Recommendations on joint capabilities for transhumeral prosthetics - Supplementary Material

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TABLE I

ALLOCATION OF EXPERIMENTS AND EXPERIMENTAL OBJECTS TO TASKS

Task types	Clusters in [2]	Experiment id's in [2]	Objects
I. drink standing	drink-utensil-to-mouth ∩ reach-to-front-far ∩ reach-to-low	mp, md, mc, cp, cd, cc	Cup, Mug
II. drink sitting	drink-utensil-to-mouth ∩ on-table-motion	ms, cs	Cup, Mug
III. eating	use-utensil	sp, fr	/
IV. pouring	on-table-motion	pr	Bottle
V. overhead picking	reach_overhead	oh	Storage can
VI. lifting	reach-to-front-close ∩ on-table-motion	st	Briefcase
VII. hygiene	reach-to-pocket ∪ reach-to-axilla	pt, ax	/
VIII. open door	reach-to-front-close	dh	Door
IX. turning	turn-knob-key	ke, kn	1.3Nm static torque

TABLE II

TASK TYPES AND ASSOCIATED EXPERIMENTAL OBJECTS.

Task ID Fig. ref	Object	OpenSim body	Dim. [mm]	Mass [kg]
I. & II. drink standing	Mug 400ml	Cylinder	r = 38.5 h = 132 handle=30	0.782
drink sitting	Cup 310ml	Cylinder	r = 43 h = 100 handle=40	0.645
III. eating	None			
IV. pouring	Bottle 500ml	Cylinder	r = 32 h = 213	0.512
V. overhead picking	Can 425ml	Cylinder	r=36.5 h=110	0.425
VI. lifting	Briefcase	Box	x=450 y=350 z=110	5
VII. hygiene	None			
VIII. open door	Door	Box	x=40 y=2032 z=890	18
IX. turning	None	1.3Nm torque		

I. ABBREVIATIONS

- SR: internal and external shoulder rotation
- EF: elbow flexion and extension
- PS: forearm pronation and supination
- WF: wrist flexion and extension
- WD: wrist Ulna and Radial deviation

II. TASK-TYPES, EXPERIMENTS AND OBJECTS

Experiments of the ADL Human Arm Motion Dataset (ADL Dataset) [1] were grouped into task-types based on their motion clusters identified in [2]. Table I assigns experiments to task types. The labels used in [2] identify motion clusters and corresponding experiments, while table **??** contains full experiment data file names (ADL Dataset) and associated task types. Objects used during simulation experiments are detailed in in table II.

III. EXPERIMENT SUCCESS AND MARKER ERRORS

Table **??** summarizes maximal marker errors for each experiment. Reported maximal marker errors were calculated as the maximal error in all frames and all markers of a trial. Table **??** summarizes Root Mean Square (RMS) marker errors for each experiment, averaged over all trial frames. Blank spots indicate experiments that were excluded from our analysis due to one of the following reasons:

- marker errors larger than 8cm.
- inconsistencies in joint trajectories produced by inverse kinematics.
- For subjects 3, 5, and 11, the door_open trials were excluded since no meaningful door axis could be extracted from data for further analysis.

IV. RELEVANT PREVIOUS WORKS

Table V presents a collection of previous works on maximal and functionally relevant (during activities of daily living (ADL)) joint capabilities of the human upper limb joints. AAOS refers to the American Academy of Orthopaedic Surgeons.

