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Publication date:
2018

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Nagaraja, V., Bergmann, J., Andersen, M. S., & Thompson, M. (2018). *Compensatory Movements Involved During Simulated Upper Limb Prosthetic Usage: Reach Task vs. Reach-to-Grasp Task*. Abstract from XV International Symposium on 3-D Analysis of Human Movement, Salford, United Kingdom. https://www.salford.ac.uk/__data/assets/pdf_file/0003/1608006/Book-of-Abstracts_A4_HiRes_20June2018.pdf

Compensatory Movements Involved During Simulated Upper Limb Prosthetic Usage: Reach Task vs. Reach-to-Grasp Task

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Introduction

Compensatory movements are usually adopted during prosthesis usage [1]-[2] and such movements have been linked to poor outcomes [3]. Studies investigating compensatory movements have found – use of high truncal displacement during reaching tasks [1]; use of higher truncal and shoulder angles and higher reliance on sound arm during bimanual tasks [2]; and altered kinematics at trunk, shoulder, and/or elbow while performing activities requiring pronation/supination [4]. Study assessing end-point accuracy for reach-to-grasp tasks [5] found that use of UL prostheses required higher time to execute movements, while the movements were less smooth, more asymmetric, and showed more decoupling between reach and grasp. Due to kinematic redundancy in the human arm, motions of *reaching-to-grasp* an object usually have very different arm postures compared to *reaching* motions that simply transport the hand to the same position [6]. Although numerous studies have compared able-bodied movement patterns involved during reaching and reach-to-grasp tasks [7]-[8], few studies have directly compared compensatory movements adopted during *Reach* and *Reach-to-Grasp* tasks during prosthesis use. These tasks are expected to entail different magnitudes/forms of compensation due to the dependence on wrist for maintaining hand positioning/orientation for successful task accomplishment [9].

Research Question

What is the difference between the compensatory movements adopted during simulated prosthesis usage throughout the execution of *Reach* and *Reach-to-grasp* tasks?

Methods

This study was approved by the local Research Ethics Committee (Ref:16/SC/0051) and five adult able-bodied participants consented to participate. Three trials of *Reach* (RF) and *Reach-to-Grasp* tasks (RGF) to the front in a 3D marker-based optical motion capture laboratory was performed in a seated-position using custom-built apparatus. Movement data were collected during task execution. Prosthesis usage was simulated using a commercially-available wrist-brace that mimics a typical prosthesis lacking a controllable wrist. Failure to satisfy parametric assumptions led to use of median(inter-quartile-ranges) for descriptive statistics. Kruskal-Wallis test was used to compare Range-of-Motion between RF and RGF tasks under unbraced and braced-conditions; p-values $\leq$ 0.05 were considered statistically significant.

