we accepted the model with two random intercepts because it had a lower AIC and BIC scores compared to both the null model and the model with Activity as a random intercept. Detailed results are listed in Tables A–E below.

Table A. Comparison of velocity models.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Null model	3	3240.3	3254.0	-1617.13	3234.3			
Activity random int.	6	1600.5	1628.0	-794.27	1588.5	1645.72	3	< 2.2e-16
Activity + Participant random int.	7	1422.5	1454.6	-704.27	1408.5	179.99	1	< 2.2e-16

Table B. Comparison of duration models.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Null model	3	10260	10272	-5126.8	10254			
Activity random int.	6	10206	10232	-5097.2	10194	59.20	3	8.72e-13
Activity + Participant random int.	7	10029	10059	-5007.3	10015	179.83	1	< 2.2e-16

Table C. Comparison of acceleration models.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Null model	3	1917.3	1931.0	-955.64	1911.3			
Activity random int.	6	1862.4	1889.8	-925.19	1850.4	60.898	3	3.779e-13
Activity + Participant random int.	7	1745.1	1777.0	-865.53	1731.1	119.326	1	< 2.2e-16

Table D. Comparison of volume models.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Null model	3	2039.3	2053.1	-1016.67	2033.3			
Activity random int.	6	1561.3	1588.8	-774.67	1549.3	484.00	3	< 2.2e-16
Activity + Participant random int.	7	1413.0	1445.0	-699.48	1399.0	150.39	1	< 2.2e-16

Table E. Comparison of pause duration models.

	npar	AIC	BIC	logLik	deviance	Chisq	Df	Pr(>Chisq)
Null model	3	3066	3080	-1530	3060			
Activity random int.	6	3014	3041	-1501	3002	58.21	3	1.416e-12
Activity + Participant random int.	7	2886	2918	-1436	2872	129.61	1	< 2.2e-16

Finally, we considered adding a random slope to the participant so as to capture the possible learning effect between conditions. However, such models either failed to converge or returned a singular fit error and are not reported herein. Their output can be viewed in the R file code submitted to the osf repository. Therefore, we accepted the models with maximal random effects structure with lowest AIC/BIC scores – the models with a random intercept for participant and activity. Tables 1–5 contain the output of the regression models and their results are reported in the paper.

Table 1. The influence of conditions on velocity, z-scored

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	0.18	0.39	3.10	0.46	0.67
Demonstration	-0.46	0.08	708	-5.94	4.36e-09
Pantomime for teaching	-0.25	0.08	708	-3.13	0.001
Pantomime for communication	-0.02	0.08	708	-0.37	0.71

Table 2. The influence of conditions on trial duration, z-scored

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	-0.25	0.29	3.81	-0.887	0.428
Demonstration	0.72	0.09	498.06	8.847	< 2e-16
Pantomime for teaching	0.36	0.08	498.56	4.36	1.6e-05
Pantomime for communication	0.04	0.08	497.41	0.57	0.57

Table 3. The influence of condition on acceleration, z-scored

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	-0.25	0.24	3.78	-1.01	0.37
Demonstration	0.65	0.08	661.90	7.99	6.15e-15
Pantomime for teaching	0.32	0.09	661.99	4.04	5.86e-05

Pantomime for communication	0.02	0.09	661.97	0.29	0.77

Table 4. The influence of conditions on total volume, z-scored

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	-0.15	0.41	3.17	-0.36	0.74
Demonstration	0.03	0.06	664.09	0.48	0.63
Pantomime for teaching	0.27	0.06	664.09	4.38	1.37e-05
Pantomime for communication	0.26	0.06	664.15	4.07	5.25e-05

Table 5. The influence of condition on movement partitioning, z-scored

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	1.4	0.54	3.88	2.62	0.06
Demonstration	1.43	0.17	664	7.99	6.05e-15
Pantomime for teaching	0.89	0.17	664	5.04	5.90e-07
Pantomime for communication	0.19	0.18	664	1.02	0.30

