Going with the Flow:
Determining the Most Ideal and Average Drinking Vessel

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Abstract: The study of flow efficiency in ceramic vessels obtained from the Dollarware assembalge is explored through the means of a timed drinking experiment. Three determinable group types (cylindrical, frustum, rounded) are defined to identify which basic measurements affect drink flow. The dimensions of the frustum shape are more demanding of the users energy which results in less efficient results while cylindrical and rounded vessels are similarly efficient due to easier dimensions that can be accommodated by users attributed to familiarity and size. 30 litres of distilled water was consumed for this experiment.

Introduction

This experiment is a focused analysis of the properties of flow efficiency in ceramic vessels. The vessels used were obtained from the *Dollarware* assemblage (see http://dollarware.org). The properties studied will be based on the basic metric measurements and dimensions of the vessels themselves to infer which attributes affect drink flow. Efficiency of the flow itself will be calculated from a function of time, determinable by the drinking speeds of the subjects tested. The reason for this function is that the vessels studied were pre-classified as drinking vessels so the consumption of liquids would be the logical determinant of efficiency. The primary questions asked are which measurements can be attributed to affect flow efficiency and how so. Are certain attributes more affective than others? Why? What contributes to the differences in times between subjects? Is there a trend between subject groups of each vessel type?

Methods

Firstly, three sets of three vessels were selected. Each set would be representative of a certain shape group. The shapes chosen were according to a ratio of top-bottom ratio to height chart (see Figure 1). Sets were chosen from three specific clusters of the graph that best represent the broadest spectrum of artefacts.

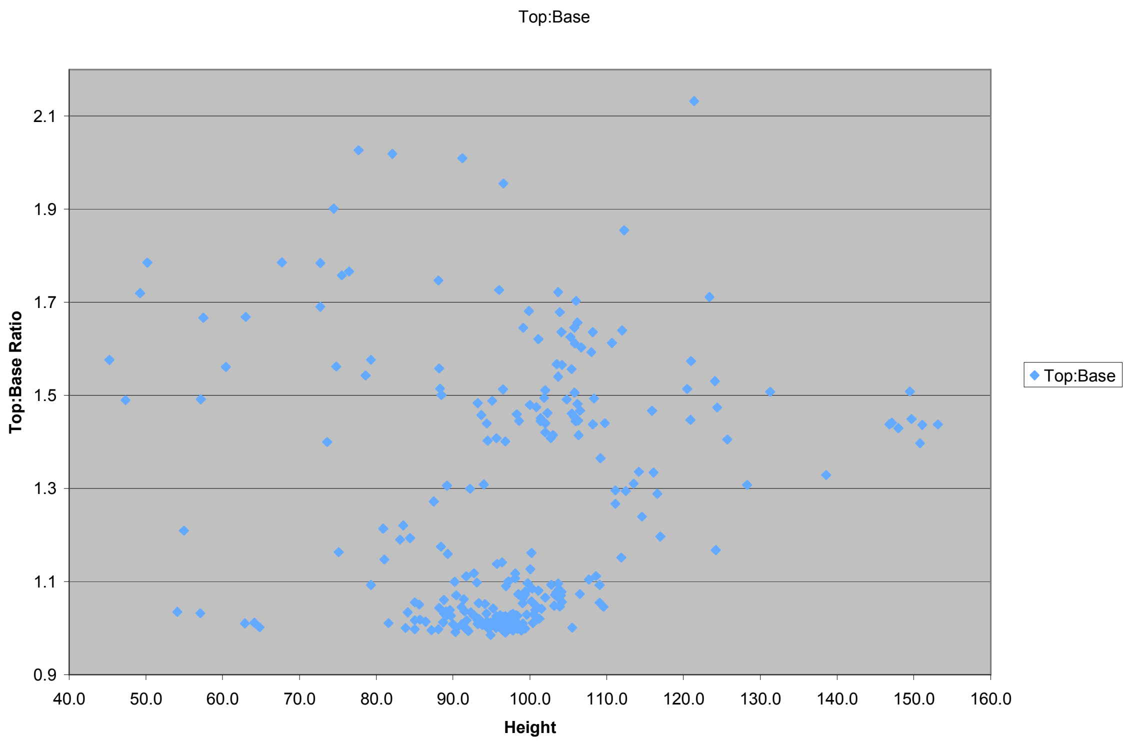

Figure 1: top-base ratio to height chart of Dollarware assemblage

The first cluster is the cylindrical. From this chart, we can see a large portion of the assemblage artefacts occurs within a cluster with the top-base ratio close to 1.0 and a height between 9-10 cm. This makes the cylindrical cluster a representative of the most common vessel, or a modal vessel. Three vessels were selected to form a cylindrical group: artefacts I-19, K-13, and N-41 (top-bottom ratio average is 1.01 and average height is 95.47mm) (see figure 2).