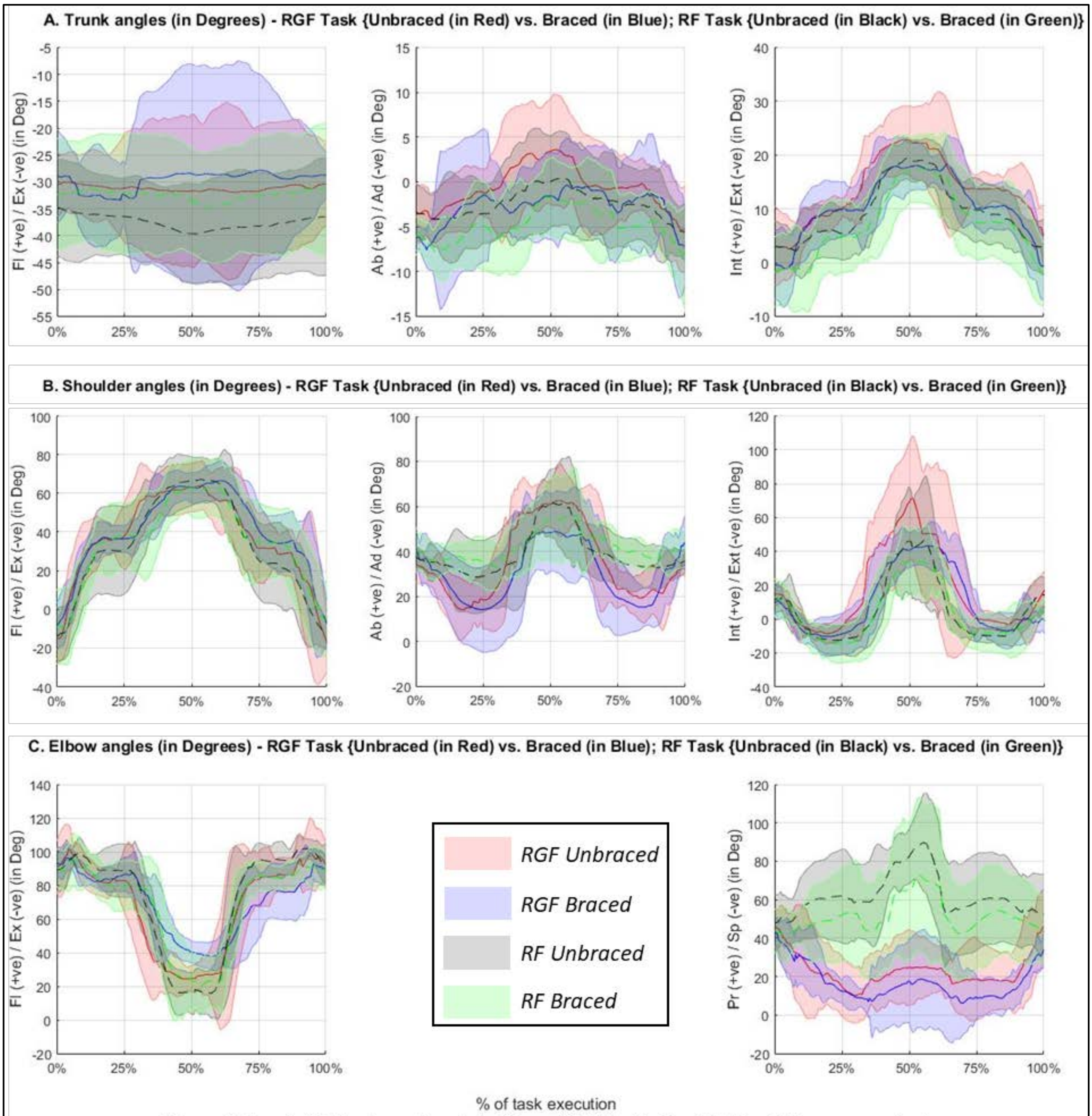

Figure 1: Reach (RF) task vs. Reach-to-Grasp (RGF) task - Qualitative difference analysis
Ensemble plots for A. Trunk, B. Shoulder, and C. Elbow Wrist angles (n = 5; 3 trials)

Table 1 (a): Reach (RF) task vs. Reach-to-Grasp (RGF) task - Quantitative difference analysis (Maximum and Minimum angles)

	Joint - Degree of Freedom	RF Task			RGF Task		
		Unbraced	Braced	Difference (Braced - Unbraced)	Unbraced	Braced	Difference (Braced - Unbraced)
Maximum angle (in ˚)	Shoulder - Fl/Ex	83.5	82.0	-1.5	75.7	72.7	-2.9
	Shoulder - Ab/Ad	76.7	84.0	7.3	96.4	61.2	**-35.2**
	Shoulder - Int/Ext	72.1	53.9	**-18.2**	102.8	50.5	**-52.3**
	Elbow - Fl/Ex	108.2	107.0	-1.2	112.8	100.0	**-12.8**
	Elbow - Pr/Sp	142.2	98.0	**-44.2**	93.8	68.7	**-25.1**
	Trunk - Fl/Ex	-8.6	-12.1	-3.6	-13.0	-1.7	**11.3**
	Trunk - Ab/Ad	3.8	4.4	0.6	8.9	17.1	8.2
	Trunk - Int/Ext	26.3	26.2	-0.1	30.0	24.4	-5.6
Minimum angle (in ˚)	Shoulder - Fl/Ex	-27.4	-22.7	4.7	-34.3	-25.5	8.8
	Shoulder - Ab/Ad	9.6	19.4	9.9	-1.7	-14.7	**-13.0**
	Shoulder - Int/Ext	-20.6	-28.2	-7.7	-12.3	-22.0	-9.8
	Elbow - Fl/Ex	5.7	5.0	-0.7	12.8	27.5	**14.7**
	Elbow - Pr/Sp	33.9	23.7	**-10.2**	-3.2	-13.7	**-10.5**
	Trunk - Fl/Ex	-45.3	-50.8	-5.4	-41.7	-42.2	-0.5
	Trunk - Ab/Ad	-13.4	-13.8	-0.4	-17.0	-14.3	2.7
	Trunk - Int/Ext	-2.8	-11.8	-9.0	-2.8	-11.8	-9.0

Table 1 (b): Reach (RF) task vs. Reach-to-Grasp (RGF) task - Quantitative difference analysis (RMS differences)

	Joint - Degree of Freedom	RF Task	RGF Task
Root mean squared difference of Braced data with Unbraced data (in ˚)	Shoulder - Fl/Ex	6.8	7.0
	Shoulder - Ab/Ad	5.3	9.4
	Shoulder - Int/Ext	5.6	**11.5**
	Elbow - Fl/Ex	8.6	13.4
	Elbow - Pr/Sp	**11.7**	7.2
	Trunk - Fl/Ex	5.1	2.4
	Trunk - Ab/Ad	2.5	2.8
	Trunk - Int/Ext	2.8	3.6