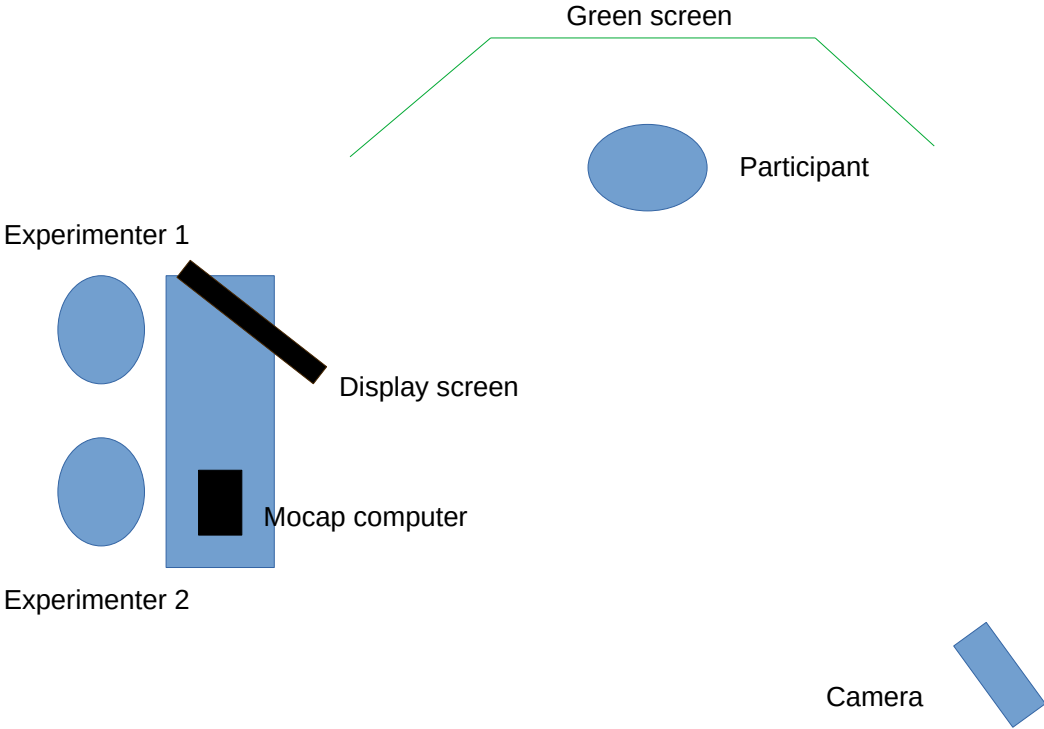
Post-hoc analysis

To investigate the dependence of overall velocity on partitioning and BBMV, we performed a post-hoc analysis and built a model with overall velocity as the outcome variable, the number of peaks of acceleration of movements and BBMV as the fixed effects, and the activity, participants and condition as random intercepts. The outcome and predictor variables were z-scored.

Table 6. The influence of peaks and BBMV on movement velocity.

	Estimate	Std.Error	df	t-value	<i>p</i>
Intercept	0.25	0.32	3.41	0.78	0.49
Peaks, z-scored	-0.12	0.02	700.40	-9.39	< 2e-16
BBMV, z-scored	0.49	0.05	710.50	11.92	< 2e-16
BBMV * peaks, both z-scored	-0.04	0.007	685.63	-5.03	6.29e-07

Experimental Setup



INSTRUCTIONS FOR PARTICIPANTS

[after putting on the motion capture suit]

Please make sure you are comfortable in the suit. Take a minute to move around freely: move your arms, move your legs, stretch. Are you comfortable? If not, we need to re-adjust the suit.

[before starting the experiment session]

Welcome to a motion capture experiment. The experiment comprises four movements connected with four different sports. Before we start, we will calibrate the suit. Then, we will ask you to perform the four movements. For calibration, please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor.

baseball pitch

[before watching the video with instruction]

Now, you will see an instructional video of how to perform a baseball pitch. Please pay close attention to the details of the technique, as later you will be asked to perform it in a way as similar to what you can see in the video as possible. While watching the video, you can already start practising the pitch.

[after watching the video with instruction – the training phase]

Take a couple of minutes to practice the baseball pitch. To make it easier, you will be able to follow the video with instructions: you can watch it three more times, it will be played in the background in a loop. When you feel you don't have to practice any more and you are ready to perform the pitch, let us know.

[task 1: praxic action]

Now, we will proceed to recording the first movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Imagine you are taking part in a baseball match. Concentrate and perform the pitch with the ball. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your pitch, we can rerecord it. Do you have any questions?

[task 2: demonstration with an object]

Now, we will proceed to recording the second movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the baseball pitch to somebody else. Please perform the movement so that your recording can be used to teach others how to perform a baseball pitch. Concentrate and perform the pitch with the ball. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your pitch, we can rerecord it. Do you have any questions?

[task 3: demonstration without an object]

Now, we will proceed to recording the third movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the baseball pitch to somebody else, but without the ball. Concentrate and perform the pitch. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your pitch, we can rerecord it. Do you have any questions?

[task 4: pantomime]

Now, your task will be to perform a pantomime of the baseball pitch so that participants in an online experiment are able to distinguish your recording from a recording of a cricket pitch. The participants will be presented with the following stimulus in a randomised order:

- the video of the baseball pitch,
- the video of the cricket pitch.

Then, the participants will be shown the recording of your pantomime and asked which type of a pitch you mimed. You should perform the pitch so that the participants can easily identify the type of a pitch. Do you have any questions?

Now, we will proceed to recording the fourth movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Concentrate and perform the pitch. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your pitch, we can rerecord it. Do you have any questions?

trivela kick

[before watching the video with instruction]

Now, you will see an instructional video of how to perform a trivela kick. Please pay close attention to the details of the technique, as later you will be asked to perform it in a way as similar to what you can see in the video as possible. While watching the video, you can already start practising the kick.

