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EFFECTS OF BRACING ON POINTING TASK ACCURACY

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INTRODUCTION

The human sensorimotor system is an extraordinarily complex system that, at the macroscopic level, exhibits some randomness in sensory processing, external state estimation, task planning and motor execution that limits the system's ability to perform motor tasks accurately [1, 2]. However, supplementary mechanical supports can improve task performance. For example, a group of experienced shooters was reported to reduce variance in shooting accuracy by 53-75% using postural balance and gun stabilization techniques [3], and a group of novice shooters was reported to reduce the variance by 26% using a similar approach [4]. Many precision manipulation tasks in surgery require accuracy near the limits of human capabilities. Hand tremors of ophthalmic surgeon were reported to have an RMS value of 182 μm [5], making it difficult to cannulate the retinal vein (40 μm to 350 μm in diameter [6]) without damaging the tissues. Bracing has been shown to reduce tremor in the tooltip position from 526 μm to 289 μm when neurosurgeons traced a line [7].

The bracing strategy [8, 9] is proposed in this study to compensate for variance in tool endpoints and thus to obtain noticeable improvement in accuracy during interactive tool manipulation. Being a natural and intuitive approach, bracing can potentially be a less complicated, time consuming and expensive alternative to the conventional techniques which are currently being used in many precision surgeries. Brace can be established through a mechanical link added in parallel to any of user-tool-target interactions in order to alter the mechanical impedance between the tool and the workpiece. Therefore, the properties of a brace can be characterized as a combination of stiffness, damping and inertia which can be modulated to achieve a certain level of accuracy in tool manipulation. However, there is no study in the literature dealing with an estimation of the bracing properties for a given task. Such study is useful for proper design of bracing systems for precision manipulation tasks. The purpose of this study is to obtain data from humans performing both braced and unbraced versions of a simple motor task that will subsequently be used to assess the accuracy of a task execution model intended to predict real-life performance. A related set of pointing tasks is examined because these are relatively simple to model as low degree-of-freedom (DOF) tasks.

METHODOLOGY

Three adult subjects were asked to perform three separate tasks using a laser pointer while experiencing four levels of bracing. The three tasks were to steadily focus the laser pointer on a point target for 10 seconds (no nominal movement); to move the laser pointer between two point targets separated vertically by 20cm (1 DOF); and to complete one revolution about a circle of 25cm diameter (2 DOF). The subjects were also asked to repeat the second and third tasks at a speed <50% of their previous attempts in order to determine if there were significant differences in behavior at different points in the speed/accuracy trade-off curve [10]. The number of trials (n) and evaluation criteria for each task are given in Table 1.

In performing these tasks, the subjects' were seated and instructed to hold their arm fully extended in front of their body while directing the laser at a target approximately 95 cm away (see Fig. 1). The subjects were also seated on a height adjustable chair to keep their arm at the same elevation. Custom made mechanisms were constructed to apply three types of bracing: elbow-only, wrist-only, and combined wrist and elbow brace.

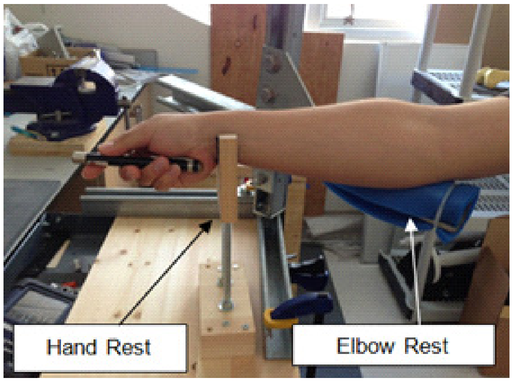


Figure 1: The experimental setup used to perform the tasks (this shows the combined wrist and elbow brace configuration).