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TABLE III

LIST OF EXPERIMENTS IN THE ADL DATASET, AND ASSOCIATED TASK TYPES. **MAXIMAL** MARKER ERRORS ARE INDICATED FOR EACH SUBJECT AND TRIAL. BLANK ENTRIES WERE OMITTED FROM OUR ANALYSIS

experiment name	task type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
amula_overhead_01	V. Overhead picking	3.99	3.56	6.81	2.39	5.55	2.85	2.44		4.47		2.59	4.57
amula_overhead_02	V. Overhead picking	3.73	3.53	6.08		5.47		2.62		4.67		2.68	4.82
amula_overhead_03	V. Overhead picking	3.83	4.10	6.45		5.48		2.53		4.15		2.72	4.80
axilla_01	VII. Hygiene	7.02	3.94	7.03	2.87	5.02		5.17		3.97	5.09	4.08	4.15
axilla_02	VII. Hygiene	6.55	5.11	7.00	2.90	6.01	4.53	5.07		4.08	5.28	3.82	4.22
axilla_03	VII. Hygiene	6.61	4.56	7.44		5.63		4.91		3.56	5.54	3.58	4.14
cup_cros_01	I. Drink standing	2.68	2.96	6.33			3.78	3.42		2.06		4.18	2.44
cup_cros_02	I. Drink standing	2.67	3.09	6.82	4.71	4.11	3.93	3.45		2.25			2.62
cup_cros_03	I. Drink standing	2.39	2.70	7.05	2.54	3.99	3.83	3.51		2.17			2.57
cup_dist_01	I. Drink standing	3.64	4.48	5.70		3.69	3.79				5.46	3.93	3.09
cup_dist_02	I. Drink standing	3.60		5.69		4.05	4.39	4.75		3.81	5.27	3.67	
cup_dist_03	I. Drink standing	3.53	4.66	5.42		4.02		5.05		3.87	5.68	3.94	
cup_prox_01	I. Drink standing	2.46		5.31			1.86	2.55		2.93	5.54	3.86	2.71
cup_prox_02	I. Drink standing	2.60		5.10	2.64	4.05		2.64		2.97	5.65	3.60	2.91
cup_prox_03	I. Drink standing	2.61	2.69	5.98	2.59		2.01	2.58		3.00	6.16	4.17	
door_key_01	XI. Turning	3.04	4.30	5.35		2.14	3.74	4.20				4.14	4.27
door_key_02	XI. Turning	2.99	4.56	5.19		2.14		4.06		4.02		4.55	3.97
door_key_03	XI. Turning	2.56	4.74	5.33		2.08		3.97		3.34			3.80
door_knob_01	XI. Turning	2.63	4.18	5.11		2.24		4.04		4.95			3.34
door_knob_02	XI. Turning	2.68	4.46	5.28		2.11	4.17	3.63					3.70
door_knob_03	XI. Turning	2.71	4.32	5.24		2.16	4.25	3.82		6.20			3.74
door_open_01	VIII. Open door	5.23	6.08					5.25		2.64			3.23
door_open_03	VIII. Open door	5.86	5.71		2.44			5.09		3.83			3.39
floor_briefcase_01	VI. Lifting	5.10	4.30	5.11		3.40	4.11	5.54	4.59	4.39	4.10	3.94	3.82
floor_briefcase_02	VI. Lifting	5.07	4.33	5.66		3.39	4.72	5.62		4.37	3.99	4.48	4.02
floor_briefcase_03	VI. Lifting	5.02	4.20	5.02		3.63	4.84	5.42		4.14	3.98	4.03	3.91
mug_cros_01	I. Drink standing	2.34	3.61	6.65		4.62		3.74			5.95	2.82	2.78
mug_cros_02	I. Drink standing	2.40	3.67	7.04		4.64	3.50	3.56		2.33	5.48	3.04	2.95
mug_cros_03	I. Drink standing	2.44	3.40	7.07		4.86	3.55	3.21		2.37	5.34	2.98	3.38
mug_dist_01	I. Drink standing	3.88	2.79	6.92	3.33	4.84	3.76	3.76	2.59	4.34	6.31	3.51	3.00
mug_dist_02	I. Drink standing	3.56	4.49	7.17	3.44	5.15		3.75		4.36	6.01	3.32	2.87
mug_dist_03	I. Drink standing	3.52	4.70	7.29	3.73	4.85		3.75	2.57	4.13	6.19	3.22	3.16
mug_prox_01	I. Drink standing	2.31	2.72	7.15	3.01	5.34	2.14	2.39		3.20	6.05	3.47	3.42
mug_prox_02	I. Drink standing	2.66	2.74	7.05	3.20	4.61		2.50		3.39	5.32	3.14	3.44
mug_prox_03	I. Drink standing	2.33	2.73	7.40	3.59	4.73		2.48		3.49	5.76	3.20	3.58
pocket_01	VII. Hygiene	2.76	3.21		2.49	3.41	4.65	3.40	2.66	2.29	3.87	3.92	2.57
pocket_02	VII. Hygiene	2.74	3.15	6.50	2.46	3.59	4.64	3.22	3.08	2.59	3.53	4.17	2.57
pocket_03	VII. Hygiene	2.79		6.44	2.30	3.52	4.60	3.42	3.03	2.56	3.56	4.13	2.56
sit_cup_01	II. Drink sitting	3.43	3.93	4.38		4.17	2.93	5.59	3.15	3.91	5.20	3.32	3.84
sit_cup_02	II. Drink sitting	3.70		4.53	2.59	4.44	2.77	5.36		3.80	5.45	3.28	4.17
sit_cup_03	II. Drink sitting	3.68		4.61	2.34	4.26	2.78	5.15	3.18			3.30	
sit_fork_01	III. Eating	2.85		4.27			3.53	3.29	3.55	4.35	4.16	4.71	4.59
sit_fork_02	III. Eating	2.60		4.59		3.43	3.53	3.46	3.85	4.46	4.54	4.77	4.20
sit_fork_03	III. Eating	2.48		4.21		3.45	3.59	3.30	3.82	4.48	4.20	4.50	4.59
sit_mug_01	II. Drink sitting	3.64	5.02	4.65		5.31	3.25	4.80	3.58	3.73	5.48	3.92	4.55
sit_mug_02	II. Drink sitting	3.82	3.92	4.39	2.26	5.67	2.97	5.00	3.62	3.60		3.59	4.94
sit_mug_03	II. Drink sitting	3.62		4.30	2.59	6.06	3.16	4.88	4.12	3.72	5.54	3.81	4.83
sit_pour_01	IV. Pouring	2.66		3.85		4.56	2.07	4.53	2.85	4.35		3.33	3.42
sit_pour_02	IV. Pouring	2.66		3.82	1.94	4.15	2.40	4.91		4.40		3.47	
sit_pour_03	IV. Pouring	2.75		4.07	1.87	4.02		4.96	2.61	4.03		3.14	3.48
sit_spoon_02	III. Eating	3.35		4.64		5.74	3.59	3.02	3.79	4.65	4.46	4.56	4.12
sit_spoon_03	III. Eating	3.58		4.43	4.23		3.56	2.78	3.73	4.71	4.91	3.70	3.94
door_open_02	VIII. Open door		5.04					5.05		3.07			3.94
sit_spoon_01	III. Eating			4.30			3.45	2.90	3.76	4.47	4.53	3.58	4.05

