

**Critical Review:
The effect of time and temperature on the viscosity of thickened liquids**

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This critical review examines the evidence regarding the effects of time and temperature on the viscosity of thickened liquids. All of the studies evaluated in this review were repeated measures designs. Overall, the research supports the fact that changes occur due to these factors; however, the evidence regarding the specific changes in viscosity is inconclusive. Recommendations for further research are provided.

Introduction

In clinical practice, many Speech-Language Pathologists (S-LPs) utilize thickened liquids in dysphagia therapy. A survey by Garcia, Chambers & Molander (2005) reported that 1/3 of S-LPs in the United States utilized pre-packaged thickened liquids in dysphagia therapy. However, most frequently in the hospital setting, S-LPs thicken liquids manually using powdered thickeners (Garcia, Chambers & Molander, 2005). Liquids must be thickened appropriately per the patient's needs since liquids that are too thin may be aspirated (Logemann, 1998). Alternatively, liquids that are too thick may be rejected by the patient, which could lead to malnutrition and/or dehydration (Dewar & Joyce, 2006). Further, previous studies have shown that high viscosity fluids may aggravate swallowing difficulties due to the increased forces required to move the bolus with the tongue (Dewar & Joyce, 2006). Survey research has found that S-LPs are not consistent in their attempts to thicken liquids, and in most hospitals, no specific training is provided to staff regarding preparation of thickened liquids (Glassburn & Deem, 1998). This inconsistency is most likely due to poor guidelines for preparation of thickened liquids and a lack of rheological information provided by the manufacturers of these products.

Research has been ongoing in an attempt to identify objective methods for assessing the viscosity of thickened liquids that are both easy to use and cost effective (Cowan, 2005). These factors have led to the development of commercially available pre-thickened liquids. While these liquids eliminate the need for measurement devices and inconsistency of thickness, these products are expensive and have limited applications for different patient tastes and nutritional requirements (Adeleye & Rachal, 2007). While most previous studies evaluating thickened liquids have evaluated thickness at room temperature, many drinks are not palatable at room temperature (e.g., coffee, milk) which limits their application to clinical situations. Also, in a hospital setting, there may be a lengthy time delay between the mixing of liquids and

service to consumption by the patient. S-LPs and patients need to be certain that the desired liquid thickness is the actual thickness that the patient will consume. In addition, the effects of time and temperature on viscosity of thickened liquids are important factors to discuss in discharge planning with patients needing to implement diet modifications on their own.

Objectives

The primary objective of this paper is to critically evaluate the recent literature concerning the changes that occur to thickened liquids due to time and temperature.

Methods

Search Strategy

Computerized databases including PubMed and CINAHL were searched using the following search strategy: ((dysphagia) OR (swallowing disorder)) AND ((thickening) OR (thickened liquids)) AND (time) AND (temperature).

Selection Criteria

Papers that were included in this critical review were written in English between 2002 and 2008. Selected studies investigated the impact of time and temperature on the viscosity of both pre-thickened and powder-thickened liquids. No limits were set on the demographics of research participants or outcome measures.

Data Collection

The reviewed studies were all either experimental or quasi-experimental, utilizing non-randomized, repeated measures designs. The studies utilized small sample sizes ranging from one to eight liquids, chosen based on facility frequency of use or author preference. Outcome measures were primarily quantitative in nature (i.e., viscosity, density, temperature, time).

Results

Strowd et al. (2008) investigated the viscosity of pre-packaged thickened liquids and barium test feeds. The pre-thickened liquids were evaluated for variability in lots, variability between flavours, changes in viscosity due to shaking, and stability over time after opening. At least five different samples of each product were tested for each condition. The investigators tested the thickness of nectar- and honey-thick pre-thickened liquids in water, apple, orange and cranberry juice flavours immediately, 30-minutes and 120-minutes after opening in comparison to corresponding barium test feeds. They tested all samples at 24°C due to the assumption that the samples would not significantly change in temperature due to open-mouth oral temperature. Data were presented as mean +/- standard error of measurement (SEM) due to the fact that the authors were investigating the absolute variability in rheology of pre-thickened liquids and barium test feeds. Therefore, they noted that statistical comparisons and power calculations would not be meaningful. They found minimal change in viscosity over two hours at room temperature in the pre-thickened liquids, while the barium suspensions demonstrated high viscosity initially, followed by a decrease in viscosity to thin liquid levels.