Table 1: Evaluation criteria to compare the bracing methods

Task (Trial Number)	Criteria
Point Target (n=72)	Variance of radial deviation in a 10 second period
Point to Point Target (n=144)	Transition period between two points
	Variance of initial overshoots (taken in a 0.5 second period after transition)
	Variance of radial deviation measured in a 3 second period after initial overshoot
Circular Target (n=144)	Time to complete one revolution
	Variance of radial deviation from the circle

The laser movements were captured at 30 Hz using a video camera and the laser dot location was extracted using Tracker (comPADRE, Aptos, California, USA). We wrote a Matlab script to calculate the desired metrics. We conducted ANOVA and MANOVA analyses to assess the significance of differences conditions (ANOVA for the first task, as there was only one dependent variable, and MANOVA for the second two, as there was more than one dependent variable in these two tasks), as well as to evaluate the statistical power of the experiment using SPSS 21 (SPSS Inc. Chicago, Illinois, USA). The bracing method was the fixed variable studied across the three tasks.

RESULTS

Task 1 – Point targeting

The results from the steady point targeting trials show that the subjects were able to reduce the positioning variability when using any of the three levels of bracing. Furthermore, the ratio of variance (see Fig. 2) suggests that the wrist brace provides more resistance to variability than other bracing configurations. The upper and lower bound is based on the maximum and minimum variance (σ^2) observed in the participants (all trials in each configuration). ANOVA detects no notable difference between the subject's radial deviation (from the target) and the deviation under different bracing techniques. The level of statistical significance is considered as α=0.05.

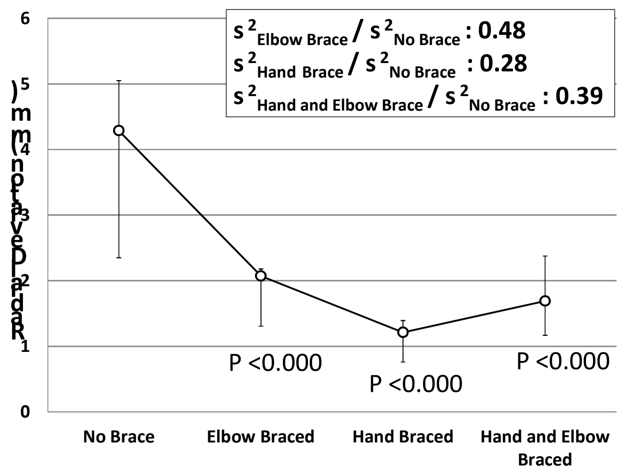
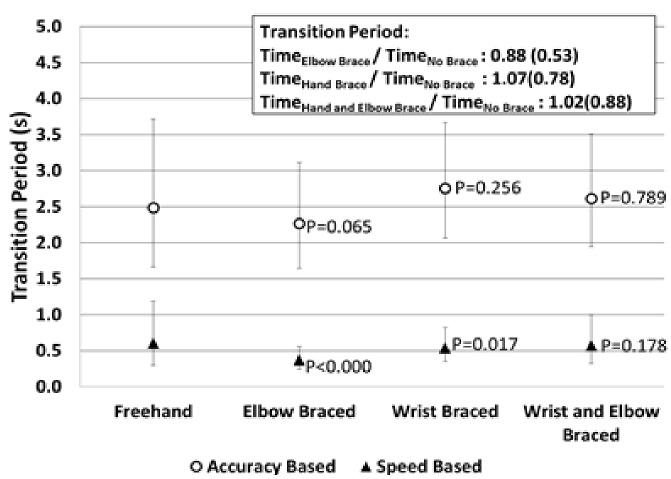


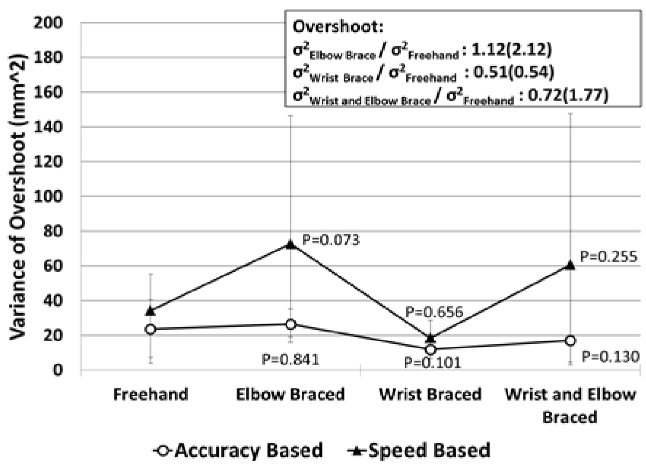
Figure 2: The variance of the subject's radial deviation from the target during the point targeting task.