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TABLE IV

LIST OF EXPERIMENTS IN THE ADL DATASET, AND ASSOCIATED TASK TYPES. **RMS** MARKER ERRORS AVERAGED OVER ALL FRAMES, ARE INDICATED FOR EACH SUBJECT AND TRIAL. BLANK ENTRIES WERE OMITTED FROM OUR ANALYSIS

experiment name	task type	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12
amula_overhead_01	V. Overhead picking	0.09	0.10	0.20	0.11	0.16	0.11	0.11		0.12		0.13	0.13
amula_overhead_02	V. Overhead picking	0.09	0.09	0.19		0.15		0.11		0.14		0.12	0.15
amula_overhead_03	V. Overhead picking	0.09	0.10	0.19		0.15		0.10		0.14		0.11	0.14
axilla_01	VII. Hygiene	0.13	0.14	0.19	0.11	0.14		0.13		0.11	0.15	0.14	0.13
axilla_02	VII. Hygiene	0.14	0.14	0.20	0.10	0.17	0.15	0.14		0.12	0.16	0.14	0.12
axilla_03	VII. Hygiene	0.14	0.12	0.20		0.16		0.14		0.12	0.17	0.13	0.14
cup_cros_01	I. Drink standing	0.08	0.13	0.18			0.11	0.11		0.09		0.12	0.12
cup_cros_02	I. Drink standing	0.08	0.13	0.19	0.13	0.13	0.11	0.11		0.09			0.12
cup_cros_03	I. Drink standing	0.08	0.12	0.19	0.13	0.13	0.11	0.11		0.09			0.12
cup_dist_01	I. Drink standing	0.10	0.14	0.17		0.12	0.11				0.15	0.12	0.13
cup_dist_02	I. Drink standing	0.10		0.17		0.12	0.11	0.12		0.10	0.15	0.11	
cup_dist_03	I. Drink standing	0.10	0.15	0.17		0.13		0.12		0.10	0.15	0.11	
cup_prox_01	I. Drink standing	0.07		0.16			0.10	0.10		0.09	0.15	0.12	0.12
cup_prox_02	I. Drink standing	0.08		0.16	0.13	0.12		0.10		0.10	0.16	0.11	0.12
cup_prox_03	I. Drink standing	0.08	0.11	0.17	0.13		0.10	0.10		0.09	0.16	0.12	
door_key_01	XI. Turning	0.13	0.16	0.19		0.10	0.12	0.14				0.19	0.16
door_key_02	XI. Turning	0.13	0.17	0.19		0.09		0.14		0.12		0.19	0.15
door_key_03	XI. Turning	0.11	0.18	0.20		0.10		0.14		0.11			0.15
door_knob_01	XI. Turning	0.13	0.17	0.19		0.10		0.13		0.16			0.16
door_knob_02	XI. Turning	0.13	0.17	0.19		0.09	0.14	0.13					0.16
door_knob_03	XI. Turning	0.13	0.16	0.19		0.09	0.14	0.13		0.21			0.15
door_open_01	VIII. Open door	0.12	0.14					0.12		0.09			0.14
door_open_03	VIII. Open door	0.14	0.14		0.11			0.14		0.09			0.13
floor_briefcase_01	VI. Lifting	0.11	0.13	0.17		0.14	0.13	0.13	0.14	0.12	0.15	0.10	0.14
floor_briefcase_02	VI. Lifting	0.11	0.12	0.17		0.14	0.12	0.13		0.12	0.14	0.12	0.14
