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Accuracy of caring personnel in estimating water intake based on missing liquid in drinking vessels*

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Abstract— **In this contribution a measurement regarding estimations of filling levels in drinking vessels is presented. Ensuring a sufficient hydration is an important task in nursing homes. Monitoring of fluid intake is normally achieved by visual examination of drinking vessels conducted by staff members. This contribution describes a measurement targeted at evaluating this method in order to analyze the requirements of technical aids. Data gained by conducting this measurement in a cooperating elderly people home is presented and analyzed. Key results are that residents drink on average 5 to 10 percent less than it is recorded and that estimations of especially partly filled vessels vary strongly. Both, the type of drinking vessel and the current filling level influence the accuracy and precision of the difference between estimation and actual missing liquid.**

I. Introduction

Germany, as well as other industrial countries, faces a huge challenge in terms of the demographic change. The ratio of elderly people rises dramatically and a significant quantity of them is in need of care [1]. A promising way to allow elderly people to live longer autonomously at their home are assistive devices [2]. However, care-giving services in nursing homes have to be evaluated first in order to support them or to provide these services independent from infrastructure and personnel at home [3].

A necessity for monitoring essential body parameters is one of the issues restricting the autonomy of elderly people. Water, for example, is fundamental for life. It is by far the most prominent part of a human body accounting for 45 - 70 % of its weight [4]. It is needed to maintain every essential body function such as heat regulation, metabolism, transport and countless further processes. A continuous regulation of the water level is required to prevent over- or undersupply [5][6]. The latter is called dehydration and interferes severely with body processes. Symptoms and effects of this include thirst, weakness, dizziness, confusion, damage to kidneys, delirium and, in the worst case, death [7]. Therefore, it is important to sustain a certain level of fluids and electrolytes by balancing water intake and output through beverages and meals respectively urine, feces, transpiration and breathing [6]. There are several standard methods to determine sufficient hydration [8], e.g. 1 ml per kcal energy consumed [9], 30 ml per kg body weight [10] or 100 ml/kg for the first 10 kg, 50 ml/kg for the next 10 kg and 15 ml/kg for the remaining body weight [11].

However, elderly people often do not match these requirements any more. Some of the reasons for this are a diminishing thirst sensation, swallowing difficulties, functional impairments, decreased kidney function and excreting more water due to medication [12]. As effect, morbidity and mortality increase. Studies about the actual water intake situation in nursing homes show that insufficient hydration is in fact a problem [13][14] – a humane one and also an economical one since effort and cost of medical care are affected [15].

II. State of the Art

Although there are countermeasures against dehydration, it has to be detected first [16][17]. The recommended method is to maintain a balance of water intakes and outputs of individual residents. A major part of it consists of monitoring the liquid consumption through beverages [18][19]. However, there are no explicit regulations about detection methods regarding this task. Therefore, the approach of a cooperating nursing home is described in the following. Individual residents are assigned to staff members who motivate them to drink by (re)filling drinking vessels and who thereby accurately protocol the overall amount of consumed liquid. This way, the actual supply through beverage can be compared to the individually calculated recommended amount to enable the staff to intervene when necessary. This protocolling is done by visual examinations of the drinking vessels which lead to an estimation about how much liquid was consumed.

III. Task

To the authors' knowledge however, there is no reliable data available about how accurate and precise those manual estimations are. The measurement presented in this contribution aims at reducing this lack of knowledge. It is in particular conducted in regard of finding a benchmark for devices able to automatically detect drinking amounts and, as a side effect, relieves staff from a routine task which takes away time from actual interpersonal care-giving.

IV. Measurement

A. Materials and methods

As mentioned earlier, staff members help residents by filling drinking vessels for them and estimate afterwards how much has been drunk. In order to create an adequate

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configuration for both realistic and comparable results, the measurement is split in two parts.

To factor in that final filling levels differ from person to person, participants are first asked to fill empty drinking vessels. It is stressed that they should only pour as much liquid in as they would normally do when filling a vessel for residents. This is repeated 3 times for every type of drinking vessel to reduce the influence of abnormalities.