Task 2 – Point to point targeting

In this task, the braces do not produce any notable effect on reducing the transition period (see Fig. 3(a)).



(a)



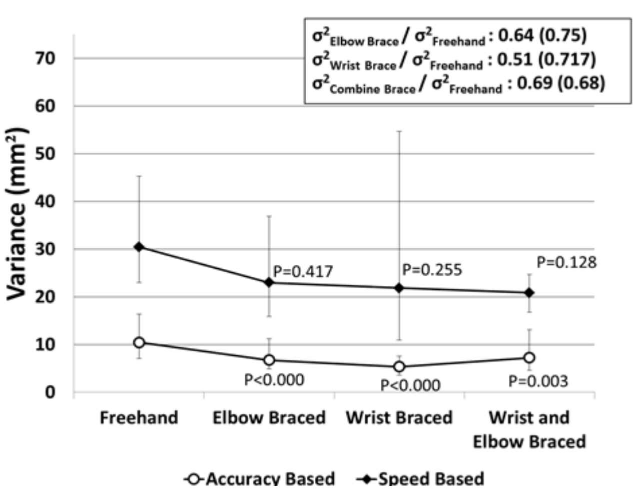
(b)

Figure 3: (a) The mean transition period between the two points, (b) The variance of deviations during overshoots.

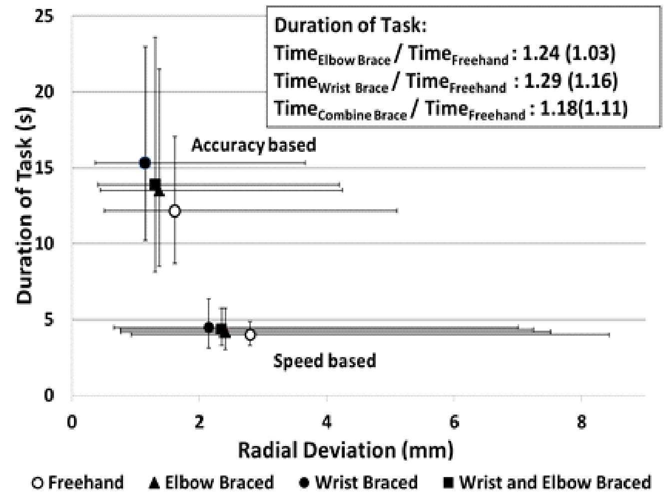
However, there is a small statistically significant reduction in task duration for elbow and wrist bracing in the fast movement. During overshoot, bracing has no consistent effect on reducing the variance. The ratio of variance for a given brace to that for free arm movement in the speed emphasizing trials is shown inside the bracket in Fig. 3 and Fig. 4.

Task 3 – Tracing circle

During tracing circle, it can be observed that the braces enhance the subject's accuracy when accuracy is given preference (see Fig. 4(a)).



(a)



(b)

Figure 4: (a) The variance of deviations during circle tracing, (b) Task duration of tracing circle in both accuracy and speed emphasizing trials.

However, in both speed emphasizing and accuracy emphasizing trials, the times (nominal values) required to complete the circle under different bracing configurations are longer than that of free arm condition (see Fig. 4(b)). The task durations (nominal values) measured under the wrist brace condition are found to be the lengthiest in both modes. However, the ratio of variances suggests that wrist brace provides slightly more resistance to the variability than other bracing configurations in accuracy emphasizing trials.

In all cases, the wrist brace is likely to provide slightly more resistance to tool endpoint variability than the other bracing techniques. The ratio of variances is often found to be the lowest in the wrist brace configuration. The counterintuitive finding is that the combined elbow and wrist brace shows negative influence on speed emphasizing trials of tracing circle and point to point targeting tasks. In the speed emphasizing tasks, the accuracy of tool positioning is worse when compared to the respective accuracy emphasizing tasks. This indicates a speed-accuracy trade-off in tool positioning under braced condition.