While their rationale for lack of statistical analysis is warranted due to the type of data collected, it would have been beneficial to the reader to have data available in tables or figures to allow comparison to other studies. Further, no data or figures are provided representing the change in viscosity of the pre-thickened liquids over time. Also, the authors did not discuss how they maintained temperature of samples at 24°C. The repeated measures design of this study would generally provide a moderate level of evidence, however, lack of disclosure and poor presentation of experimental data may lead the reader to question the reliability of the results. Therefore the evidence provided by this study of minimal change in viscosity of pre-thickened liquids over time is suggestive.

Dewar & Joyce (2006) limited their repeated measures investigation of time-dependent viscosity of starch-based thickeners to water as their base liquid. They added various concentrations of thickener (0.5, 1.0, 1.5, 2.0, or 2.5 g) to 50 ml of tap water and then measured the viscosity of each sample at 30-minute intervals for 17 hours at room temperature (20°C). The investigators found that the maltodextrin-based thickener increased in thickness over 30 minutes at room temperature and then stabilized, while the maize-based thickener decreased in thickness over the first 1-4 hours after thickening.

A limitation of this study is the fact that the investigators did not fully describe the statistical

analysis of their results. The authors report percent decreases in viscosity of the various concentrations of thickener added to the water samples. They did not, however, report data on variance between time periods within a sample or comparisons across samples. Further analyses could have included statistical differences of viscosity between the concentrations of thickeners as well as percent change in viscosity over each time interval. Although the design and procedures of this paper were sound, the lack of thorough statistical analyses somewhat limits the reliability and validity of these results. This paper provides suggestive evidence that time causes changes in viscosity of powder-thickened liquids.

Biggs et al. (2003) utilized a repeated measures design to investigate the differences in viscosity of powder-thickened juices over two- and ten-minute time periods. They utilized apple juice and orange juice as their base liquids, with samples chilled to between 5.7°C and 8.4°C. Four different brands of powdered thickeners were utilized for this study. They found that viscosity varied across all of the brands of thickeners tested. Time was a significant factor in the comparison of viscosity for honey-thick juices, but not for nectar-thickened juices. For three out of four brands, the liquids were thicker at ten minutes than they were at two minutes. Statistical analyses included a three-way analysis of variance test as well as post-hoc analysis of significant interactions, which were appropriate measures for examining changes in viscosity, which is a continuous variable.

One limitation of this study is that thickness was measured only at two- and ten-minute intervals. In clinical practice, thickened liquids often sit for periods in excess of ten minutes and many other studies have looked at the effect of liquids thickening for 30+ minutes. Adaptation of the design to include measurements at longer thickening durations would improve clinical applicability. Overall, this study provides moderate evidence that time causes changes in the viscosity of thickened liquids, especially those thickened to honey-thick consistency.

Koperna et al. (2004) attempted to follow-up on the work of Biggs et al. (2003) by completing an investigation into the changes in viscosity over time and temperature for multiple liquids thickened to nectar and honey consistencies. They evaluated room temperature thickened liquids (tap water, apple juice), cold liquids (2% milk, skim milk, ginger ale, pre-packaged apple juice), and hot liquids (coffee, chicken broth) immediately after mixing as well as at 20- and 45-minute intervals. Results showed that nectar thickened liquids remained at that consistency while honey thick liquids continued to thicken over time.

The limitations of this study include poor description of methodology, which would make

replication of the study incredibly difficult, as well as poor viscosity measurement technique. The investigators chose to utilize the methodology in *Safe Liquids* (Lockhart & Radar, 1998) to obtain thickness measurements. Flow rates of the fluids were compared to a table in the *Safe Liquids* text to determine the thickness category of the liquid (i.e., thin, nectar, syrup, sauce, honey, or pudding). Multiple difficulties were encountered in attempting to utilize this method of measurement, ultimately resulting in changes to the classification and procedures from those indicated in the text of *Safe Liquids*. This may have resulted in inaccurate categorization of multiple liquids involved in this study.