Table 1 (c): Kruskas-Wallis test - (1) Unbraced RF vs Unbraced RGF and (2) Braced RF vs Braced RGF tasks

Joint - Degree of Freedom Angles (in ˚)	Unbraced condition			Braced condition		
	Reach to front (RF)	Reach-to-grasp to front (RGF)	*p-Value*	Reach to front (RF)	Reach-to-grasp to front (RGF)	*p-Value*
	ROM angles - Median (IQR)			ROM angles - Median (IQR)		
Shoulder - Fl/Ex	85.2 (0.4)	85.3 (1.7)	0.443	80.3 (5.1)	74.9 (2.9)	0.165
Shoulder - Ab/Ad	33.7 (1.4)	45.4 (1.9)	0.001*	24.4 (3.1)	39.5 (4.4)	0.011*
Shoulder - Int/Ext	59.5 (17.7)	84.7 (5.7)	0.191	49.9 (10.2)	54.7 (1.1)	0.950
Elbow - Fl/Ex	89.9 (2.2)	79 (8.5)	0.010*	79.8 (1.1)	57 (5.6)	0.000*
Elbow - Pr/Sp	41.4 (7.7)	43.2 (4.5)	0.663	31.8 (16.9)	48.7 (3.5)	0.019*
Trunk - Fl/Ex	3.8 (1.2)	5.2 (1.5)	0.290	4.3 (1.4)	6.1 (1.5)	0.021*
Trunk - Ab/Ad	5.8 (1.7)	8.9 (2.8)	0.036*	6.8 (1.2)	9.8 (3.3)	0.004*
Trunk - Int/Ext	18.7 (1.6)	23.1 (2.4)	0.002*	18.1 (0.7)	20.8 (1.1)	0.191

*Statistical significance ($p < 0.05$) tested via non-parametric Kruskal-Wallis test

Note: Flexion (Fl), Abduction (Ab), Pronation (Pr), and Internal rotation (Int) are positive (+ve); Extension (Ex), Adduction (Ad), Supination (Sp), and External rotation (Ext) are negative (-ve); Unbraced and Braced conditions (n = 5; 3 trials); Values > 10˚ are highlighted in **Bold** for differences

Results

Qualitative comparison (*Figure-1*): The ensemble curves are generally symmetrical reflecting the tasks' cyclic nature. Trends are similar for both tasks, although magnitudes are higher for RGF than RF, especially for trunk angles, shoulder Ab/Ad and Int/Ext angles. Higher variability is seen for shoulder Ab/Ad and Int/Ext angles. Effect of bracing is seen in terms of disparities in angles adopted and variability during braced and unbraced-conditions for both tasks, although the magnitudes are higher for RGF compared to RF under braced-condition.

Quantitative comparison (*Table-1 (a)-(b)*): Except for elbow Pr/Sp, differences are higher between the braced and unbraced-conditions for RGF compared to RF as evident by use of joint angles and RMS differences, especially for shoulder angles. Both the tasks differ predominantly in terms of usage of elbow Pr/Sp angles. *Post-hoc* Kruskas-Wallis test shows significant differences *(Table-1 (c))* for several angles for following comparisons - (i) Unbraced RF vs Unbraced RGF and (ii) Braced RF vs Braced RGF.

Discussion

Shoulder angles have reduced values for braced-condition, trunk Fl/Ex and Ab/Ad angles witness both an offset in central-tendencies and maintain near-constant values. These results suggest postural change, which was visually observable on the video-recording. A few of the participants adopted a new posture, while other participants increased truncal movement for task accomplishment, these results agree with a recent study [10]. It should be noted that the compensatory movements adopted usually are task-specific and depend highly on the demand for maintaining a certain position/orientation of the hand for task execution. Increased trunk movement adopted during the RGF task that relied on properly orienting the 'braced' wrist is similar to earlier studies [1]-[2],[11]. Slight reduction in elbow Pr/Sp due to bracing might also have contributed to increased reliance on trunk and shoulder to perform the task. Our findings are similar to research that focused on compensatory trunk movement during reaching tasks in prosthesis users [2]. The difference between RF and RGF joint kinematics [8] holds for simulated prosthetic users.

Conclusion

A study involving characterisation of movements adopted during simulated prosthesis use for RF and RGF tasks is performed which shows that simulated prosthetic usage can be applied to gain insights into adopted compensatory strategies. Additionally, this approach provides a control-group for comparison with patients with the added benefit of lesser dependency on patient availability during protocol development and patient sample-size required to power statistics. Future work in our study would involve estimation of *in vivo* loading patterns and actual patient data.

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