Figure 2: The cylindrical group artefacts I-19, K-13, and N-41 (http://dollarware.org/i-19.jpg)(http://dollarware.org/k-13.jpg) (http://dollarware.org/n-41.jpg)

The second cluster is the frustum. The frustum cluster exists within the margins of a 1.5 top-base ratio and a height between 9-11 cm. As frustum is defined by the cone shape determined by top-base ratio (where top is larger than the bottom), the range of height is greater than that of the cylindrical cluster, nonetheless, the three vessels chosen from this group share similar metrical properties throughout. In order to increase the range of diversity of groups, the frustum group vessels are chosen from the taller and extreme end of the cluster, not from the majority. The frustum group consists of artefacts E-02, E-05, E-08 with a top-base ratio average of 1.433 and a height average of 14.81cm (see figure 3).

Figure 3: The frustum group artefacts E-02, E-05, E-08 (http://dollarware.org/e-02.jpg)(http://dollarware.org/e-05.jpg) (http://dollarware.org/e-08.jpg)

The third cluster is the rounded. Like the frustum, rounded cups are determinable by the top-base ratio, however, unlike the frustum where the sides of the vessels are always straight, these vessels expand outwards in a bowl-like shape, often with higher ratios than that of the frustum due to the nature of the rounded bottom. From the chart, there is no majority cluster for this group; in fact, it is hard to differentiate just by looking at the plots. Therefore, I have chosen an outlier that qualifies in the rounded shape and differs from the frustum and cylindrical groups in terms of top-base ratio and height. Artefacts A-09, C-02, C-04 (average top-base ratio is 1.765, average height is 74.9), make up the rounded group (see figure 4).

Figure 4: The rounded group artefacts A-09, C-02, C-04 (http://dollarware.org/a-09.jpg)(http://dollarware.org/c-02.jpg) (http://dollarware.org/c-04.jpg)

Once the choice of vessels has been established, the experiment set-up is as follows. Each vessel in each group (cylindrical, frustum, and rounded) will be filled with 150ml of distilled water, combining for 450ml per group. This is slightly less than two standard 250ml cups of water, an amount deemed reasonable to drink in one sitting. Nineteen volunteers were recruited thereafter to participate as test subjects, twelve females and seven males. Each subject would be timed on drinking continuously through all three vessels of each group, one group at a time and at an interval in which the subjects themselves felt comfortable at between each group. Times are recorded for each individual for how long it took them to drink through each set, and a mean and standard deviation was calculated (see figure 5).

	sex	Cylindrical	Frustum	Rounded		Average	Std. Dev.
Lars Anderson	M	22.56	32.9	39.02		31.49	8.32
Sarah Bedard	F	45.22	54.78	44.27		48.09	5.81
Emma Chait	F	46.9	58.87	47.98		51.25	6.62
Stephen Chrisomalis	M	28.06	32.88	27.72		29.55	2.89
**Claudine Gravel Miguel*	*F*	*110.68*	*107.81*	*74.97*		*97.82*	*19.84*
David Groves	M	18.26	26.56	27.82		24.21	5.19
Dario Guiducci	M	25.94	28.05	21.25		25.08	3.48
Emma Johnson	F	27.97	33.55	34.87		32.13	3.66
Solomon Klein	M	23.17	24.86	27.99		25.34	2.45
Gabriel Kravitz	M	38.11	40.86	30.78		36.58	5.21
Elizabeth Penttila	F	23.1	30	26.89		26.66	3.46
**Julien Shoenfeld*	*M*	*13.76*	*16.85*	*11.35*		*13.99*	*2.76*
Anna Titcomb	F	20.72	32.17	26.78		26.56	5.73
Katherine Tong	F	40.43	43.45	42.48		42.12	1.54
Alison Vadnais	F	56.08	55.48	49.37		53.64	3.71
**Sarah Vannice*	*F*	*75.57*	*58.99*	*60.2*		*64.92*	*9.24*
Yujing Wang	F	30.03	33.53	28.61		30.72	2.53
**Andrea Wong*	*F*	*10.6*	*15.29*	*14.95*		*13.61*	*2.62*
Lisa Zimanyi	F	28.06	32.88	27.72		29.55	2.89

Figure 5: Individual drinking times of each subject in seconds (s)
*** indicates outliers, not used for calculations on the representative sample**

As well as the timed tests, an additional tipping angle test was also conducted. Each vessel was tested for the maximum angle achieved before liquid pours out of the rim. This was tested for the standard 150ml per vessel to correspond with the rest of the experiment. Figure 6 shows the results (see figure 6).

