Constraints on Demarcating Left and Right Areas in Designing of a Performance-Based Workstation

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Abstract. The purpose of this study was to show the constraints that demarcate right and left areas in designing a performance-based workstation. As a part of the larger project, the current experiment was designed to determine the directional location at which people change from using their right hand to using their left hand when reaching for a pen to write their name. The results from 21 right-handed participants showed that their left hand was not used significantly in any azimuth lines. Although right-handed participants used their left hand more often as the target location approached their contralateral side of their body, the frequencies of left hand use were not significantly dominant even beyond the left shoulder plane used in this experiment. Along with findings from previous work, we conclude that for this particular task the hand-use transition occurs beyond 20 degrees left of left shoulder plane. The location of this boundary is markedly farther to the left than identified in other research, thereby demonstrating the importance of task constraint in describing work area.

Keywords: Lab study; constraints, reach, handedness, performance-based approach; workstation design.

1 Introduction

On what basis should the work area be demarcated right and left side when designing a workspace? Geometric models of normal work area [1] have typically been based on limb size and a typical body posture or movement, i.e. upright torso with rotating forearm. The obtained model is then reflected to the left side of the body assuming that the work area is symmetrical around the body median.

In contrast, a performance-based approach demarcates the boundary of a reach envelope as the distance or direction at which the worker changes from one type of reach movement to another. When observing the movements used in performing a reach task, we find that as reach distance increases, people introduce more parts of the body (i.e. from arm movement to arm and torso movement). Mark et al. [2] pointed out that this transition from arm movement to arm and torso movement occurs at shorter distances than the absolute maximum distance for their arm movement. This is because people rarely seem to commit to an extreme movement or potentially

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awkward posture, such as extending their arm or leaning forward as far as possible. Rather, people prefer to rotate their shoulder or lean their torso instead of extending their arm to its maximum reach distance. Also, they would rather stand up to avoid an extreme forward lean. A number of studies have found that people preferred to change their posture in order to avoid such extreme movements that might place them at increased risk for injury [2, 3, 4]. When these finding are applied to delineating work area, the final area actually reached by the same type of movement is smaller than its absolute maximum area of that movement, and is considered the "performance-based normal work area" where "work is handled most efficiently and workers can reach with comfortable arm movement"[4]. There is also evidence that the location of the transition between different reach movements may be related to the reacher's attempt to minimize discomfort [5].

This preference-driven movement selection is also true for limb (arm) selection. Given that almost all people have a dominant hand, it was observed that the actual area of right and left hands used in uni-manual tasks was not symmetrical around the body median [6,7]. In general, people used their dominant hand more often when they were allowed to use their preferred hand [8]. This trend is more distinctive when the required skill level of the task is increased. People tend to use their dominant hand more often when the task requires fine motor skills than when the task is simple. For example, people are more likely to use their dominant hand when moving a cup fully filled with water than when they pick up a small, nonbreakable object. Also, it was reported that when people were instructed to perform the same task with their non-dominant hand in their dominant area (i.e., asking strongly right-handed individuals to use their left hands when reaching for an object located in his right side), both accuracy and speed were impaired [7].

Choi et al. [9] varied object locations and observed participants' hand selection during a simple reaching task. They found that the location of transition between the right and left hands depended on the reach distance as well as direction. In another experiment, Choi et al. [10] found that strongly right-handed people used their right hand up to their left shoulder plane for simple reaching tasks. Beyond left shoulder plane, people used their left hand significantly more often than their right hand. Choi et al. [10] also brought up a question to ask whether different types of actions would affect the selection of hand use. A reaching action to pick up a small, nondelicate object is a simple and fundamental action and does not require a particularly skillful action. That is, it doesn't matter which hand you choose to pick up a baseball or an apple because both hands will complete the task, "pick-up", equally well. This indicates that it is the location of the object that may affect hand selection when performing these types of neutral tasks. But suppose that after picking up the object an additional task had to be performed that required the use of the dominant hand. Would this additional task affect limb used to reach for and grasp the object? In other words, if a right-handed individual is asked to pick up a baseball and throw it to a target, would limb selection for picking up a baseball differ from when he is asked just to pick up a baseball? The purpose of this research reported here is to determine whether a task requiring right hand use for right-handed people affects the selection of hand used to grasp the object. The results have implications for our efforts to demarcate left and right hand using area.