floor_briefcase_03	VI. Lifting	0.11	0.14	0.16		0.15	0.13	0.13		0.11	0.15	0.10	0.15
mug_cros_01	I. Drink standing	0.08	0.13	0.18		0.16		0.11			0.17	0.10	0.13
mug_cros_02	I. Drink standing	0.08	0.14	0.19		0.17	0.11	0.11		0.09	0.16	0.11	0.13
mug_cros_03	I. Drink standing	0.08	0.14	0.19		0.16	0.11	0.11		0.09	0.15	0.10	0.13
mug_dist_01	I. Drink standing	0.10	0.11	0.19	0.13	0.16	0.11	0.11	0.11	0.11	0.17	0.11	0.13
mug_dist_02	I. Drink standing	0.10	0.14	0.19	0.13	0.17		0.12		0.11	0.17	0.11	0.12
mug_dist_03	I. Drink standing	0.10	0.15	0.19	0.13	0.16		0.11	0.11	0.11	0.16	0.11	0.13
mug_prox_01	I. Drink standing	0.08	0.11	0.19	0.12	0.16	0.10	0.10		0.10	0.17	0.12	0.13
mug_prox_02	I. Drink standing	0.08	0.11	0.19	0.12	0.16		0.11		0.11	0.15	0.12	0.13
mug_prox_03	I. Drink standing	0.08	0.11	0.19	0.12	0.16		0.10		0.10	0.16	0.11	0.13
pocket_01	VII. Hygiene	0.10	0.09		0.09	0.10	0.15	0.12	0.09	0.09	0.13	0.12	0.11
pocket_02	VII. Hygiene	0.10	0.12	0.19	0.09	0.11	0.15	0.10	0.09	0.09	0.11	0.16	0.10
pocket_03	VII. Hygiene	0.09		0.19	0.09	0.11	0.13	0.11	0.11	0.10	0.12	0.13	0.11
sit_cup_01	II. Drink sitting	0.12	0.16	0.18		0.16	0.12	0.15	0.13	0.19	0.18	0.18	0.17
sit_cup_02	II. Drink sitting	0.12		0.18	0.13	0.15	0.12	0.15		0.18	0.18	0.18	0.17
sit_cup_03	II. Drink sitting	0.12		0.18	0.13	0.16	0.12	0.14	0.13			0.18	
sit_fork_01	III. Eating	0.12		0.18			0.13	0.14	0.14	0.18	0.18	0.18	0.17
sit_fork_02	III. Eating	0.11		0.18		0.18	0.13	0.13	0.15	0.18	0.18	0.18	0.18
sit_fork_03	III. Eating	0.11		0.17		0.18	0.13	0.13	0.15	0.19	0.18	0.18	0.18
sit_mug_01	II. Drink sitting	0.12	0.17	0.18		0.17	0.13	0.13	0.13	0.18	0.18	0.19	0.17
sit_mug_02	II. Drink sitting	0.12	0.14	0.18	0.13	0.18	0.13	0.14	0.13	0.18		0.19	0.18
sit_mug_03	II. Drink sitting	0.12		0.17	0.12	0.18	0.13	0.14	0.14	0.18	0.19	0.18	0.18
sit_pour_01	IV. Pouring	0.12		0.17		0.18	0.10	0.15	0.13	0.20		0.17	0.16
sit_pour_02	IV. Pouring	0.12		0.17	0.10	0.17	0.11	0.16		0.20		0.16	
sit_pour_03	IV. Pouring	0.12		0.17	0.10	0.17		0.16	0.12	0.19		0.17	0.17
sit_spoon_02	III. Eating	0.12		0.18		0.19	0.13	0.12	0.15	0.17	0.19	0.17	0.18
sit_spoon_03	III. Eating	0.13		0.18	0.16		0.13	0.12	0.15	0.18	0.19	0.18	0.18
door_open_02	VIII. Open door		0.15					0.13		0.07			0.13
sit_spoon_01	III. Eating			0.18			0.13	0.13	0.16	0.15	0.19	0.18	0.17