A-09	33°
C-02	23°
C-04	34°
E-02	70°
E-05	63°
E-08	67°
I-19	51°
K-13	52°
N-41	51°

Figure 6: Tipping angles of each artefact

Results

There are many conclusions that can be drawn into consideration as possibilities for the result. Firstly, the outlier group is defined; the data of Claudine Gravel Miguel, Julien Shoenfeld, Sarah Vannice, and Andrea Wong constitutes the top and bottom 10% of the test group in terms of speed. For the comparative averages, the group will not be counted, however, they will still be considered when looking for trends. This is to eliminate the outlier variables that may have attributed to rather faster or slower times. Although, the outlier data is not considered when calculating overall averages and means, their times can still be ranked in accordance to personal trends per person as well.

Next, we can compare the timed results. The average time taken by all subjects (an average of the average of all subjects) is 34.20s. If this is determinable as the average drinking time, then times that are similar can also be considered the norm. To illustrate this point, let's arbitrarily use a +/- of seconds category to classify subjects of each shape group to determine how many recorded times per shape are close to the overall average of 34.20s.

The first +/- will be 2 seconds (see figure 7). In the cylindrical group, no subjects qualify between this time limit. In the Frustum group, 5 subjects (Lars Anderson, Stephen Chrisomalis, Emma Johnson, Yujing Wang, Lisa Zimanyi) are included. In the Rounded group, 1 subject (Emma Johnson) fits in this category.

Lars Anderson	22.56	32.9	39.02
Sarah Bedard	45.22	54.78	44.27
Emma Chait	46.9	58.87	47.98
Stephen Chrisomalis	28.06	32.88	27.72
Claudine Gravel Miguel	110.68	107.81	74.97
David Groves	18.26	26.56	27.82
Dario Guiducci	25.94	28.05	21.25
Emma Johnson	27.97	33.55	34.87
Solomon Klein	23.17	24.86	27.99
Gabriel Kravitz	38.11	40.86	30.78
Elizabeth Penttila	23.1	30	26.89
Julien Shoenfeld	13.76	16.85	11.35
Anna Titcomb	20.72	32.17	26.78
Katherine Tong	40.43	43.45	42.48
Alison Vadnais	56.08	55.48	49.37
Sarah Vannice	75.57	58.99	60.2
Yujing Wang	30.03	33.53	28.61
Andrea Wong	10.6	15.29	14.95
Lisa Zimanyi	28.06	32.88	27.72

Figure 7: +/- of 2 seconds from 34.20 (overall average)
Qualified times are highlighted in red

For further investigation, we can increase the +/- category to 5 seconds (see figure 8). In the cylindrical group, 1 subject (Gabriel Kravitz) would fall under this category. In the Frustum category, 7 subjects (Lars Anderson, Stephen Chrisomalis, Emma Johnson, Elizabeth Penttila, Anna Titcomb, Yujing Wang, Lisa Zimanyi) qualify. In the rounded group, there are 3 subjects (Lars Andreson, Emma Johnson, Gabriel Kravitz). We can conclude that the group most closely associated with the average drinking time is the Frustum group.