Second, several differently filled drinking vessels are shown to the participants. They are asked to estimate how much liquid is missing compared to the corresponding drinking vessels they previously had filled by themselves. It is emphasized that they should estimate in a common way, especially not to be more accurate then normally. Those shown objects consist of every combination of drinking vessel type and staggered volume. For example, to get a resolution of 20 ml for a cup with a nominal capacity of 200 ml, 11 cups are needed which are filled with 0 ml, 20 ml, 40 ml, and so forth until 200 ml. This way, an objective equipment configuration is created which allows comparisons between different participants while including the subjective characteristics mentioned before. To eliminate biases through pattern recognition, it is beneficial to shuffle the order and to use randomly assigned common liquids for filling those prepared drinking vessels.

This measurement method is used in an elderly peoples' home of the Kuratorium Wohnen im Alter gemeinnützige AG called Luise-Kiesselbach Haus. In order to detect the actual situation, only staff members who regularly estimate drinking amounts were invited to participate in the measurement. The 9 chosen ones are exclusively female and between 21 and 56 years old with a median of 34 years. They consist of 3 members of the early shift, 3 from the late shift, 2 members of the staff administration and the chef. There are four different types of drinking vessels regularly in use there: a tumbler and a coffee cup with a nominal capacity $V_{nominal}$ of 200 ml, a feeding cup with $V_{nominal}$ = 200 ml, too, but an actual capacity of 220 ml, and a mug with $V_{nominal}$ = 300 ml, but an actual capacity of 320 ml. To simulate realistically looking drinking vessels, they are filled with common liquids. Coffee is used in coffee cups and mugs, red spritzer and water are used in tumblers and feeding cups, thickened water is used in tumblers and mugs, and apple juice is used in tumblers, feeding cups, mugs and coffee cups (feigning tea). These liquids are randomly assigned to different filling levels. Additionally, all objects are arranged in a random order. As a result, there are 51 drinking vessels consisting of a unique combination of vessel type and staggered liquid level in random order and with typical content. Table 1 summarizes the different parameters used in this measurement and their connection. A picture of the setup is displayed in Fig. 1. Fig. 2 shows the configuration for the detection of subjective capacities.

TABLE I. SUMMARY OF IN THIS MEASUREMENT VARIED PARAMETERS WITH A STEP SIZE OF 20 ML REGARDING THE VOLUME

Vessel type	Volume [ml]	Beverage
Tumbler	0 … 200	Red spritzer, water, thickended water, apple juice
Coffee cup	0 … 200	Coffee, apple juice
Feeding cup	0 … 220	Red spritzer, water, apple juice
Mug	0 … 320	Coffee, thickened water, apple juice

Figure 1. Exemplary selection of differently filled drinking vessels as basis for estimations regarding missing volume

Figure 2. Configuration of empty drinking vessels which have to be filled fully (top to bottom: mug, feeding cup, tumbler, coffee cup)

B. Deduction of results from measured data

The raw data is processed by calculating the mean value of the volume in a self-filled drinking vessel of a certain type to get a participant's subjective capacity V_{filled} of said type. The missing volume is obtained by subtracting the exactly known volume in each of the prepared drinking vessels $V_{prepared}$ from this subjective capacity. After subtracting the recorded corresponding estimation E, a difference D between estimated and actual missing volume is gained based on subjective filling characteristics.

$$D = (V_{filled} - V_{prepared}) - E \quad (1)$$

Positive values of D signal that a resident would have drunk more than estimated, negative values imply that less has been drunk. This formula doesn't use absolute values because a resident's body buffers a large amount of water compared to the content of a single drinking vessels. Temporary over- and undersupply is evened out, whereas systematic differences sum up.

This is repeated for each participant and each of the prepared, differently filled drinking vessels. Using these subjective capacities and differences, several statements can be deduced. A distribution of D is gained by plotting their frequency of occurrence over their value. Combining values within intervals of a proper size improves the readability of such a plot. Calculating mean values μ and standard deviations σ provides numbers about multiple subsets such as the average difference between estimated and actually missing volume in regard to particular drinking vessel types, individual participants or drinking vessels sharing the same filling level, as well as an overall picture. Considering the offset O between subjective capacity V_{filled} and nominal capacity $V_{nominal}$, commonly labelled near the top, calculated in (2) accompanies the above mentioned subsets.

$$O = (V_{filled} - V_{nominal}) \qquad (2)$$

A positive offset means that there is more content in a vessel than one would expect, resulting in a most likely higher liquid consumption. A potentially more intuitive representation of these figures is found by using ratios r in regard to the nominal capacity of a certain drinking vessel while using a $\mu \pm \sigma$ scheme as in (3).

$$r = 100\ \% \cdot \mu / V_{nominal} \pm 100\ \% \cdot \sigma / V_{nominal} \qquad (3)$$

V. RESULTS

The 9 participants provided 108 references by self-filling drinking vessels and 459 estimations. Results are deduced from this data using the methods introduced earlier.