To investigate this question, "reaching for and picking up a pen and writing words with it" was selected as the task. "Reaching for a pen" is one of the common actions in an office environment and “writing words” is a task which involves using the dominant hand. In this investigation, a writing task which involves absolute usage of dominant (right) hand will be performed to see how often people use their non dominant hand to pick up an object (pen) at different locations. The resulting critical boundaries will delineate the work area based on the interaction of physical, environmental and task constraints as such. This performance-based boundary provides a basis for the design of ergonomic work areas.

1.1 Pilot Study

One man and two women participated in a pilot experiment that was intended to identify two settings for the experiment: azimuth lines for the object (pen) location and the spatial orientation of the object (pen). From the previous study [10], the boundary delineating left and right hand using area for reaching task was suggested as the left shoulder plane when the task doesn’t require higher or skillful performance. In addition, the skill level of the task was expected to affect the location of the directional boundary (i.e. the more skillful task being performed, the more often right hand will be selected to perform the task when reaching toward the left side of body part). Therefore, various azimuth lines for target location were examined for these three participants and a final set of azimuth lines were selected based on the frequencies that our pilot participants used their left hand to pick up the pen presented. Since no one used their left hand on the azimuth lines located on the right side of their body median, the azimuth lines for the experiments were decided to be located at body median and left of body median.

The pilot experiment also enabled us to establish an orientation for the pen. There was one assumption that we consider. If asked to pick up a tool that has a handle, which would indicate the place to grab on with hand, would participants reach for the indicated part, handle, spontaneously [11]? In this study, rubber grip was assumed as the handle of target. Thus, the center of the rubber grip was located at the target location. From this pilot test, it was confirmed that all the participants reached for the pen by the rubber grip, but there were some exceptional cases. When the grip part of the pen is far enough to introduce other parts of body severely to pick it up, but the other end of pen is closer (i.e. when required to stand up to reach for the rubber grip, otherwise possible to pull the pen by leaning forward), participants easily reached for the closer part of the pen. Thus, to make the rubber grip as the closer part to the participants, the pen was presented directing toward the participants [Figure 1].

Fig. 1. Center of the rubber grip is placed at the target location

2 Method

2.1 Participants

11 men and 10 women participated for course credit. Each participant was tested individually. All participants were strongly right handed as determined using the Handedness Questionnaire [12] that describes 12 common actions. Participants were counted as strongly right-handed if they indicated they used their right hand to perform at least 10 out of 12 actions.

2.2 Apparatus

A Roc-n-Soc (Ashville, NC) chair was used. The chair was height-adjustable with a small backrest, and no armrests. The table was part of motorized, height-adjustable workstation (220cm * 122cm). A video camera recorded the actions from the participant's right side. The target was a 14-cm long pen that could be grasped by the rubber grip. A piece of white paper containing a blank table was placed in front of each participant.

2.3 Procedure

This experiment consisted of two parts whose order was counterbalanced. There were 23 object locations in each part so that there were total of 46 different object (pen) locations [Figure 2]. There was a total of five azimuth lines which included body median (0 degree) and 5-degrees left of the body median, left-shoulder plane and 10-degrees, 20-degrees to the left of the left shoulder plane. Along each azimuth line, there was total of five locations (reach distances), except for the 20-degree to the left from the left shoulder plane on which only 3 locations. All the reach locations were scaled based on each participant's maximum reach capability. Each participant's maximum reach distance (100% capability location) was measured. The maximum arm-only reach was used in the first part of the study and the maximum arm-and-torso

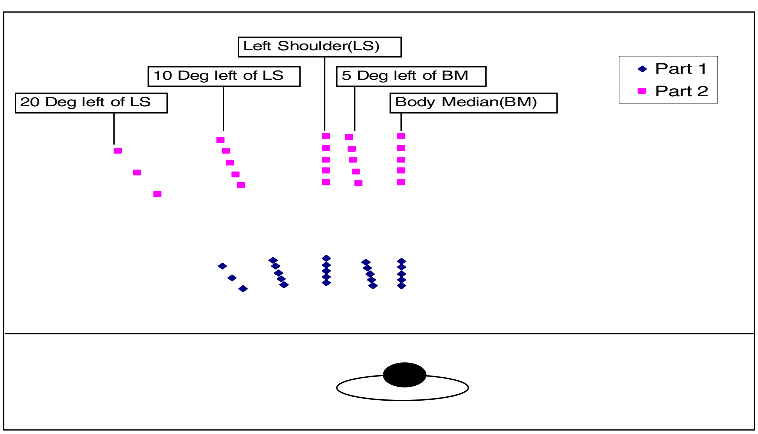

Fig. 2. Direction and distance of 46 target locations

reach was used in the second part of the study. In part 1 of the study, five locations that participants reached for the target object were calculated based on their maximum arm-only reach distance from 80% to 100% of their maximum arm-only reach in 5% increments. In the 20 degrees left of left shoulder direction, participants reached for the target object at three distances ranging from 80% to 100% of their maximum arm-only reach in 10% increments. In the second part of the study, the maximum arm-and-torso reach distance was used to calculate the ranges from 85% to 105% of their maximum arm-and-torso reach.

