Introduction

On Earth, we use many cues to determine our orientation and maintain our balance, including information from our eyes, our vestibular system, and from the sensors in our skin and joints [1-4]. Astronauts working in microgravity are deprived of specific sensory input and may consequently experience difficulties with determining their orientation. For example, there is no pressure under the sole of their feet, and their vestibular system no longer senses Earth’s gravity [5]. Lack of these cues hampers
the astronaut’s orientation awareness [6], increases the susceptibility to visually induced motion illusions [4, 5] and may also be a factor involved in space sickness [3, 6]. In the International Space Station (ISS), the visual cues from the station itself and the idiotropic vector are the major orientation cues used by the astronauts. The latter refers to the fact that astronauts take the orientation of their body axis as framework for up and down [7].

Supporting astronauts’ orientation awareness is important because it is related to performance, safety, and well-being [8]. Previous experiments have shown that touch cues that mimic the cues we have in a 1 G environment improve the orientation awareness of astronauts. Bungee cords that pull an astronaut’s feet to the floor give a strong indication of up and down [4, 5, 9]. However, they also prohibit free movement and are thus of limited operational relevance. During mission Delta, a novel technology was demonstrated that also uses the sense of touch to support the orientation awareness of the astronaut. The tool (called Tactile Orientation Awareness Support Tool or TOAST) consisted of a vest containing 56 vibrating elements (called tactors) based on the vibration technology used in mobile phones (see Figure 1). Contrary to bungee cords, TOAST allows the astronaut to move around freely. The localised vibration of each tactor is directly mapped to the body co-ordinates. Like the proverbial tap on the shoulder, this is an intuitive and fast way to present spatial information [10,11]. Toast technology has shown to be able to counteract spatial disorientation of pilots [12] and support people with a vestibular dysfunction. In the demonstration, we presented an astronaut with orientation information via the analogy of an artificial gravity vector: The location of vibration on the torso indicates the direction of ‘down’ (i.e., the floor of the station).

Significance: science and spin-off
The major goal of the project was a technology demonstration. Of scientific importance is the study of orienting in 3D without confounding with Earth’s 1G environment. The scientific data gathered in this project is presented in [13]. There are also several issues related to the operational use, which is the focus of this paper. Firstly, there are indications that a microgravity environment hampers the perception and quality of the vibratory signals. Studies focussing on tactile intensity and pattern perception in the NASA Reduced Gravity Aircraft indicate that tactile perception is negatively affected by reduced gravity [14,15]. Secondly, there are no data available that indicate the use of TOAST technology for astronauts and the desirability of the suggested applications. This paper presents the first data on these operational issues.

The major impulse for the recent development of TOAST technology comes from applications for military aviation. However, we expect that not only astronauts and pilots can benefit from this innovative development. Spin-off is foreseen for, amongst others, divers and people with a vestibular disorder. A simpler variant (e.g., a belt around the torso) could be useful as a navigation display for visually handicapped [11], for drivers who need to keep their eyes on the road [16], and for first responders and fire fighters who operate in smoke, dust or darkness.

Apparatus, research plan and the experiment
The experiment was performed by a male ESA astronaut. During the experiment, the astronaut was assisted by a second crewmember who moved the astronaut, read out questionnaires and cared after the safety of the astronaut. One part of the experiment consisted of various orientation tasks that are described and discussed elsewhere [13], one part focussed on the operational issues. In this paper we present the operational issues, data that have not been published before.

TOAST consisted of 56 tactors in a vest covering the astronaut’s torso, three gyroscopes to determine the direction of down, a control unit with data storage device, and a voice recorder. The hardware was manufactured by Dutch Space (Leiden, The Netherlands). The tactor nearest to the intersection of the astronaut’s torso with a vector perpendicular to the station floor was activated, indicating “down”.

A total of four basic data collection and training sessions were completed within six months prior to the mission. The first two were used to optimise the fit of the vest and to familiarise the astronaut with the support tool (Figure 1). The last two sessions were used to train the tasks procedures and equipment operation. During these sessions, baseline data were collected. During the experiment onboard the ISS, four sessions were run on four different days to measure the effects of adaptation to microgravity. During the first session in the ISS, the crew used the full crew procedures for the experiment, in the following sessions they used the short version of the procedures (so-called Q-cards). After return to Earth, two debriefing sessions were held to collect post-flight data and to discuss the preliminary experimental results.

To measure the effect of microgravity on perceiving the tac-