ASTRONAUT ROTATIONAL MOTION DURING SIMULATED MICROGRAVITY

Leia Stirling, Dava Newman, and Karen Willcox

Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA
Email: leia@mit.edu

INTRODUCTION

In order to reduce astronaut adaptation time and provide a safety countermeasure during extravehicular activity (EVA), this research effort investigates astronaut reorientation. Even though astronauts undergo hundreds of hours of training, the strategies for locomotion and orientation in a reduced gravity environment are not specifically prescribed. The problem of self-rotation, which is a human-body rotation without external torques, has been previously studied to determine its feasibility (Kulwicki et al., 1962; Scher and Kane, 1969; Parin and Gazenko, 1975). Since astronauts are not familiar with reorienting without external forces, they are unlikely to develop self-rotation techniques naturally. The goal of the current study was to experimentally examine the effects of rotation training. Understanding self-rotation will help develop an astronaut motion-training program and could contribute to safety countermeasures during EVA.

METHODS AND PROCEDURES

This study adhered to MIT's Committee On the Use of Human Experimental Subjects and the participants gave their written informed consent to participate. There were 20 volunteer subjects (10 male, 10 female) with a mean age of 23.6 ± 3.5. The experiments used a suspension and harness system, with the subjects in three different configurations allowing rotations about each body axis. Subjects performed a series of rotations about the body axes in both the counterclockwise and clockwise directions. A total of 48 rotations were performed by each subject, with an equal number of counterclockwise and clockwise rotations. The subjects were placed in one of two groups, minimally and fully trained. Prior to performing the experiment, the subjects went through a training program based on their group. The minimally trained group received a theoretical description of momentum conservation, while the fully trained group was additionally provided with descriptions and videos of strategies for rotating about all three body axes (Figure 1).

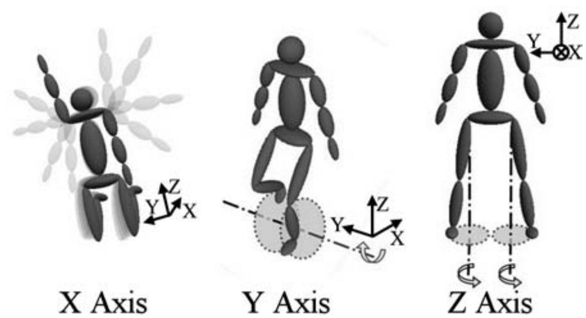

Figure 1. Recommended methods for single-axis rotations for the fully trained group.

Experimental measures included a subject coordination score, video data, a motion usability score (modified Cooper-Harper), a fatigue rating, and a cognitive workload measure (NASA-TLX).

RESULTS AND DISCUSSION

In this study it was observed that fully trained subjects had a better initial performance time than the minimally trained groups for Y and Z axis rotations ($p < 0.0005$ and $p = 0.027$, respectively). All subjects in the fully trained group showed typical learning curves, with the highest performance time during the first trial. However, five of the ten minimally trained subjects showed an increase in performance time over the first few trials. This was due to a misconception of the feature in their technique that produced the rotation. When steady state performance times were analyzed, a statistically significant difference was only found for counter-clockwise Y rotations ($p = 0.006$). The steady state analysis was performed with 19 of the 20 subjects, as one minimally trained subject never reached a steady state for rotations about Y. For an emergency EVA scenario, it is important to examine the first attempt of each motion (Figure 2). While all fully trained subjects completed the rotation in the allotted time, not all minimally trained subjects could. If this were an emergency scenario, an untrained astronaut would have significant difficulty rotating about Y.

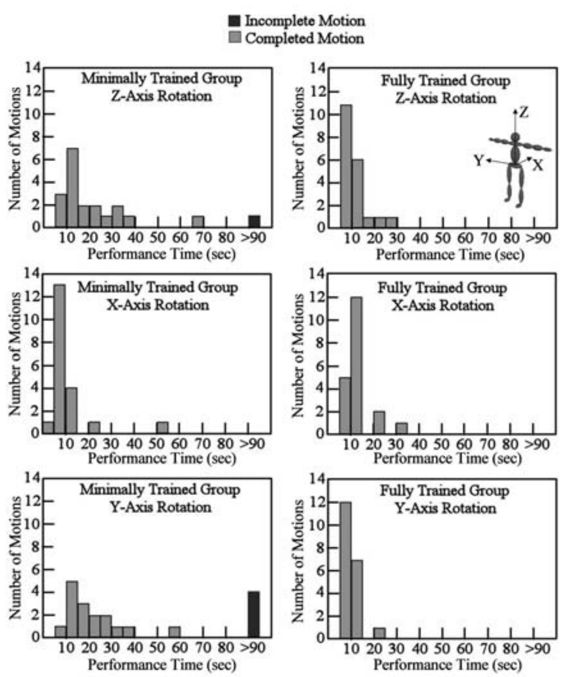

Figure 2. The distribution of performance times for the first trial for each axis ($n = 20$).