In each part, participants sat in front of a table and were asked to close their eyes while the experimenters place the object at the proper location on the table. Participants were then instructed to reach for and pick up a pen by whatever reach action and hand that they felt would be the most natural or comfortable. After picking up the pen, they wrote their initial in one location on the table drawn on the white paper placed in front of them.

The order of the 23 locations in each part was randomized such that participants could not anticipate the target location in advance. Participants were videotaped as they performed three sets of (randomized) trials at each reach location. Three experimenters reviewed the videotapes of all trials. For each trial, the hands used to pick up the object and to write their initials were recorded separately. The most frequently used hand (twice or more) out of three trials at each location was encoded as the data point for analysis. If an individual grasped the pen with right hand (1st trial), left hand (2nd trial) and right hand (3rd trial) at 95% location on left shoulder plane, that person's final data was encoded as "right hand" for grasping action at that location.

3 Results

The data for the 21 participants were analyzed using chi-square tests to determine which hand used at each location was significantly predominant.

Table 1. $\chi 2$ Statistics with frequency and percentage of hand use for part 1

Azimuth	% of ACB1	Left hand		Right hand		$\chi 2$
		Freq.	%	Freq.	%	(1, N = 21)
Body Median	100	0	0.00	21	100.00	21.00*
	95	0	0.00	21	100.00	21.00*
	90	0	0.00	21	100.00	21.00*
	85	0	0.00	21	100.00	21.00*
	80	0	0.00	21	100.00	21.00*
5 degrees to left of Body Median	100	1	4.76	20	95.24	17.19*
	95	0	0.00	21	100.00	21.00*
	90	1	4.76	20	95.24	17.19*
	85	0	0.00	21	100.0	21.00*
	80	1	4.76	20	95.24	17.19*
Left Shoulder	100	4	19.05	17	80.95	8.05*
	95	1	4.76	20	95.24	17.19*

Table 1. (*continued*)

	90	7	33.33	14	66.67	2.33
	85	3	14.29	18	85.71	10.71*
	80	3	14.29	18	85.71	10.71*
10 degrees to left of Left shoulder	100	7	33.33	14	66.67	2.33
	95	8	38.09	13	61.91	1.19
	90	7	33.33	14	66.67	2.33
	85	7	33.33	14	66.67	2.33
	80	7	33.33	14	66.67	2.33
20 degrees to left of Left shoulder	100	7	33.33	14	66.67	2.33
	90	8	38.09	13	61.91	1.19
	80	7	33.33	14	66.67	2.33

ACB1: Maximum Arm-only Reach, * Sig, Right hand use

Table 2. χ2 Statistics with frequency and percentage of hand use for part 2

Azimuth	% of ACB2	Left hand		Right hand		χ^2
		Freq.	%	Freq.	%	(1, N = 21)
Body Median	105	0	0.00	21	100.00	21.00*
	100	0	0.00	21	100.00	21.00*
	95	0	0.00	21	100.00	21.00*
	90	1	4.76	20	95.24	17.19*
	85	0	0.00	21	100.00	21.00*
5 degrees to left of Body Median	105	4	19.05	17	80.95	8.05*
	100	0	0.00	21	100.00	21.00*
	95	2	9.52	19	90.48	13.76*
	90	2	9.52	19	90.48	13.76*
	85	3	14.29	18	85.71	10.71*
Left Shoulder	105	3	14.29	18	85.71	10.71*
	100	5	23.81	16	76.19	5.76*
	95	4	19.05	17	80.95	8.05*
	90	3	14.29	18	85.71	10.71*
	85	2	9.52	19	90.48	13.76*
10 degrees to left of Left shoulder	105	10	47.62	11	52.38	0.05
	100	8	38.10	13	61.90	1.19
	95	9	42.86	12	57.14	0.43
	90	6	28.57	15	71.43	3.86*
	85	6	28.57	15	71.43	3.86*
20 degrees to left of Left shoulder	105	10	47.62	11	52.38	0.05
	95	9	42.86	12	57.14	0.43
	85	9	42.86	12	57.14	0.43

ACB2: Maximum Arm-and-Torso Reach, * Sig, Right hand use

All participants used their right hand to write down their initials on the paper. Thus, the chi-square tests were done on the frequencies of hand use for grasping the pen at each location. Since the hand selection at each location was independent of one another, and all participants had two choices in hand selection at each location, the expected frequency at each location was calculated as half of the total participants, 10.5 (Expected frequency = total number of participants/total number of categories = 21/2 = 10.5). Observed frequencies at each location along with the chi-square statistics are presented in Table 1 for part 1 and Table 2 for part 2.