CONCLUSION

In static pointing, bracing reduces the variability (as measured by RMS error) by 52-72%. In point-to-point movement tasks, bracing has no consistent effect on either task duration or overshoot, except for a small statistically significant reduction in task duration for two forms of bracing in the fast movement. In circle tracing, there appears to be a small reduction in deviations (on the order of 31-49%) with bracing, at the expense of a small increase (11-29%) in task execution time. The effect of bracing on reducing deviation was only significant for the fast circle tracing task. These results show a similar magnitude of effect size to the results from a previous study of bracing in a simulated surgical milling task in which subjects reduced cutting error by 27% when the tool was braced [11].

The study limitations include a small number of subjects, and small effect sizes relative to the trial-to-trial variations. The braces used for this study were not optimized, so there might be more effective braces for these tasks and the potential benefits of bracing may therefore be understated.

This study has shown that while bracing can have a significant effect on variability, the results are still highly variable and occasionally opposite to the desired effect (e.g., more overshoot, longer task duration). Therefore, a better understanding of the interaction between the human performing a task and the design of the brace is required in order to be able to design braces that will effectively and consistently enhance performance. This paper therefore provides useful baseline data quantifying pointing task performance under various bracing conditions and we plan to use this data to develop and validate models of bracing behavior that we can use to predict the effect of bracing and improve future designs.

REFERENCES

[1] D. W. Franklin, and D. M. Wolpert, "Computational mechanisms of sensorimotor control," Neuron, vol. 72, pp. 425-442, 2010.

[2] J. Gordo, M. F. Ghilardi, and C. Ghez, "Accuracy of planar reaching movements. I. Independence of direction and extent variability," Experimental Brain Research, vol. 99, pp. 97–111, 1994.

[3] J. T. Viitasalo, P. Era, N. Konttinen, H. Mononen, K. Mononen, K. Norvapalo, and E. Rintakoski, "The posture steadiness of running target shooters of different skill levels. Kinesiology, vol. 31, pp. 18-28, 1999.

[4] K. Mononen, N. Konttinen, J. Viitasalo, and P. Era, "Relationships between postural balance, rifle stability and shooting accuracy among novice rifle shooters," Scandinavian Journal of Medicine & Science in Sports, vol. 17, pp. 180-185, 2007.

[5] F. Peral-Gutierrez, A. L. Liao, and C. N. Riviere, "Static and dynamic accuracy of vitreoretinal surgeons," Proceedings of the 26th Annual International Conference of the IEEE EMBS, pp. 2734-2737, 2004.

[6] B. Mictell, J. Koo, I. Iordachita, P. Kazanzides, A. Kapoor, J. Handa, G. Hager, and R. Taylor, "Development and application of a new steady-hand manipulator for retinal surgery," IEEE International Conference on Robotics and Automation, pp. 623-629, 2007.

[7] R. Sandoval, R. A. MacLachlan, M. Y. Oh, and C. N. Riviere, "Positioning Accuracy of Neurosurgeons," Proceedings of the 29th Annual International Conference of the IEEE EMBS, pp. 206-209, 2007.

[8] M. A. Fehlberg, B. T. Gleeson, and W. R. Provancher, "Active Handrest: A large workspace tool for precision manipulation," The International Journal of Robotics Research, vol. 31, no. 3, pp. 289-301, 2012.

[9] S. R. Moore, and N. Hogan, "Part reference manipulation – A strategy applied to robotic drilling," ASME Winter Annual Meeting, Boston, pp. 183-191, 1983.

[10] P. M. Fitts, "The information capacity of the human motor system in controlling the amplitude of movement," Journal of Experimental Psychology, vol. 47, pp. 381–391, 1954.

[11] J. Kooyman, "Tool bracing for performance improvement in simulated femoral head-neck osteochondroplasty," Master's Thesis, University of British Columbia, Canada, 2013.