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Effect of an auditory feedback substitution, tactilo-kinesthetic, or visual feedback on kinematics of pouring water from kettle into cup

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ABSTRACT

Pouring hot water from a kettle into a cup may prove a hazardous task, especially for the elderly or the visually-impaired. Individuals with deteriorating eyesight may endanger their hands by performing this task with both hands, relaying on tactilo-kinesthetic feedback (TKF). Auditory feedback (AF) may allow them to perform the task singlehandedly, thereby reducing the risk for injury. However since relying on an AF is not intuitive and requires practice, we aimed to determine if AF supplied during the task of pouring water can be used naturally as visual feedback (VF) following practice. For this purpose, we quantified, in young healthy sighted subjects ($n = 20$), the performance and kinematics of pouring water in the presence of three isolated feedbacks: visual, tactilo-kinesthetic, or auditory. There were no significant differences between the weights of spilled water in the AF condition compared to the TKF condition in the first, fifth or thirteenth trials. The subjectively-reported difficulty levels of using the TKF and the AF were significantly reduced between the first and thirteenth trials for both TKF ($p = 0.01$) and AF ($p = 0.001$). Trunk rotation during the first trial using the TKF was significantly lower than the trunk rotation while using VF. Also, shoulder adduction during the first trial using the TKF was significantly higher than the shoulder adduction while using the VF. During the AF trials, the median travel distance of the tip of the kettle was significantly reduced in the first trials so that in the thirtieth trial it did not differ significantly from the median travel distance during the thirtieth trial using TKF and VF. The maximal velocity of the tip of the kettle was constant for each of the feedback conditions but was higher in 10 cm s^{-1} using VF than TKF, which was higher in 10 cm s^{-1} from using AF. The smoothness of movement of the TKF and AF conditions, expressed by the normalized jerk score (NJSM), was one and two orders of magnitude higher from the VF, respectively. The median NJSM then decreased significantly by the fifth trial. Monitoring in-house activity via motion capture and classification of movements, i.e. liquid pouring, can assist with daily activities via AF. As a built-in feature in a smart home, this task-specific AF may prevent burn injuries of the visually-impaired.

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1. Introduction

Pouring hot water from a kettle into a cup may prove a hazardous task, especially for the elderly or the visually-impaired. Most burn injuries in the elderly occur in the kitchen (Redlick et al., 2002), the majority of which occur due to accidental spillage of hot water. A study over a 12-month follow-up period among older adults with age-related macular degeneration reported that burns or scalds accounted for 9% of non-fall-related injuries (Wood et al., 2011).

Although several assistive devices, aimed to increase the safety of liquid pouring exist, e.g. a mechanical kettle tipper, they fail to provide a solution for this problem since they are usually limited to shape-specific kettles and the user is embarrassed to use them, saying they feel like crutches. While most of the hot water related injuries might not be severe enough for the individual to seek medical assistance, they might have an impact on the perceived difficulty in daily activities.

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While blind individuals may adopt strategies for preventing burns by placing the cup on the counter and pouring the water without holding the cup with the opposite hand, individuals with deteriorating eyesight, may be prone to retain their accustomed daily behavior of pouring hot water while the second hand is holding the cup. For these visually impaired individuals, the task of pouring hot water from a kettle to a cup is therefore controlled with both hands, relaying on tactilo-kinesthetic feedback (TKF) of the upper limbs. The proximity of the hot water poured by one hand to the hand holding the cup, endanger the later for burns. An in-house technology providing auditory feedback (AF) indication that the kettle is safely above the cup, may allow the individual to successfully pour the water safely, either singlehandedly or by using both hands, thereby preventing burn injury.

Current technology allows for smart homes equipped with cameras and various sensors, that can detect falls, bed/chair occupancy, gestures (Choi et al., 2014), recognize activities (Krishnan and Cook, 2014) and more, e.g. the GiraffPlus project (Palumbo et al., 2014). The smart home will ultimately contribute to a higher occupational performance, satisfaction and higher functional independence of persons with disabilities and elderly people (Ocepek et al., 2013). As the prevalence of moderate and severe vision impairment and blindness continues to grow (Stevens et al., 2013), so does the need for in-house or in-office solutions for safety. Among the plentiful potential benefits of the smart house, preventing burn injuries of the visually-impaired by using AF has yet to be explored. The rational for sensory substitution via AF is derived from researches depicting its role in motor learning. A recent study (Oscari et al., 2012) supports the aforementioned rational by showing that AF is readily incorporated into brain learning networks in the absence of visual feedback (VF). Also, it has been concluded in a recent review (Sigrist et al., 2013) that AF may reallocate perceptual and cognitive workload, as well as reduce distraction, since it does not require a focus of attention. However, since relying on an AF, e.g. for indicating distance from a rear obstacle when reversing a car, is not intuitive and requires practice, we aimed to determine if AF supplied during the task of pouring water can be used naturally as VF following practice. For this purpose we quantified, in a small sample of young healthy sighted subjects, the performance and kinematics of pouring water from a kettle into a cup in the presence of three isolated feedbacks: auditory, tactilo-kinesthetic, or visual.