Lars Anderson	22.56	32.9	39.02
Sarah Bedard	45.22	54.78	44.27
Emma Chait	46.9	58.87	47.98
Stephen Chrisomalis	28.06	32.88	27.72
Claudine Gravel Miguel	110.68	107.81	74.97
David Groves	18.26	26.56	27.82
Dario Guiducci	25.94	28.05	21.25
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Elizabeth Penttila	23.1	30	26.89
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Yujing Wang	30.03	33.53	28.61
Andrea Wong	10.6	15.29	14.95
Lisa Zimanyi	28.06	32.88	27.72

Figure 8: +/- of 5 seconds from 34.20 (overall average)
Qualified times are highlighted in red

Let's try calculating the same attributions on a +/- 10 seconds category from the average (see figure 9). The results would be 7 subjects (Stephen Chrisomalis, Dario Guiducci, Emma Johnson, Gabriel Kravitz, Katherine Tong, Yujing Wang, Lisa Zimanyi) for the Cylindrical group, 12 subjects (Lars Anderson, Stephen Chrisomalis, David Groves, Dario Guiducci, Emma Johnson, Solomon Klein, Grabriel Kravitz, Elizabeth Penttila, Anna Titcomb, Katherine Tong, Yujing Wang, Lisa Zimanyi) for the Frustum group, and 11 subjects (Lars Anderson, Stephen Chrisomalis, David Groves, Emma Johnson, Solomon Klein, Grabriel Kravitz, Elizabeth Penttila, Anna Titcomb, Katherine Tong, Yujing Wang, Lisa Zimanyi) for the Rounded group.

Lars Anderson	22.56	32.9	39.02
Sarah Bedard	45.22	54.78	44.27
Emma Chait	46.9	58.87	47.98
Stephen Chrisomalis	28.06	32.88	27.72
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David Groves	18.26	26.56	27.82
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Emma Johnson	27.97	33.55	34.87
Solomon Klein	23.17	24.86	27.99
Gabriel Kravitz	38.11	40.86	30.78

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Julien Shoenfeld	13.76	16.85	11.35
Anna Titcomb	20.72	32.17	26.78
Katherine Tong	40.43	43.45	42.48
Alison Vadnais	56.08	55.48	49.37
Sarah Vannice	75.57	58.99	60.2
Yujing Wang	30.03	33.53	28.61
Andrea Wong	10.6	15.29	14.95
Lisa Zimanyi	28.06	32.88	27.72

Figure 9: +/- of 10 seconds from 34.20 (overall average)
Qualified times are highlighted in red

For all three sets of +/- categories, it is the Frustum group that contains the most times that are closest to the average. The Cylindrical group contains the least while the Rounded group increasingly diminishes the discrepancy from itself and the Frustum group as the +/- categories increase, however, while the discrepancy decreases, so does its relevance. From this simple +/- test, we can conclude that the Frustum group holds the most average drinking times from the subjects.

Yet, while the Frustum shape may hold the average dinking times, it cannot be concluded that it is the average drinking vessel. This is because, average is relative per subject. I will try to use a ranking system to illustrate this point. For each of the subjects, a rank order is given to each time. The fastest time is given a rank of 1, and the middle time given a rank of 2 and the slowest time given the rank of 3 (see figure 10).

Lars Anderson	1	2	3
Sarah Bedard	2	3	1
Emma Chait	1	3	2
Stephen Chrisomalis	2	3	1
Claudine Gravel Miguel	3	2	1
David Groves	1	2	3
Dario Guiducci	2	3	1
Emma Johnson	1	2	3
Solomon Klein	1	2	3
Gabriel Kravitz	2	3	1
Elizabeth Penttila	1	3	2
Julien Shoenfeld	2	3	1
Anna Titcomb	1	3	2
Katherine Tong	1	3	2
Alison Vadnais	3	2	1
Sarah Vannice	3	1	2
Yujing Wang	2	3	1
Andrea Wong	1	3	2
Lisa Zimanyi	2	3	1

Total #s	1	9	1	9
	2	7	6	6
	3	3	12	4
Sum		32	49	33
Average		1.684	2.579	1.737

Figure 10: Individual subject rank order for fastest, slowest, and middle times

From the rank order system, one can immediately see that the Frustum group is the slowest group of the three. The sum of the 49 rank points denotes that it contains more slow values than the Cylindrical or the Rounded. This result differs greatly from that of the +/- test from above which showed the Frustum group to be "average" according to times. While the rank order system simplifies the overall times into a value and does not take into account the array of differences in times between each group, it is still shows effectively which times were fastest and slowest. While the Frustum group is clearly defined as the slowest of the three groups, the Cylindrical and the Rounded are equally fast in the respective categories with the Cylindrical group having the slightest of advantage in speed.