The motions developed by the minimally trained subjects for rotations about X were greatly affected by the suspension system. This group tended to use leg motions that achieved the net rotation, but would have yielded off-axis motions in true microgravity. The trained group performed the recommended strategy that yielded planar motions, but took longer to perform, thus yielding similarities in performance time.

For the minimally trained group, the Y rotations had the highest workload when compared to the other two axes. However, for the fully trained group, the X rotations were perceived as most difficult. Significant differences in the workload between groups were seen in Y and Z rotations ($p = 0.002$ and 0.023, respectively).

In the development of motion strategies, it is important to understand their usability. The modified Cooper-Harper rating and the NASA TLX implemented in this study have been beneficial in showing perceived difficulty of a motion. We have shown that certain axes are easier to rotate about than others and that trained subjects have an easier time performing the body rotations than those that have not been trained. This study has provided groundwork for the development of an astronaut motion control training program.

REFERENCES

Kulwicki, P et al. (1962). AMRL-TDR-62-129.

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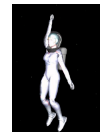

Leia Stirling, Dava Newman, and Karen Willcox

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MOTIVATION

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METHODS

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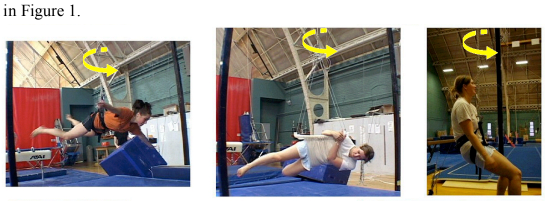

Figure 1. Harness arrangements for rotations about the three body axes.

Subjects performed a series of rotations about the body axes in both the counterclockwise and clockwise directions (Table 1). A total of 48 rotations were performed by each subject, with an equal number of counterclockwise (ccl) and clockwise (cl) rotations. The subjects were placed in one of two groups, minimally and fully trained. Prior to performing the experiment, the subjects went through a training program based on their group. The minimally trained group received a theoretical description of momentum conservation, while the fully trained group was additionally provided with descriptions and videos of strategies for rotating about all three body axes (Figure 2). Experimental measures included a subject coordination score, video data, a motion usability score (modified Cooper-Harper), a fatigue rating, and a cognitive workload measure (NASA-TLX).

Table 1. Self-rotations performed by each subject during the experiment.

Block	Rotation Axis	Number of Trials	Rotation Magnitude (deg.)
1	Z	12 (6 ccl, 6 cl)	180
2	X	6 (3 ccl, 3 cl)	90
3	Y	6 (3 ccl, 3 cl)	90
4	Y	6 (3 ccl, 3 cl)	90
5	X	6 (3 ccl, 3 cl)	90
6	Z	12 (6 ccl, 6 cl)	180

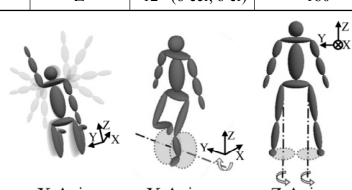

Figure 2. Recommended methods for single-axis rotations for the fully trained group.

RESULTS AND DISCUSSION

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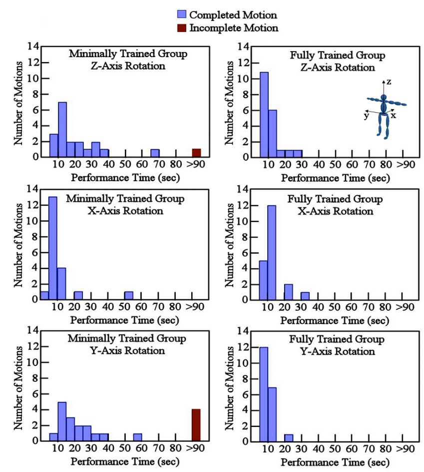

Figure 3. The distribution of performance times for the first trial for each axis (n = 20).

The NASA TLX scores after each rotational block are shown in Figure 4. For the minimally trained group, the Y rotations had the highest workload when compared to the other two axes. However, for the fully trained group, the X rotations were perceived as most difficult. Significant differences in the workload between groups were seen in Y and Z rotations ($p = 0.002$ and 0.023, respectively). For each group, the perceived difficulty of the rotation decreased after the second repetition ($p < 0.01$ for all cases).

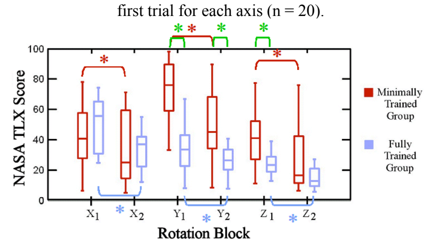

Figure 4. The distribution of the NASA-TLX workload scores for all subjects (n = 20).

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Kulwicki P., Schlei E., Vergamini E. (1962). Weightless man: Self-rotation techniques. Technical Documentary Report No. AMRL-TDR-62-129.

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