The chi-square test was significant if more than 15 people (about 70%) used their right hand for grasping the object (pen) at each location. Tables 1 and 2 show that as the reach direction approached the left side of the body, participants used their left hand more frequently, but the frequency of left hand use was not significant at any location even on 20 degrees to left of the left shoulder plane. Figure 3 summarizes these results: Red markers (to the right on the scale) indicate predominant right-hand use. Color changes from red to blue (left) reflect an increasing percentage of left-hand use. Based on the color in the figure, it is clear that left hand (blue) was not used very often in any azimuth line.

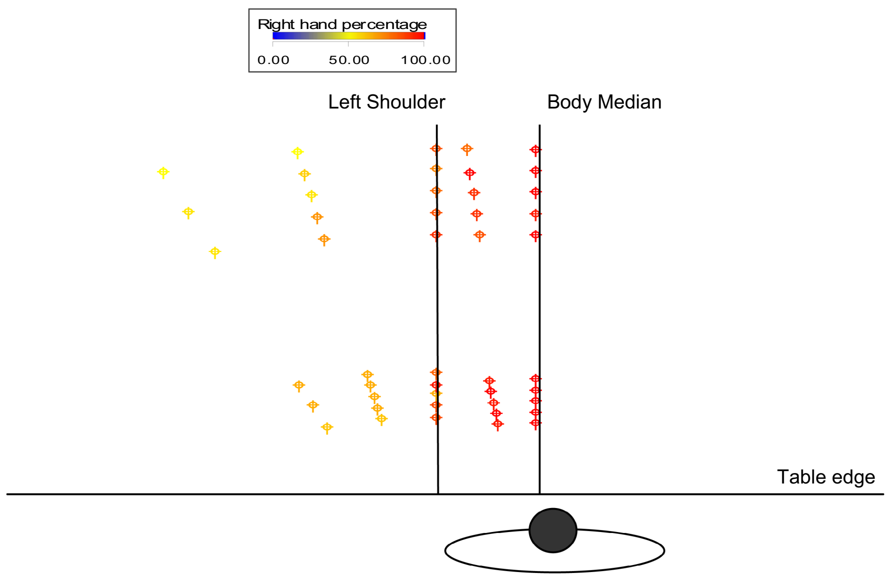

Fig. 3. Envelope of significant hand use

4 Discussion

In summary, right-handed people used their left hand more often as the target location approached their contralateral side of their body but the frequencies of left hand use were not significant even beyond the left shoulder plane. From these results we conclude that right-handed people will use their dominant hand predominately up to 20 degrees to the left of their left shoulder plane when the task that they perform requires them to use their right hand. The transition between the right and left hand use is expected to occur beyond 20 degrees to the left of their left shoulder plane. This transition is markedly to the left of the boundary identified in previous research [9, 10] for tasks that did not involve the use of the actors' dominant hand. Thus, task constraints affected the location of the directional boundary at which people change from reaching with their right hand to left hand.

There have been a few other experiments to explain why people use their dominant or preferred hand more often than their non-dominant hand. Recently, Farina et al. (2003) pointed out that muscles in the non-dominant side are more easily fatigued than those in the dominant side. They argued that this could be due to "long preferential use of the specific side." People use their dominant hand for longer periods of time, which causes gradual changes in the muscle fiber membranes of that side. This will eventually cause different performance levels between sides. Although their research still could not explain young children's hand preference which they might have born with, it can explain why people use their dominant hand so often willingly and why the area reached by their dominant hand is relatively wider than the area reached by their non dominant hand. Thus, when designing the workstation layout, handedness of the target population should be considered such that tasks with heavy loads or requiring fine motor skill could be easily accessed by the operators' dominant hand side without causing awkward postures.

Finally, one limitation of this study is chair function. The chair used in this study was fixed so that participants were not allowed to rotate it. Had participants been allowed to rotate chair, the frequency of left hand would likely have decreased because by rotating the chair participants could relocate the target relative to their right hand. Under those conditions, it is questionable whether strongly right-handed people would actually use their left hand.

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