Table 2 shows how drinking vessels are filled compared to their nominal capacity. Coffee cups are the least filled with 86.3 % of $V_{nominal}$, followed by mugs with 94.2 %. Feeding cups are filled with 103.8 %, which is possible because they can contain larger amounts of liquid than labelled upon. Tumblers are with 97.4 % quite accurately filled. On average, the examined care-givers don't pour the complete nominal capacity into drinking vessels, leading to 4.6 % systematically missing. The standard deviation of these offsets O lies between 5.2 % and 8.2 %. Fig. 3 visualizes these values in a graph.

Based on the estimations and the corresponding individual offsets, differences D are calculated. Fig. 4 shows the frequency of occurrence of all differences. It can be clearly seen that the results create a normal distribution, although with a slightly negative skewness: the bulk of the values lies to the right of the mean. The mean value of this distribution is located in the negative area around -22 ml which is consistent with the observation that the subjective capacity is smaller than the nominal one. The most extreme differences

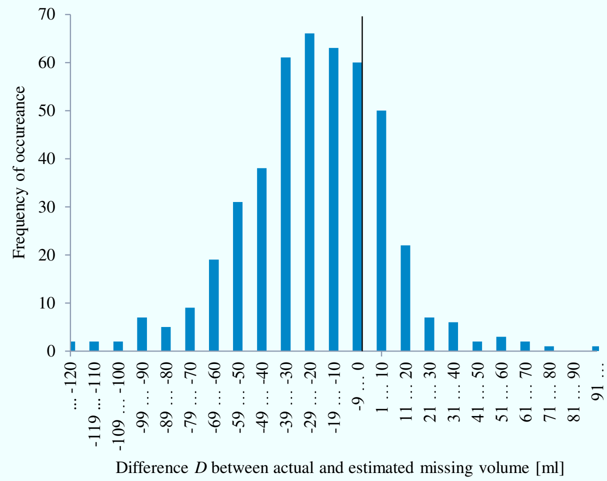

Figure 3. Frequency of occurrence of differences between actual and estimated missing volume

are probably caused by confusing visible and missing volume, but this might happen on daily routine, too.

Table 3 lists the differences between actual and estimated missing volume based on individual offsets. Overall, estimations are wrong by 9.2 % with a standard deviation of 12.1 %. This means that on average almost 10 % has been drunk less per drinking vessel than it is recorded and that most (68.3 % of all values lie within $\pm 1\sigma$) estimations have a discrepancy somewhere between 21.3 % missing volume and 2.9 % oversupply. This changes depending on drinking vessel type, though. Following the trend of Table 2, estimations of tumblers are quite accurate, whereas missing liquid in coffee cups and mugs is overestimated by 17.5 % respectively 10.9 %. Although being slightly overfilled, drinking amounts in feeding cups are also overestimated by 5.5 %. The standard deviation of these differences is between 10.6 % and 14.5 %. These results are visualized in

TABLE III. OFFSET BETWEEN THE VOLUME IN PARTICIPANT-FILLED DRINKING VESSELS AND THE NOMINAL CAPACITY AS DIFFERENCE O AND AS RATIO R_O COMPARED TO THE NOMINAL CAPACITY (VALUES ARE DISPLAYED IN A $\mu \pm \sigma$ SCHEME)

	Overall	Tumbler	Coffee cup	Feeding cup	Mug
O [ml]	-11±15	-5±15	-27±15	+8±16	-17±16
r_O [%]	-4.6±7.0	-2.6±7.4	-13.7±7.4	+3.8±8.2	-5.8±5.2

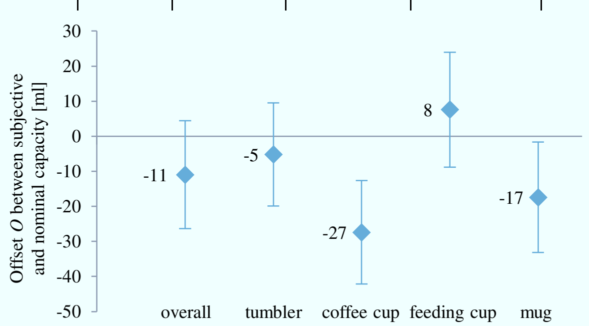

Figure 4. Offset between the volume in participant-filled drinking vessels compared to the nominal capacity