While the authors note that ideally thickness is measured using a viscometer, they reported that these devices are not used in health care agencies in Ohio where the study was performed. Although viscometers may not be used consistently in clinical situations, they are an accurate tool for measuring changes in fluid thickness and would have been a more appropriate choice to ensure the reliability and validity of the results (Koperna et al., 2004). Also, Koperna et al. (2004) utilized a cooking thermometer to measure the temperature of all liquids at each time interval, which may not have provided the appropriate level of accuracy for this study. Most studies investigating changes in temperature in thickened liquids utilize water baths to maintain consistent temperature of samples and employ sophisticated tools that provide precise measurement of temperature.

Further limitations of this study included the lack of statistical analysis provided by the authors. All data was presented in tabular form with no provision of means, standard deviations or analyses of variance. The investigators also did not control for starting temperature in their cold and hot liquids, which may have had an effect on viscosity measurements and weakens the reliability of their results. Therefore, due to poor statistical analyses, poor methodology and procedures, and lack of control of many variables within the study, the validity and reliability of these results should be questioned. Given the multiple limitations of this study, the evidence of the effect of time and temperature changes on thickened liquids must be considered with caution.

Adeleye & Rachal (2007) utilized a repeated measures design to investigate the rheological differences in commercially available pre-thickened beverages and powder-thickened beverages at two different temperatures and using three different measurements of viscosity (line-spread test, funnel test and viscometer). They studied the following nectar- and honey-thick pre-packaged liquids: milk, lemon-flavoured water, apple juice, orange juice and cranberry juice. They compared the pre-packaged liquids to one

brand of powdered thickener (ThickenUp) mixed with 2% reduced fat milk, water, apple juice, orange juice and cranberry concord grape juice. Unlike other studies, these authors utilized household devices (i.e., tablespoons, teaspoons, and measuring cups) to measure the appropriate amount of powdered thickener, per manufacturer instructions. As an added reliability measure, Adeleye & Rachal (2007) weighed the measured ingredients and took an average of four measurements to determine a standard amount to use in preparation of the sample liquids. Samples of each of the liquids were refrigerated at 10°C and 20°C. Statistical analyses included one-way ANOVA with Tukey's test for means showing a significant difference. Significance level was set at $p \leq 0.05$. The authors found that the commercially available pre-thickened beverages were thicker at 10°C and 20°C than the corresponding powder-thickened beverages, even when the products were made by the same manufacturer. Commercially available beverages were also more viscous than the standards of the National Dysphagia Diet Task Force.

This study may have provided added clinical validity if the investigators had tested their cold samples at a temperature consistent with average refrigerator temperature of approximately 4°C (Garcia et al., 2008). A possible limitation of this study is that the investigators tested each sample three times with each of the three measurement tools (line-spread test, funnel test and viscometer). They noted that all measurements were completed within 30 minutes of sample preparation, however, they did not indicate if measurement tools were randomly varied in use. If the same order of tools were used to measure each sample, the effect of time on the samples may have been a confounding factor to the results. However, the investigators did report a strong correlation between the viscosity measurements from the funnel test and viscometer, indicating that these two methods evaluated the liquid viscosities in a consistent manner. Overall, this study provided appropriate statistical analyses (ANOVA for continuous variable measurement); excellent methodology that provided ecological validity and reliability measures, as well as an appropriate experimental design, indicating significant evidence that temperature affects the viscosity of thickened liquids.

Garcia et al. (2005) investigated the effect of starch- and gum-based powdered thickeners on various liquids at room temperature (25°C) and over differing periods of thickening. They examined three starch-based thickeners and two gum-based thickeners mixed with water, apple juice, orange juice, 2% milk, and coffee. Measurements were taken at the manufacturer recommended thickening time, at 10-minutes and 30-

minutes of thickening. Statistical analysis included repeated-measures ANOVA and use of Fisher's protected least-significant-difference procedure for determination of existence of significant difference ($p < 0.05$). Overall, Garcia et al. (2005) found a significant interaction for both nectar- and honey consistencies, indicating that comparing each variable (type of liquid, type of thickener, time) is dependent on the other variables measured. With respect to the variable of time, they found that starch-based thickeners produced significantly higher viscosity liquids after sitting for 10-minutes, while gum-based thickeners did not vary significantly in viscosity from standard preparation time to 10- or 30-minutes of thickening time.