TABLE V

PREVIOUS STUDIES REPORTING MAXIMAL AND FUNCTIONALLY REQUIRED JOINT RANGE OF MOTION, TORQUE, AND VELOCITY

Joint	RoM		torque		velocity	
	max	func	max	func	max	func
SR	[3]–[5], AAOS	[3], [6]–[11]	[12]–[15]	[16]	[17], [18]	[19]
EF	[3], [7], [20], [21] [4], [22]–[24], AAOS	[3], [6], [7], [25], [26] [8], [9], [19], [23], [27], [28]	[29]–[31]	[16]	[17]	[19]
PS	[3], [7], [23], [24], [32], AAOS	[3], [6], [7], [26] [8], [9], [19], [23], [28]'	[12], [33], [34] [31], [35], [36]'	[16]	[32], [37]	[19], [38]
WF	[4], [7], [20]–[22], [32], [39], [40] [41]–[46], AAOS	[6], [20], [25], [47], [48] [7], [8], [10], [19], [21], [22], [49]	[12], [50]–[52] [36], [53]–[55]	[16]	[32], [37]	[19], [38], [56], [57]
WD	[4], [20]–[22], [42] [32], [43]–[46], [58]	[6], [20], [47], [48] [8], [10], [19], [21], [22]	[12], [36], [50], [55]	[16]	[32], [37]	[19], [38], [57]

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