2. Methods

2.1. Participants

Twenty healthy right-handed subjects (2 males and 18 females; mean $\pm$ SD for age of 27.6 $\pm$ 3.3 years) participated in this study. Participants were recruited through personal contact and snowball sampling. The study was approved by the Occupational Therapy Department Ethics Committee at Tel Aviv University. Exclusion criteria were cognitive or upper body orthopedic impairments. All participants had normal or corrected-to-normal vision and hearing.

2.2. Research tools

Eleven passive-reflective spherical markers were placed on the right upper arm and forearm of each subject. Markers were placed at the following bony landmarks: spinous process of the seventh cervical vertebrae, deepest point of incisura jugularis, xiphoid process of the sternum, left and right acromio-clavicular joints, right mid-clavicle, right greater tubercle of humerus, right lateral elbow epicondyle, right upper arm between the elbow and the shoulder markers, right radial styloid, right ulnar styloid. The following segments were determined: trunk, right upper arm, right forearm. Trunk rotation was computed in relation to the lab coordinate system, shoulder flexion and adduction were computed for the upper arm in relation to the trunk, and elbow flexion was computed for the forearm in relation to the upper arm. Also, four markers were located on a standard electric water kettle (Fig. 1). A six-camera motion capture system (Qualisys Medical AB, Sweden) was used to stream the markers 3D coordinates in real time at a sampling rate of 100 Hz, and automatically identify the markers placed on the kettle. Real-time output was streamed to LabView software (V12, National Instruments, USA), where the 4 markers placed on the 6DOF kettle were recognized and the coordinates of a fifth virtual marker of the tip of the kettle (the endpoint), were calculated in real-time. In order to produce the auditory signal, the LabView code was used to calculate the position of the tip of the kettle in regard to the rim of the cup, set on the table in a constant position. Preliminary attempts of pouring water from the kettle at different locations above the cup, at different velocities were performed to determine the boundaries of a "safety volume", in which the probability for water spilling is minimal (Fig. 1, radius of cup was 4.2 cm, "safety volume" of 55.4 cm^3). These trial-and-error attempts were performed while monitoring the location of the tip of the kettle in relation to the upper rim of the cup during water pouring. The attempts were conducted while pouring at slow, normal and fast tilting velocities. The boundaries of the location of the tip, in those trials where water did not spill, were chosen as the "safety volume"; however, it should be noted that the selected volume was chosen as a mean for studying the aforementioned research questions, and not for validating a safety protocol for pouring hot liquids.

When the virtual marker located at the tip of the kettle entered these boundaries, a clearly audible 300 Hz beeping sound was activated and held for as long as the tip was inside the "safety volume".

Calibration of the motion capture system was performed according to the guidelines of the manufacturer, using an L-shaped construction placed at a constant location on the table and rotating a wand for 20 s in the captured volume. Kinematics of body movement and tip of the kettle were analyzed for consecutive trials and between the three different feedback conditions, detailed below.

2.3. Protocol

Each subject started each trial in a standing position with the right hand holding the handle of the lightweight kettle, set on a marked position on a table, 42 cm from the cup. Both kettle and cup were placed 13 cm far from the edge of the table. The height of the table was adjusted to the pelvic level of each subject and the subject stood at a midpoint between the kettle and the cup. The subject was instructed to pick up the kettle, pour its content (200 ml water at room-temperature) into a cup (capacity of the cup: 330 ml) and place the kettle back on the table. Each subject repeated this activity 13 times blindfolded with an opaque cloth and touching the handle of the cup with the free left hand (TKF condition), then 13 times blindfolded with the AF activated when the kettle is at the safe location above the cup (AF condition), and finally, 3 times with only VF (control condition). This was a randomized AB/BA design where 10 subjects first performed the task with the TKF and then with the AF and 10 subjects performed the reversed order. The 3 trials with the VF were always last. Each subject then filled a visual analog difficulty scale regarding the difficulty level (ranging from '1' = very easy, to '5' = very difficult) of pouring water on the first and thirteenth trials using the AF or TKF conditions.

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