A limitation of this repeated measures study is the fact that all samples were prepared at 25°C. While coffee may be somewhat palatable at this temperature, it is questionable whether orange juice, apple juice and especially milk would be appetizing to drink at room temperature. It is unlikely that a patient would consume many of the tested fluids at the measured temperature; therefore results may not be fully applicable to clinical situations. However, the investigators may have been controlling for temperature to decrease confounding variables in their results. The authors provided appropriate statistical analyses, thorough description of procedures and suitable measurement techniques. Therefore, this study provides significant evidence that changes occur to thickened liquids due to prolonged periods of setting time.

In a subsequent study, Garcia et al. (2008) investigated changes in viscosity of water, apple juice, orange juice, 2% milk, and decaffeinated coffee, thickened with starch- and gum-based powdered thickeners at various serving temperatures. Procedures for this study were very clearly outlined with multiple samples of each liquid tested to increase reliability of their results. The authors allowed samples to thicken for the manufacturer-recommended time (immediately to three minutes), 10-minutes and 30-minutes. Serving temperatures ranged from 4°C (+/- 2°C) for water, apple juice, milk and orange juice, while coffee was served at 70°C (+/- 2°C). A between factors and repeated-within-subject factor ANOVA was completed and results indicated a three-way interaction for nectar-like consistency ($p < 0.0001$) and honey-like consistency ($p < 0.001$). These results indicate that the factors of time, thickening product, and base beverage all interact to affect the thickness of the final product. Overall, the investigators found that gum-based powdered thickeners produced thinner liquids at 3-, 10-, and 30-minute intervals than starch-based powdered thickeners. They also noted that the gum-based thickeners were thinner with increased temperatures but remained the most stable overall, as starch-based thickeners

continued to thicken over time. Garcia et al. (2008) concluded that standardization of thickening products and label information is necessary to ensure consistency across clinicians and facilities.

A limitation of this study noted by the authors is that the samples were measured at the same temperatures (either 4°C or 70°C) across the three setting times. This does not take into account the fact that liquids may cool or warm over setting time, which may affect the resulting viscosity. Garcia et al. (2008) note that investigation into "subtle gradations in temperature" (p.73) should be a focus of future research. Another limitation is that measurements of viscosity were taken at only one shear rate, while the flow of a liquid in the oral cavity can be quite variable (Garcia et al., 2008). Overall, this study provided an excellent outline of procedures, appropriate statistical analyses and visual figures, appropriate measurement techniques, as well as rationale for limitations in design. Therefore, this study provides significant evidence that temperature and time have an effect on viscosity of powder-thickened liquids.

Discussion

A review of the available evidence regarding the effect of time and temperature on viscosity of thickened liquids revealed that viscosity changes can be associated with alterations in temperature and increased setting times. However, other factors also influence the resulting thickness of modified liquids. Factors such as base liquid type, composition of powdered thickener (starch vs. gum) and manufacturer preparation instructions all contribute to the resulting thickness of the prepared liquid.

The studies reviewed in this paper suggest that powder-thickened liquids left to thicken for periods greater than 10 minutes in duration are significantly thicker than at baseline, with additional increases in thickness occurring after 30 minutes of thickening time. Further, multiple studies noted that most starch-based thickeners continue to thicken significantly over time, while gum-based thickeners do not demonstrate significant changes in viscosity from the initial preparation (Garcia et al., 2005). Pre-packaged thickened liquids often do not demonstrate significant changes in viscosity over a two hour period (Strowd et al., 2008); however, further research into the changes in pre-packaged thickened liquids is warranted due to a lack of studies in the literature.