In comparison to the +/- test, it is evident that Frustum group contains the most average times but it is not the average drinking vessel per subject. It is also evident that most subjects drink faster than the average time since the Frustum group is the slowest of all three groups. This conclusion would leave one to wonder how the Frustum group can contain the most average times but still be the slowest of all drinking vessels and not be the average vessel per subject? This is because of the use of means in general are problematic in representing limits. I would then infer that the Frustum category is not representative of a large enough limit. For instance, the +/- test also encompasses the times that are significantly above the average but are not noticeable in the results because they were not included as part of the qualifiers. These are direct results of the methodology used in this experiment.

Discussion

In this section, I would like to discuss the contributing factors to the results. As stated in the introduction, a primary discussion on the metric measurements will contribute to the explanation of varying results. Please refer to Appendix A for basic measurements of dollarware vessels used in this experiment.

We can use the tipping angle (see figure 6) as the first reference of discussion. Again, the Frustum group contains the obvious results, requiring the largest of angles for tipping test. This result is determinable by the height of the Frustum vessels to be significantly larger than the other two groups. As well, the straight sides of the vessel do not interfere with the liquid when being poured making the morphology a contributing factor. This is much harder to determine between the Cylindrical and Rounded vessels who boast similar rank results but relatively different timed results. The tipping angles of both sets would suggest that the Cylindrical group should have slower results than the Rounded times. If we were to use the rank order results to conclude this, this would be indeterminable as the difference between the two groups is not significant. However, using the timed results, we can also disprove the hypothesis that the cylindrical group is the slower group. If we were to take the results from the timed tests, and eliminate the average qualifiers for each +/- category, then we will see why the Cylindrical group contains the least averages. This is because the times are significantly faster than averages which do not qualify the times for the times in the test. While in the Rounded group, increasingly more times qualify into the averages, giving it in general a much slower limit than that of the cylindrical. Still, how would this explain the differences in the tipping angles? I would conclude that while the differences exist, it cannot be the only determinable factor.

In an analysis the Frustum vessels, they are the tallest, heaviest, and most voluminous. The Rounded vessels are the shortest, lightest and least voluminous. The Cylindrical vessels fit nicely in the middle of all categories. How do these basic measurements affect the times of the subjects? For the Frustum category, the taller, heavier morphology, along with the larger tipping angle affects the drinking times most significantly due to energy required to the compensate for the larger morphology. Following the same theory, the Rounded category should have the fastest times due to less energy required to use, however the results of both tests illustrate the contrary. How is the Cylindrical category able to over compensate its basic measurements to produce the fastest results? My conclusion is that the Cylindrical category is the most common and familiar category to the subjects as drinking vessels. It is also has the most ideal dimensions, morphology and basic measurements that balance accordingly to human consumers. While the Rounded vessels require the least energy and effort, it is possible that is lies below the equilibrium line of efficiency and its smaller stature would actually deter its performance.

Finally, I would like to end the report on a discussion of variables. This was the most difficult control to establish as the varying factors for each experimental subject at different experimental times greatly differed. Environmental factors were unpredictable and although controlled to a great extent, it was not possible to have an identical setting for each individual during testing. As well, the thirst of the individual was determinable only by the subjects themselves and each was given liberty to determine their own performance abilities and the times in which they would complete each set of test groups. Also, drinking speed was also established by the subject and while instructions were to drink each set of shape categories identically, this cannot be measured accordingly and difficult to determine and manage.

Appendix A: Basic Metric Measurements of Dollarware Vessels

Specimen	Rim Thickness (mm)	Base Diameter (mm)	Volume (ml)	Displacement (ml)	Density (g / cm3)
A-09	4.9	51.9	274.2	118	2.33
C-02	2.3	45.7	203.5	71	2.18
C-04	4.0	52.0	273.8	118	2.33
E-02	5.0	62.2	450.4	246	2.28
E-05	3.4	59.8	419.0	221	1.54
E-08	4.2	61.5	467.3	229	2.28
I-19	4.0	80.4	325.5	160	2.23
K-13	3.5	81.0	327.4	163	2.30
N-41	3.1	80.0	329.5	156	2.32

Specimen	Rim Thickness (mm)	Base Diameter (mm)	Volume (ml)	Displacement (ml)	Density (g / cm3)
A-09	4.9	51.9	274.2	118	2.33
C-02	2.3	45.7	203.5	71	2.18
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E-05	3.4	59.8	419.0	221	1.54
E-08	4.2	61.5	467.3	229	2.28
I-19	4.0	80.4	325.5	160	2.23
K-13	3.5	81.0	327.4	163	2.30
N-41	3.1	80.0	329.5	156	2.32