TABLE II. DIFFERENCES BETWEEN ACTUAL AND ESTIMATED MISSING VOLUME AS DIFFERENCE D AND AS RATIO R_D COMPARED TO THE NOMINAL CAPACITY (VALUES ARE DISPLAYED IN A $\mu \pm \sigma$ SCHEME)

	Overall	Tumbler	Coffee cup	Feeding cup	Mug
D [ml]	-22±31	-5±29	-35±25	-11±21	-33±33
r_D [%]	-9.2±12.1	-2.7±14.5	-17.5±12.3	-5.6±10.6	-10.9±11

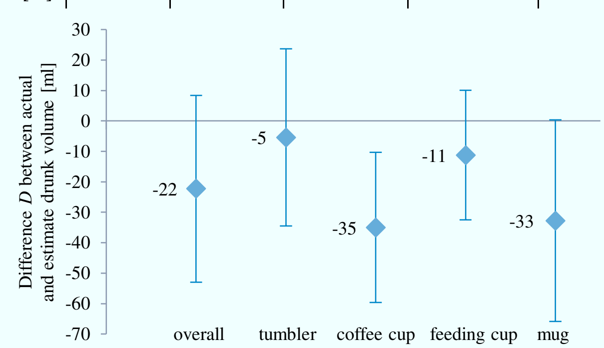

Figure 5. Difference between actual and estimated missing volume for individual drinking vessel types and the overall value

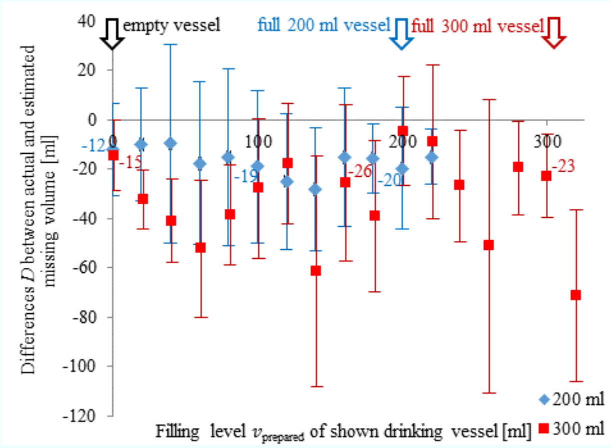

Figure 6. Difference between actual and estimated missing volume depending on different remaining volumes in drinking vessels with nominal capacities of 200 ml and 300 ml

Fig. 5.

Fig. 6 displays the distribution of differences in relation to a shown liquid level. The blue graph of drinking vessels build to contain 200 ml (tumbler, coffee and feeding cup) shows that empty vessels are rather accurately estimated with an average of -12 ml, which correlates with 6 % of their nominal capacity. The remaining difference is caused by participants calculating based on nominal and not on subjective capacities of vessels. However, estimations on partly filled ones are less accurate, e.g. a semi-filled one is on average rated -19 ml wrong and even completely filled vessels show differences of -20 ml. The standard deviation follows this trend as the blue error bars clearly indicate. Since mugs are the only type of 300 ml drinking vessels, strongly deviating estimations are less balanced out, leading to a fluctuating red colored graph. Nevertheless, empty mugs are accurately estimated with -15 ml, or 5 % of their nominal capacity, too. Partly filled ones often differ much, though. A semi-filled mug is overestimated by -26 ml and a completely filled one by -23 ml. The general absolute difference is higher because of the bigger size compared to 200 ml vessels. Speaking of standard deviation, estimations of empty or full mugs are more precise than partly filled ones.

VI. Conclusion

This measurement shows that the current way of monitoring hydration in nursing homes - estimations of staff based on visual examination of drinking vessels - is not optimal. The negative mean value indicates that residents systematically drink roughly 10 % less than it is recorded. Even in the best case when a drinking vessel has been completely emptied by a resident, there is still 5 % less liquid drunk due to a difference between subjective filling and nominal capacity of a drinking vessel. Another aspect is the broad distribution of differences especially of partly emptied vessels. Since residents drink only the content of a couple of vessels a day, a sequence of several unfavorable estimations is possible. This might lead to a bigger difference between actually drunk and recorded amount.

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