[after watching the video with instruction – the training phase]

Take a couple of minutes to practice the trivela kick. To make it easier, you will be able to follow the video with instructions: you can watch it three more times, it will be played in the background in a loop. When you feel you don't have to practice anymore and you are ready to perform the kick, let us know.

[task 1: praxic action]

Now, we will proceed to recording the first movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Imagine you are taking part in a football match. Concentrate and perform the kick with the ball. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

[task 2: demonstration with an object]

Now, we will proceed to recording the second movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the trivela kick to somebody else. Please perform the movement so that your recording can be used to teach others how to perform a trivela kick. Concentrate and perform the kick with the ball. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your pitch, we can rerecord it. Do you have any questions?

[task 3: demonstration without an object]

Now, we will proceed to recording the third movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the trivela kick to somebody else, but without the ball. Concentrate and perform the kick. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

[task 4: pantomime]

Now, your task will be to perform a pantomime of the trivela kick so that participants in an online experiment are able to distinguish your recording from a recording of a knuckle kick. The participants will be presented with the following stimulus in a randomised order:

- the video of the trivela kick,
- the video of the knuckle kick.

Then, the participants will be shown the recording of your pantomime and asked which type of a kick you mimed. You should perform the kick so that the participants can easily identify the type of a kick. Do you have any questions?

Now, we will proceed to recording the fourth movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Concentrate and perform the kick. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

kesagiri (diagonal cut with a sword)

[before watching the video with instruction]

Now, you will see an instructional video of how to perform a diagonal cut with a sword, called kesagiri. Please pay close attention to the details of the technique, as later you will be asked to perform it in a way as similar to what you can see in the video as possible. While watching the video, you can already start practising the cut.

[after watching the video with instruction – the training phase]

Take a couple of minutes to practice the cut. To make it easier, you will be able to follow the video with instructions: you can watch it three more times, it will be played in the background in a loop. When you feel you don't have to practice anymore and you are ready to perform the cut, let us know.

[task 1: praxic action]

Now, we will proceed to recording the first movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Imagine you want to strike an enemy. Concentrate and perform the cut with the sword. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your cut, we can rerecord it. Do you have any questions?

[task 2: demonstration with an object]

Now, we will proceed to recording the second movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the cut to somebody else. Please perform the movement so that your recording can be used to teach others how to perform a cut. Concentrate and perform the cut with the sword. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your cut, we can rerecord it. Do you have any questions?

[task 3: demonstration without an object]

Now, we will proceed to recording the third movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the cut to somebody else, but without the sword. Concentrate and perform the cut. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your cut, we can rerecord it. Do you have any questions?

[task 4: pantomime]

Now, your task will be to perform a pantomime of the diagonal cut so that participants in an online experiment are able to distinguish your recording from a recording of a straight cut, called shomengiri. The participants will be presented with the following stimulus in a randomised order:

- the video of the diagonal cut (kesagiri),
- the video of the straight cut (shomengiri).

Then, the participants will be shown the recording of your pantomime and asked which type of a cut you mimed. You should perform the cut so that the participants can easily identify the type of a cut. Do you have any questions?

Now, we will proceed to recording the fourth movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Concentrate and perform the cut. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your cut, we can rerecord it. Do you have any questions?

footbag inside kick

[before watching the video with instruction]

Now, you will see an instructional video of how to perform an inside kick with a footbag. Please pay close attention to the details of the technique, as later you will be asked to perform it in a way

as similar to what you can see in the video as possible. While watching the video, you can already start practising the kick.

[after watching the video with instruction – the training phase]

Take a couple of minutes to practice the kick. To make it easier, you will be able to follow the video with instructions: you can watch it three more times, it will be played in the background in a loop. When you feel you don't have to practice any more and you are ready to perform the kick, let us know.

[task 1: praxic action]

Now, we will proceed to recording the first movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Imagine you are playing footbag. Concentrate and perform the kick with the footbag. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

[task 2: demonstration with an object]

Now, we will proceed to recording the second movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the kick to somebody else. Please perform the movement so that your recording can be used to teach others how to perform a kick. Concentrate and perform the kick with the sword. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

[task 3: demonstration without an object]

Now, we will proceed to recording the third movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Now, imagine you have to teach the kick to somebody else, but without the footbag. Concentrate and perform the kick. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

[task 4: pantomime]

Now, your task will be to perform a pantomime of the inside kick so that participants in an online experiment are able to distinguish your recording from a recording of a toe kick. The participants will be presented with the following stimulus in a randomised order:

- the video of the inside kick,
- the video of the toe kick.

Then, the participants will be shown the recording of your pantomime and asked which type of a kick you mimed. You should perform the kick so that the participants can easily identify the type of a kick. Do you have any questions?

Now, we will proceed to recording the fourth movement. First, we need to calibrate the suit again. Please put your arms alongside your body and stand still, in an upright position, on the cross marked on the floor. Concentrate and perform the kick. The movement should begin when you're standing on the cross marked on the floor. If you are not happy with your kick, we can rerecord it. Do you have any questions?

Additional visualisations