The results of investigations into the effects of temperature on liquid thickness revealed some interesting findings. Some studies indicated significant effects of temperature for pre-packaged thickened liquids – colder liquids were found to be more viscous (Adeleye & Rachal, 2007). Conversely, the viscosity of

the powder-thickened liquids seemed to depend on the composition of the thickener itself. Starch thickeners were thicker at higher temperature (vs. room temperature) especially after 10+ minutes, while gum-based thickened liquids were thinner when temperature was increased. Both gum- and starch-based thickeners were thicker at cold temperatures (4°C) than at room temperature (Garcia et al., 2008).

These results have implications for S-LPs in clinical practice in that clinicians must be aware of the changes that will occur to thickened liquids to ensure that their patients are receiving the appropriate diet modifications to facilitate/promote safe swallowing. S-LPs must be aware of the multiple interacting factors that influence the thickness of the fully prepared liquid: time lapse to consumption, temperature, composition of powdered thickener, as well as base liquid composition. Garcia et al. (2008) found in their study that orange juice and milk were the thickest of all liquids thickened with starch-based thickeners regardless of the temperature at which they were measured. They proposed that ions, proteins, and acids in base liquids all interact with thickening agents, resulting in liquids of different viscosity than intended at mixing (Garcia et al., 2008).

Recommendations

While all of the reviewed studies provided evidence that time and temperature influence the final viscosity of thickened liquids, the results of three of these studies must be considered with caution due to poor methodology, measurement technique, and/or analysis of results. One of the inherent difficulties of this research is that the liquids studied are mixtures of multiple compounds, all interacting together. These liquid interactions, when combined with prolonged thickening time, and changes in temperature can cause variable results in final viscosity. The inherent complexities of performing this research are also noted among clinicians performing dysphagia therapy. Clinically, only half of S-LPs reported that their facilities train staff in preparation of thickened liquids (Garcia, Chambers & Molander, 2005) and many S-LPs have been found to be inconsistent in their attempts to thicken liquids (Glassburn & Deem, 1998). Further, S-LPs often utilize Modified Barium Swallow Studies (Logemann, 1998) to determine the appropriate texture for patients with dysphagia; however, these liquids may not have a consistent viscosity to those utilized in treatment and at meals.

Further research would be beneficial to provide additional information regarding the effect of temperature and time on all forms of thickened liquids. Future research should focus on the following:

- 1) Further study of pre-thickened liquids to document changes occurring due to time and temperature,
- 2) Further comparison of pre-thickened liquids to powder-thickened liquids to determine which product is most suitable in specific situations,
- 3) Further investigation regarding the most appropriate viscosity measurement tool to for use in clinical situations to increase consistency within and across clinicians,
- 4) Comparison of pre-thickened and powder-thickened liquids to barium test feed to determine consistency of textures between assessment and treatment.

Additional recommendations include discussion among clinicians to determine specific acceptable viscosity ranges for nectar- or honey-thick liquids to ensure consistency between facilities and clinicians. Also, appeals should be made to manufacturers to provide different mixing guidelines based on the type of base liquid and serving temperature of the target product.

Clinical Implications

Clear consensus on the specific effects of temperature and time cannot be made based on the above findings due to variances in base liquids and thickener composition. However, there are some basic factors that clinicians should consider when preparing or choosing to utilize thickened liquids.

- Gum-based powdered thickeners (e.g., Simply Thick[®], Thick & Clear[®]) tend to maintain consistent thickness over 30 minutes,
- Gum-based thickened liquids tend to become thinner with increased temperature,
- Starch-based thickeners (Thick & Easy[®], Thick-it[®], Thicken Up[®]) tend to thicken more over time,
- Coffee thickened with starch-based thickeners tends to be thicker when served hot (as compared to room temperature) and thicker after 10-minutes of setting time,
- Cold temperatures tend to cause liquids thickened with both types of powdered thickener (gum and starch) to become thicker than those served at room temperature,
- Pre-thickened liquids tend to be thicker than powder-thickened liquids (even those made by the same manufacturer),

- Pre-thickened liquids tend to be thinner at higher temperatures as compared to lower temperatures,
- Weight measurement of powdered thickener is more accurate than volume measurements.

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